APPLICATION OF FLOW PRINCIPLES IN THE PRODUCTION MANAGEMENT OF CONSTRUCTION SITES

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TABLE OF CONTENTS

TABLE OF CONTENTS II

LIST OF TABLES XV

LIST OF FIGURES XVII

ACKNOWLEDGEMENTS XXI

ABSTRACT XXII

PREFACE XXIII

CHAPTER 1

1.1 OVERVIEW 2

1.2 BACKGROUND 2

1.2.1 CURRENT MISCELLANY OF THEORIES 2

1.2.2 USING A PRODUCTION THEORY TO ENABLE LEARNING 4

1.2.2.1 LEARNING OPPORTUNITIES IN A GLOBAL CONTEXT 4

1.2.2.2 ABSTRACTION AS A MECHANISM FOR KNOWLEDGE TRANSFER 5

1.2.2.3 DEMAND DRIVEN vs. SUPPLY DRIVEN KNOWLEDGE 6

1.2.3 PRESSURES TO IMPROVE PRODUCTION MANAGEMENT IN CONSTRUCTION 8

1.2.3.1 LOW PRODUCTIVITY 8

1.2.3.2 SOCIAL DEMANDS 8

1.2.3.3 HIGH LEVELS OF WASTE 8

1.2.3.4 BAD IMAGE 10

1.3 KEY AREA OF CONCERN 10

1.4 RESEARCH QUESTIONS 11

1.5 OBJECTIVES AND WORKING HYPOTHESES 12

1.6 SCOPE OF THE WORK 13

1.7 OUTLINE OF THE RESEARCH PROCESS 14

1.8 ORGANISATION OF THE THESIS 15

1.9 SUMMARY 18

CHAPTER 2

2.1 OVERVIEW 21

2.2 RECENT HISTORY OF MANAGEMENT THEORY 21

2.2.1 THE IMPORTANCE OF UNDERSTANDING HISTORY 21

2.2.2 THE SCIENTIFIC MANAGEMENT SCHOOL 23

2.2.3 THE HUMAN RELATIONS SCHOOL 26

2.2.4 THE NEO-CLASSIC SCHOOL 29

2.2.5 DISCUSSION 30

2.3 GENERALISATION OF MANAGEMENT THEORIES 31

2.3.1 GENERALISATION OF TECHNICAL FINDINGS 31

2.3.2 GENERALISATION OF HUMAN RELATED FINDINGS 31

2.3.3 MAIN BARRIERS FOR GENERALISATION 32

2.3.4 DISCUSSION 34

2.4 THE PRODUCTION MANAGEMENT CASE 35

2.4.1 DYNAMIC FLOW BETWEEN PRACTICE AND THEORY 35

2.4.2 PRODUCTION MANAGEMENT RESEARCH AGENDA 37

2.4.3 DISCUSSION 39

2.5 DEVELOPING PRODUCTION MANAGEMENT IN CONSTRUCTION 40

2.5.1 CHARACTERISTICS OF THE CONSTRUCTION INDUSTRY 40

2.5.2 USUAL STRATEGIES FOR DEVELOPING PRODUCTION MANAGEMENT IN CONSTRUCTION 43

2.5.2.1 ADAPTATION OF IDEAS FROM OTHER INDUSTRIES 43

2.5.2.2 DEVELOPMENT OF CONSTRUCTION'S OWN THEORY 45

2.5.3 DISCUSSION: AN ALTERNATIVE STRATEGY 48

2.6 INTERACTIONS OF PRODUCTION WITHIN THE ORGANISATION 51

2.6.1 THE FUNCTIONAL PERSPECTIVE 51

2.6.2 THE PROCESS PERSPECTIVE 53

2.6.3 DISCUSSION 55

2.7 THE STRATEGIC ROLE OF PRODUCTION 55

2.7.1 DIFFERENTIATING STRATEGIC, TACTICAL AND OPERATIONAL DECISIONS 55

2.7.2 THE CONTEXT OF STRATEGIC THINKING IN PRODUCTION 56

2.7.3 THE MISSING LINK BETWEEN PRODUCTION DECISIONS AND THE BUSINESS STRATEGY 57

2.7.4 DEFINING PRODUCTION STRATEGY 60

2.7.5 COMPETITIVE CRITERIA IN PRODUCTION DECISIONS 60

2.7.5.1 QUALITY 61

2.7.5.2 TIME 61

2.7.5.3 COST 62
2.7.5.4 FLEXIBILITY 62
2.7.6 THE FALL OF THE TRADE-OFF PARADIGM 63
2.7.7 DISCUSSION 65
2.8 CONCLUDING REMARKS 66
2.9 SUMMARY 66

CHAPTER 3

3.1 OVERVIEW 68
3.2 POSITIONING THE THEORETICAL FRAMEWORK 68
3.2.1 IMPORTANCE OF A THEORETICAL FRAMEWORK 68
3.2.2 ABSTRACT LEVELS WITHIN THE FRAMEWORK 70
3.3 INTRODUCTION TO CORE CONCEPTS 72
3.3.1 PRODUCTION AS A CONVERSION ACTIVITY 72
3.3.1.1 DESCRIPTION 72
3.3.1.2 PRACTICAL IMPLICATIONS OF THE CONVERSION MODEL 73
3.3.1.3 DISCUSSION 75
3.3.2 PRODUCTION AS A FLOW 75
3.3.2.1 DESCRIPTION 75
3.3.2.2 PRACTICAL IMPLICATIONS OF THE FLOW MODEL 77
3.3.2.3 DISCUSSION 79
3.3.3 PRODUCTION AS A VALUE GENERATING PROCESS 80
3.3.3.1 DESCRIPTION 80
3.3.3.2 PRACTICAL IMPLICATIONS 82
3.3.3.3 DISCUSSION 82
3.3.4 INTERACTION AMONG CONCEPTS 83
3.4 EMERGING HEURISTIC PRINCIPLES 85
3.4.1 INTRODUCTION 85
3.4.2 FOCUS OF THIS RESEARCH 87
3.5 REDUCTION OF PROCESS CYCLE TIME 89
3.5.1 DEFINITION OF THE PRINCIPLE 89
3.5.2 IMPACT ON PRODUCTION SYSTEMS 91
3.5.3 IMPLEMENTATION APPROACHES 91
3.5.3.1 Reducing the Batch Size 92
3.5.3.2 Reducing the Work-in-Progress 94
3.5.3.3 Minimising Distances 95

3.5.3.4 Isolating Value Adding Activities from Support Activities *96*
3.5.3.5 Changing the Order of the Process *96*
3.5.3.6 Synchronising and Smoothing the Flows *97*
3.5.3.7 Solving the Control Problems and Constraints to a Speedy Flow *99*
3.5.3.8 Reduction of Variability *100*
3.5.4 DISCUSSION 100
3.6 REDUCTION OF VARIABILITY 101
3.6.1 DEFINITION OF THE PRINCIPLE 101
3.6.2 IMPACT ON PRODUCTION SYSTEMS 104
3.6.3 IMPLEMENTATION APPROACHES 105
3.6.3.1 Measuring, Finding and Eliminating the Root Cause of Problems *105*
3.6.3.2 Standardisation *107*
3.6.3.3 Poka-Yoke *108*
3.6.4 DISCUSSION 109
3.7 INCREASE OF TRANSPARENCY 110
3.7.1 DEFINITION OF THE PRINCIPLE 110
3.7.2 IMPACT ON PRODUCTION SYSTEMS 111
3.7.3 IMPLEMENTATION APPROACHES 112
3.7.3.1 Reducing the Interdependence between Workstations *112*
3.7.3.2 Use of Visual Controls Enabling Immediate Recognition of Process Status *113*
3.7.3.3 Making the Process Directly Observable *115*
3.7.3.4 Incorporating Information into the Process *115*
3.7.3.5 Maintaining a Clean and Orderly Workplace *117*
3.7.3.6 Rendering Invisible Attributes Visible Through Measurements *118*
3.7.4 DISCUSSION 118
3.8 BUILDING CONTINUOUS IMPROVEMENT 119
3.8.1 DEFINITION OF THE PRINCIPLE 119
3.8.2 IMPACTS ON PRODUCTION SYSTEMS 121
3.8.3 IMPLEMENTATION APPROACHES 123
3.8.3.1 Setting Stretch Target *123*
3.8.3.2 Giving Responsibility for Improvement to All Employees *124*
3.8.3.3 Using Standards as Hypothesis of Best Practice *126*
3.8.3.4 Measuring and Monitoring Improvements *127*
3.8.3.5 Linking Improvement to Priorities set by the Control *127*
3.8.3.6 Pull Instead of Push Production Orders *128*
3.8.4 DISCUSSION 129
3.9 CONCLUDING REMARKS 130
3.10 SUMMARY 131

CHAPTER 4

4.1 OVERVIEW 134

4.2 OVERALL RESEARCH DESIGN 134

4.3 PHILOSOPHICAL BACKGROUND 138

4.3.1 POSITIVIST APPROACH vs. INTERPRETATIVE APPROACH 138

4.3.2 THE BALANCED APPROACH ADOPTED IN THIS THESIS 139

4.3.3 DISCUSSION 141

4.4 ACTUAL RESEARCH STRATEGY ADOPTED 141

4.4.1 CASE STUDY RESEARCH STRATEGY 142

4.4.2 DEFINING THE NUMBER OF CASES 143

4.4.3 CRITICAL ASPECTS OF CASE STUDY RESEARCH 144

4.4.4 DISCUSSION 146

4.5 PROTOCOL FOR DATA COLLECTION 146

4.5.1 OVERVIEW 146

4.5.2 FIRST CONTACT 148

4.5.3 DATA COLLECTION 148

4.5.3.1 MAIN QUESTIONS DURING DATA COLLECTION 148

4.5.3.2 A TYPICAL DATA COLLECTION PROCEDURE 151

4.5.4 REPORTING 157

4.5.5 DISCUSSION 158

4.6 SELECTING CRITERIA FOR THE CASE STUDIES 159

4.7 PRESENTATION OF CASE STUDIES 160

4.7.1 GENERAL VIEW 160

4.7.2 CASE STUDY 1 (PILOT STUDY) - BRADFORD, ENGLAND 161

4.7.3 CASE STUDY 2: WIGAN, ENGLAND 162

4.7.4 CASE STUDY 3: SALFORD, ENGLAND 164

4.7.5 CASE STUDY 4: PORTO ALEGRE, BRAZIL 165

4.7.6 CASE STUDY 5: PORTO ALEGRE, BRAZIL 166

4.7.7 CASE STUDY 6: SÃO PAULO, BRAZIL 167

4.8 ANALYTICAL STRATEGY 169

4.8.1 UNIT OF ANALYSIS 169

4.8.2 ANALYTICAL STRATEGY ADOPTED 169

4.8.3 CRITICAL ASPECTS OF THE ANALYTICAL STRATEGY 170

4.8.4 BOUNDARY SEARCHING 171

4.8.5 LINKING EMPIRICAL EVIDENCE AND THEORY 172

4.8.6 DISCUSSION 173

4.9 CONCLUDING REMARKS 174
4.10 SUMMARY 174

CHAPTER 5

5.1 OVERVIEW 177
5.2 GENERAL ANALYTICAL STRUCTURE 177
5.3 REDUCTION OF CYCLE TIME 179
5.3.1 REDUCTION OF BATCH SIZE 179
5.3.1.1 WORKING DEFINITION 179
5.3.1.2 OBSERVATIONAL FOCUS 180
5.3.1.3 KEY INDICATORS 180
5.3.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS 181
5.3.1.5 SUMMARY OF RESULTS 182
5.3.1.6 DISCUSSION 188
5.3.1.7 CONCLUSION 190
5.3.2 REDUCTION OF WORK-IN-PROGRESS 191
5.3.2.1 WORKING DEFINITION 191
5.3.2.2 OBSERVATIONAL FOCUS 191
5.3.2.3 KEY INDICATORS 192
5.3.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS 192
5.3.2.5 SUMMARY OF RESULTS 193
5.3.2.6 DISCUSSION 198
5.3.2.7 CONCLUSION 199
5.3.3 MINIMISATION OF DISTANCES 200
5.3.3.1 WORKING DEFINITION 200
5.3.3.2 OBSERVATIONAL FOCUS 200
5.3.3.3 KEY INDICATORS 200
5.3.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS 201
5.3.3.5 SUMMARY OF RESULTS 202
5.3.3.6 DISCUSSION 207
5.3.3.7 CONCLUSION 209
5.3.4 ISOLATION OF VALUE ADDING ACTIVITIES FROM SUPPORTING ACTIVITIES . 209
5.3.4.1 WORKING DEFINITION 209
5.3.4.2 OBSERVATIONAL FOCUS 209
5.3.4.3 KEY INDICATORS 210
5.3.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS 210
5.3.4.5 SUMMARY OF RESULTS 211
5.3.4.6 DISCUSSION 215

5.3.4.7 CONCLUSION *217*
5.3.5 CHANGING THE ORDER OF THE PROCESS 217
5.3.5.1 WORKING DEFINITION *217*
5.3.5.2 OBSERVATIONAL FOCUS *217*
5.3.5.3 KEY INDICATORS *217*
5.3.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *218*
5.3.5.5 SUMMARY OF RESULTS *218*
5.3.5.6 DISCUSSION *224*
5.3.5.7 CONCLUSION *226*
5.3.6 DEVELOPING SYNCHRONOUS AND SMOOTH FLOWS 226
5.3.6.1 WORKING DEFINITION *226*
5.3.6.2 OBSERVATIONAL FOCUS *226*
5.3.6.3 KEY INDICATORS *227*
5.3.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *227*
5.3.6.5 SUMMARY OF RESULTS *228*
5.3.6.6 DISCUSSION *233*
5.3.6.7 CONCLUSION *234*
5.3.7 SOLVING CONTROL PROBLEMS AND CONSTRAINTS TO A SPEEDY FLOW 234
5.3.7.1 WORKING DEFINITION *234*
5.3.7.2 OBSERVATIONAL FOCUS *235*
5.3.7.3 KEY INDICATORS *235*
5.3.7.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *236*
5.3.7.5 SUMMARY OF RESULTS *237*
5.3.7.6 DISCUSSION *243*
5.3.7.7 CONCLUSION *244*
5.3.8 CONCLUDING REMARKS 244
5.4 REDUCTION OF VARIABILITY 245
5.4.1 MEASURING, FINDING AND ELIMINATING ROOT CAUSES 245
5.4.1.1 WORKING DEFINITION *245*
5.4.1.2 OBSERVATIONAL FOCUS *245*
5.4.1.3 KEY INDICATORS *246*
5.4.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *246*
5.4.1.5 SUMMARY OF RESULTS *247*
5.4.1.6 DISCUSSION *251*
5.4.1.7 CONCLUSION *252*
5.4.2 STANDARDISATION 253
5.4.2.1 WORKING DEFINITION *253*
5.4.2.2 OBSERVATIONAL FOCUS *253*
5.4.2.3 KEY INDICATORS *253*
5.4.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *254*

5.4.2.5 SUMMARY OF RESULTS *254*
5.4.2.6 DISCUSSION *259*
5.4.2.7 CONCLUSION *261*
5.4.3 POKA-YOKE 261
5.4.3.1 WORKING DEFINITION *261*
5.4.3.2 OBSERVATIONAL FOCUS *262*
5.4.3.3 KEY INDICATORS *262*
5.4.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *262*
5.4.3.5 SUMMARY OF RESULTS *263*
5.4.3.6 DISCUSSION *267*
5.4.3.7 CONCLUSION *268*
5.4.4 CONCLUDING REMARKS 269
5.5 INCREASE OF TRANSPARENCY 270
5.5.1 REDUCING THE INTERDEPENDENCE BETWEEN PROCESSES 270
5.5.1.1 WORKING DEFINITION *270*
5.5.1.2 OBSERVATIONAL FOCUS *270*
5.5.1.3 KEY INDICATORS *270*
5.5.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *271*
5.5.1.5 SUMMARY OF RESULTS *272*
5.5.1.6 DISCUSSION *276*
5.5.1.7 CONCLUSION *278*
5.5.2 USE OF VISUAL CONTROLS TO ENABLE IMMEDIATE RECOGNITION OF PROCESS STATUS 278
5.5.2.1 WORKING DEFINITION *278*
5.5.2.2 OBSERVATIONAL FOCUS *278*
5.5.2.3 KEY INDICATORS *278*
5.5.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *279*
5.5.2.5 SUMMARY OF RESULTS *279*
5.5.2.6 DISCUSSION *284*
5.5.2.7 CONCLUSION *285*
5.5.3 MAKING THE PROCESS DIRECTLY OBSERVABLE 285
5.5.3.1 WORKING DEFINITION *285*
5.5.3.2 OBSERVATIONAL FOCUS *285*
5.5.3.3 KEY INDICATORS *286*
5.5.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *286*
5.5.3.5 SUMMARY OF RESULTS *287*
5.5.3.6 DISCUSSION *291*
5.5.3.7 CONCLUSION *292*
5.5.4 INSTALLING INFORMATION INTO THE PRODUCTION ENVIRONMENT 293
5.5.4.1 WORKING DEFINITION *293*

5.5.4.2 OBSERVATIONAL FOCUS *293*
5.5.4.3 KEY INDICATORS *293*
5.5.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *293*
5.5.4.5 SUMMARY OF RESULTS *294*
5.5.4.6 DISCUSSION *298*
5.5.4.7 CONCLUSION *299*
5.5.5 MAINTENANCE OF A CLEAN AND ORDERLY WORKPLACE 299
5.5.5.1 WORKING DEFINITION *299*
5.5.5.2 OBSERVATIONAL FOCUS *299*
5.5.5.3 KEY INDICATORS *300*
5.5.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *300*
5.5.5.5 SUMMARY OF RESULTS *301*
5.5.5.6 DISCUSSION *305*
5.5.5.7 CONCLUSION *306*
5.5.6 RENDERING INVISIBLE ATTRIBUTES VISIBLE THROUGH MEASUREMENTS 307
5.5.6.1 WORKING DEFINITION *307*
5.5.6.2 OBSERVATIONAL FOCUS *307*
5.5.6.3 KEY INDICATORS *307*
5.5.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *308*
5.5.6.5 SUMMARY OF RESULTS *309*
5.5.6.6 DISCUSSION *312*
5.5.6.7 CONCLUSION *313*
5.5.7 CONCLUDING REMARKS 314

5.6 BUILD CONTINUOUS IMPROVEMENT INTO THE PROCESS 315
5.6.1 SETTING STRETCH TARGETS 315
5.6.1.1 WORKING DEFINITION *315*
5.6.1.2 OBSERVATIONAL FOCUS *315*
5.6.1.3 KEY INDICATORS *315*
5.6.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *315*
5.6.1.5 SUMMARY OF RESULTS *316*
5.6.1.6 DISCUSSION *320*
5.6.1.7 CONCLUSION *321*
5.6.2 SHARING THE RESPONSIBILITY FOR IMPROVEMENT WITH ALL EMPLOYEES 322
5.6.2.1 WORKING DEFINITION *322*
5.6.2.2 OBSERVATIONAL FOCUS *322*
5.6.2.3 KEY INDICATORS *322*
5.6.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS *323*
5.6.2.5 SUMMARY OF RESULTS *323*
5.6.2.6 DISCUSSION *328*
5.6.2.7 CONCLUSION *329*

5.6.3 USING STANDARDS AS HYPOTHESES OF BEST PRACTICE....330
5.6.3.1 WORKING DEFINITION....330
5.6.3.2 OBSERVATIONAL FOCUS....330
5.6.3.3 KEY INDICATORS....330
5.6.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS....331
5.6.3.5 SUMMARY OF RESULTS....332
5.6.3.6 DISCUSSION....335
5.6.3.7 CONCLUSION....336
5.6.4 MEASURING AND MONITORING IMPROVEMENTS....337
5.6.4.1 WORKING DEFINITION....337
5.6.4.2 OBSERVATIONAL FOCUS....337
5.6.4.3 KEY INDICATORS....337
5.6.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS....337
5.6.4.5 SUMMARY OF RESULTS....338
5.6.4.6 DISCUSSION....342
5.6.4.7 CONCLUSION....343
5.6.5 LINKING IMPROVEMENTS TO PRORITIES SET BY THE CONTROL ACTIVITIES. 343
5.6.5.1 WORKING DEFINITION....343
5.6.5.2 OBSERVATIONAL FOCUS....344
5.6.5.3 KEY INDICATORS....344
5.6.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS....344
5.6.5.5 SUMMARY OF RESULTS....345
5.6.5.6 DISCUSSION....349
5.6.5.7 CONCLUSION....350
5.6.6 CHANGING PUSH ORDERS TO PULL ORDERS....351
5.6.6.1 WORKING DEFINITION....351
5.6.6.2 OBSERVATIONAL FOCUS....351
5.6.6.3 KEY INDICATORS....351
5.6.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS....352
5.6.6.5 SUMMARY OF RESULTS....353
5.6.6.6 DISCUSSION....358
5.6.6.7 CONCLUSION....359
5.6.7 CONCLUDING REMARKS....359
5.7 DISCUSSION....360
5.8 SUMMARY....361

CHAPTER 6

6.1 OVERVIEW....363

6.2 EXPECTED PATTERN OF INTER-RELATIONSHIPS 363

6.3 INTER-RELATIONSHIPS OBSERVED IN PRACTICE 365

6.3.1 SUMMARY OF FINDINGS 365

6.3.2 CASE STUDY 1 367

6.3.2.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 367

6.3.2.2 DISCUSSION 368

6.3.3 CASE STUDY 2 369

6.3.3.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 369

6.3.3.2 DISCUSSION 371

6.3.4 CASE STUDY 3 372

6.3.4.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 372

6.3.4.2 DISCUSSION 374

6.3.5 CASE STUDY 4 375

6.3.5.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 375

6.3.5.2 DISCUSSION 376

6.3.6 CASE STUDY 5 378

6.3.6.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 378

6.3.6.2 DISCUSSION 379

6.3.7 CASE STUDY 6 380

6.3.7.1 SUMMARY OF MAIN INTER-RELATIONSHIPS 380

6.3.7.2 DISCUSSION 382

6.4 INVESTIGATING THE LINK BETWEEN PROCESS PERFORMANCE AND INTEGRATION OF HEURISTICS 382

6.4.1 THE COMPLEXITIES IN ESTABLISHING THIS LINK 383

6.4.2 ANALYSIS OF EVIDENCES 383

6.4.2.1 Case Study 2: Good Performer 384

6.4.2.2 Case Study 4: Good Performer 385

6.4.2.3 Case Studies 6: Modest Performer 386

6.4.2.4 Case Studies 1: Modest Performer 386

6.4.2.5 Case Studies 5: Poor Performer 387

6.4.2.6 Case Studies 3: Poor Performer 388

6.4.3 CONCLUSION 388

6.5 DISCUSSION 388

6.6 SUMMARY 390

CHAPTER 7

7.1 OVERVIEW 392

7.2 THE NEED FOR CHANGE IN CONSTRUCTION 392

7.3 MANAGING CHANGE 395

7.3.2 FROM INDIVIDUAL CHANGE TO SYSTEMIC CHANGE 395

7.3.2.1 INDIVIDUAL CHANGE 395

7.3.2.2 GROUP CHANGE 396

7.3.2.3 SYSTEMIC CHANGE 396

7.3.3 FROM PLANNED CHANGE TO EMERGENT CHANGE 396

7.3.3.1 PLANNED CHANGE 396

7.3.3.2 EMERGENT CHANGE 398

7.3.4 APPROACH FOR CHANGE ADOPTED IN THIS RESEARCH 399

7.3.5 DISCUSSION 399

7.4 CREATING A "LEARNING MOOD" TO NEW IDEAS 400

7.4.1 PRODUCTION AS A LEARNING LABORATORY 400

7.4.2 "PUSH LEARNING" 402

7.4.3 "PULL" LEARNING 403

7.4.4 DISCUSSION 405

7.5 LESSONS LEARNED IN CASE STUDY 7 406

7.5.2 INTRODUCTION 406

7.5.3 DESCRIPTION OF THE ACTION LEARNING APPROACH 407

7.5.4 "PUSHING" THE LEARNING 408

7.5.4.1 RESEARCHER'S ROLE 408

7.5.4.2 DESCRIPTION OF THE SUBJECT OF ANALYSIS 409

7.5.4.3 DATA COLLECTION AND PRE-ANALYSIS 410

7.5.4.4 BRAINSTORMING SESSION ON SITE 412

7.5.4.5 PRESENTATION OF FINDINGS TO THE COMPANY 415

7.5.4.6 MAIN OUTCOME OF THE "PUSH LEARNING" ATTEMPT 416

7.5.5 "GESTATION" PERIOD 417

7.5.6 "PULLING" THE LEARNING 419

7.5.6.1 RESEARCHER'S ROLE 419

7.5.6.2 DESCRIPTION OF THE SUBJECT OF ANALYSIS 419

7.5.6.3 DATA COLLECTION AND PRE-ANALYSIS 420

7.5.6.4 PRESENTATION TO THE COMPANY 424

7.5.6.5 MAIN OUTCOMES OF "PULL LEARNING" 424

7.5.7 DISCUSSION 426

7.6 CONCLUDING REMARKS 427

7.7 SUMMARY 428

CHAPTER 8

8.1 OVERVIEW 431

8.2 REPLICATION OF THE THEORY IN PRACTICE 431

8.3 THE NEED FOR CHANGE AT THE BOTTOM LINE 433

8.4 CREATING A LEARNING MOOD TO NEW IDEAS 435

8.5 IMPLICATIONS OF THE THEORY IN INNOVATION 436

8.6 VALIDITY OF THE METHODOLOGY 442

CHAPTER 9

9.1 OVERVIEW 445

9.2 CONTRIBUTIONS OF THIS RESEARCH WORK 445

9.2.1 ARE THERE CONSTRUCTION PRACTICES MATCHING THE PRODUCTION FLOW PRINCIPLES? 446

9.2.2 WHAT IS THE EXTENT TO WHICH CONSTRUCTION INTEGRATES THE FLOW PRINCIPLES IN PRACTICE? 447

9.2.3 HOW DOES ONE CREATE A 'LEARNING MOOD' IN A CONSTRUCTION COMPANY? 448

9.3 FINAL CONCLUSION 449

9.4 SUGGESTIONS FOR FUTURE RESEARCH 450

REFERENCES 451

LIST OF TABLES

Table 1.1 – Compilation of Data on Construction Waste (Koskela, 1992) 9

Table 2.1 - Problems on Generalising the Theory XY (Hofstede, 1994) 33

Table 2. 2 – Level and trend of publication rate in the *International Journal of Operations and Production Management* by topic (Voss, 1995) 38

Table 2.3- Comparison of Contents among Key Operations and Construction Management Books 47

Table 2.4 - Excellent Companies with Similar Characteristics of Construction 49

Table 3.1 - The Different Views of Engineering According to Koskela (1999) 84

Table 3.2 - Evolving Heuristic Principles of Production Management (Koskela, 1992/1999): 86

Table 4.1 - Key Features of Positivist and Interpretative Paradigm 139

Table 4.2 - Research Methods vs. Research Characteristics 142

Table 4.3 - Basic Symbols used in Flow Charts 153

Table 4.4 – Distribution of Case Studies According to the Expected Level of Production Practices 160

Table 4.5 – Description of Procedures for Obtaining Indicators 256

Table 5.1 - Performance of Case Studies Regarding *Reduction of Batch Sizes* 182

Table 5.2 - Performance of Case Studies Regarding Work-in-Progress 193

Table 5.3 – Performance of Case Studies Regarding *Minimisation of Distances* 202

Table 5.4 - Performance of Case Studies regarding *Isolation of Value Adding Activities from Supporting Activities* 212

Table 5.5 - Performance of Case Studies Regarding *Change in the Process Order* 219

Table 5.6 - Performance of Case Studies Regarding *Synchronisation and Smooth of Flows* 228

Table 5.7 - Performance of Case Studies Regarding *Solution of Control and Constraint to Speedy Flow* 238

Table 5.8 - Performance of Case Studies Regarding *Measurement, Identification and Elimination of Root Causes* 247

Table 5.9 - Performance of Case Studies Regarding *Standardisation* 255

Table 5.10 - Performance of Case Studies Regarding Poka-Yoke 263

Table 5.11 - Performance of Case Studies Regarding *Reduction of Interdependencies* 272

Table 5.12 - Performance of Case Studies Regarding *Visual Controls* 280

Table 5. 13 - Performance of Case Studies Regarding *Making the Process Directly Observable* 288

Table 5.14 - Performance of Case Studies Regarding *Installation of Information into the Production Environment* 294

Table 5.15 - Performance of Case Studies Regarding the *Maintenance of a Clean and Orderly Workplace* 301

Table 5.16 - Performance of Case Studies Regarding *Rendering Invisible Attributes Visible through Measurements* 309

Table 5.17 - Performance of Case Studies Regarding the *Setting of Stretch Targets* 317

Table 5.18 - Performance of Case Studies Regarding *Sharing the Responsibility for Improvement with All Employees* 324

Table 5.19 - Performance of Case Studies Regarding the *Use of Standards as Hypothesis of Best Practice to be Challenged* 332

Table 5.20 - Performance of Case Studies Regarding to *Measuring and Monitoring Improvements* 338

Table 5.21 - Performance of Case Studies Regarding *Linking Improvement to Priorities Set by the Control Activities* 346

Table 5.22 - Performance of Case Studies Regarding *Change from Push Orders to Pull Orders* 353

Table 6.1 - Literal Replications identified across the Cases 366

Table 7.1 - Facts from Case Study 7 and their Relationship with the Principles in Study 411

Table 7.2 – List of Ideas Produced during Brainstorming Session on Case Study 7 414

Table 7.3 - Priorities of Improvement Following Brainstorming 415

LIST OF FIGURES

Figure 1.1 - Abstraction as a Mechanism of Knowledge Transfer (adapted from Lillrank, 1995) 6

Figure 1.2 - Model of Transfer Channels (Lillrank, 1995) 6

Figure 2.1 - Evolution of Management throughout History 23

Figure 2.2 – Evolution of Domain Knowledge (after Harmon & King, 1985) 35

Figure 2.3 - Change of Management Emphasis Through Time (after Sjoholt, 1998) 36

Figure 2.4 - Process Alternatives versus Product Characteristics [adapted from Hayes & Wheelwright (1979) and Vonderembse & White (1996:260)] 44

Figure 2.5 – Production as one of the Organisational Functions 51

Figure 2.6 – Production as Part of the Business Process 54

Figure 2.7 – The Trade-Off Paradigm 63

Figure 3.1 - Abstract Levels within the Production Management Theory (based on Koskela, 1992) 70

Figure 3.2 - Concept of Production as a Conversion Activity (Koskela, 1992) 73

Figure 3.3 - Concept of Production as a Flow 76

Figure 3.4 - Concept of Production as a Value Generating Activity 81

Figure 3.5 - Interconnection of the Three Concepts 83

Figure 3.6 – A Perspective of the Abstract Layers Related to the Flow Concept 88

Figure 3.7 – Cycle Time Within Production 89

Figure 3.8 - Traditional Paradigm of Fixed Set-up Time 94

Figure 3.9 - Frequency Distribution from Two Different Processes 103

Figure 3.10 - Illustration of the PDCA Cycle 120

Figure 4.1 – General Structure of the Research Design 135

Figure 4.2 - Protocol for Data Collection 147

Figure 4.3 – General View of the Data Collection Procedure 152

Figure 4.4 – Location of the Case Studies 161

Figure 4.5 – View of Case Study 1 162

Figure 4.6 – View of Case Study 2 163

Figure 4.7 – View of Case Study 3 165

Figure 4.8 – View of Case Study 4 166

Figure 4.9 – View of Case Study 5 167

Figure 4.10 – View of Case Study 6 168

Figure 5.1 - Literal Replication of *Reduction of Batch Size* (Case Study 2) 185

Figure 5.2 - Theoretical Replication of *Reduction of Batch Size* (Case Study 3) 186

Figure 5.3 - Literal Replication of *Reduction of Batch Size* (Meta Case) 189

Figure 5.4 – Illustration of Production Batch, Transfer Batch and Production Batch Unit 190

Figure 5.5 - Literal Replication of Work-in-Progress Reduction (Case Study 3) 196

Figure 5.6 - Theoretical Replication of Work-in-Progress Reduction (Case Study 5) 197

Figure 5.7 - Literal Replication of *Minimisation of Distances* (Case Study 2)..... 204

Figure 5.8 - Theoretical Replication of *Minimisation of Distances* (Case Study 5) 206

Figure 5.9 - Literal Replication of *Minimisation of Distances* (Meta-Case) 208

Figure 5.10 - Literal Replication of *Isolation of Value Adding Activities from Supporting Activities* (Case Study 2) 213

Figure 5.11 - Literal Replication of *Isolation of Value Adding Activities from Supporting Activities* (Case Study 5) 214

Figure 5.12 - Literal Replication of *Change in the Process Order* (Case Study 1) 220

Figure 5.13 - Literal Replication of *Change in the Order of Process* (Case Study 3) 222

Figure 5.14 - Literal Replication of *Change in the Order of the Process* (Case Study 4)..... 222

Figure 5.15 - Theoretical Replication of *Change in the Order of the Process* (Case Study 5)..... 223

Figure 5.16 – Literal Replication of *Developing Synchronous and Smooth Flows* (Case Study 2)..... 230

Figure 5.17– Theoretical Replication of *Developing Synchronous and Smooth Flows* (Case Study 3)... 231

Figure 5.18 - Literal Replication of *Developing Synchronous and Smooth Flows* (Case Study 4)..... 232

Figure 5.19 - Literal Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 1)..... 239

Figure 5.20 - Literal Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 4)..... 241

Figure 5.21 - Theoretical Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 5)..... 242

Figure 5.22 - Literal Replication of *Measurement, Identification and Elimination of Root Causes* (Meta Case/Brazil) 248

Figure 5.23 - Theoretical Replication of *Measurement, Identification and Elimination of the Root Causes of Problems* (Case Study 6) 251

Figure 5.24 - Literal Replication of *Standardisation* (Meta-Case/Brazil)..... 256

Figure 5.25 - Literal Replication of *Standardisation* (Case Study 2) 257

Figure 5.26 – Theoretical Replication of *Standardisation* (Case Study 6)..... 259

Figure 5.27 - Theoretical Replication of *Poka-Yoke* (Case Study 3) 265

Figure 5.28 - Literal Replication of *Poka-Yoke* (Case Study 4) 266

Figure 5.29 Theoretical Replication of *Reduction of Interdependence between Workstations* (Case Study 1)..... 273

Figure 5.30 - Literal Replication of *Reduction of Interdependence between Processes* (Meta Case/England)..... 275

Figure 5.31 - Literal Replication of *Use of Visual Controls* (Case Study 1)..... 281

Figure 5.32 - Literal Replication of Use of Visual Controls (Case Study 2)..... 282

Figure 5.33 - Theoretical Replication of *Use of Visual Controls* (Case Study 6)..... 283

Figure 5.34 -Theoretical Replication of *Making the Process Directly Observable* (Case Study 1)..... 289

Figure 5.35 - Literal Replication of *Making the Process Directly Observable* (Case Study 2)..... 289

Figure 5.36 - Literal Replication of *Installation of Information into the Production Environment* (Meta Case/England)..... 295

Figure 5.37 - Literal Replication of *Installation of Information into the Production Environment* (Case Study 2) 296

Figure 5.38 – Theoretical Replication of *Installation of Information into the Production Environment* (Case Study 4)..... 297

Figure 5.39 - Literal Replication of *Maintenance of a Clean and Orderly Workplace* (Case Study 1) ... 302

Figure 5.40 - Literal Replication of *Maintenance of a Clean and Orderly Workplace* (Case Study 4) ... 304

Figure 5.41 - Literal Replication of *Rendering Invisible Attributes Visible through Measurements* (Meta Case/Brazil) ... 310

Figure 5.42 - Theoretical Replication of *Setting Stretch Targets* (Case Study 3) ... 319

Figure 5.43 - Theoretical Replication of *Sharing the Responsibility for Improvement with All Employees* (Meta Case/Brazil) ... 325

Figure 5.44 - Literal Replication of *Sharing the Responsibility for Improvement with All Employees* (Case Study 2) ... 326

Figure 5.45 – Theoretical Replication of *Use of Standards as Hypotheses of Best Practice to be Challenged* (Case Study 6) ... 335

Figure 5.46 – Theoretical Replication of *Measuring and Monitoring Improvements (*Meta Case) ... 339

Figure 5.47 - Literal Replication of *Measuring and Monitoring Improvements* (Meta Case/Brazil) ... 340

Figure 5.48 - Literal Replication of *Linking Improvement to Priorities Set by the Control* (Meta Case/Brazil) ... 347

Figure 5.49 – Theoretical Replication of *Linking Improvement to Priorities Set by the Control* (Case Study 3) ... 348

Figure 5.50 - Literal Replication of *Change Push Order to Pull Order* (Case Study 1) ... 355

Figure 5.51 - Theoretical Replication of *Change Push Order to Pull Order* (Case Study 6) ... 356

Figure 6.1 – Expected Inter-relationships among the Implementation Approaches ... 364

Figure 6.2 – Integration of Heuristic Implementation Approaches in Case Study 1 ... 367

Figure 6.3 - Integration of Heuristic Implementation Approaches in Case Study 2 ... 370

Figure 6.4 - Integration of Heuristic Implementation Approaches in Case Study 3 ... 373

Figure 6.5 - Integration of Heuristic Implementation Approaches in Case Study 4 ... 375

Figure 6.6 - Integration of Implementation Approaches in Case Study 5 ... 378

Figure 6.7 - Integration of Implementation Approaches in Case Study 6 ... 380

Figure 6.8 - Illustration of the Integration of Literal Replications among the Best Case Studies ... 389

Figure 7.1 – "Push" Learning Concept ... 402

Figure 7.2 – "Pull" Learning Concept ... 404

Figure 7.3 – View of Case Study 7 ... 410

Figure 7.4 – General Pattern Matching Assessment of Case Study 7 ... 412

Figure 7.5 – Representation of Successful Gestation of Ideas within Action Learning ... 418

Figure 7.6 - Business Processes gathered from the Exploratory Visits ... 420

Figure 7.7 –Use of Managerial Time throughout the Business Process ... 424

Figure 7.8 – Contrasting the Focus of the Study throughout the Study ... 425

Figure 8.1 – A Bottom-Up Approach for Sustainable Improvement ... 433

To my family.

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ABSTRACT

This thesis is concerned with the improvement of construction practices by studying the application in the sector of some core principles underlying current production management theories. The research is motivated by the recognition in recent literature that the best production practices world-wide have a common core. The core principles investigated in this research are the "reduction of cycle time", "reduction of variability", "increase of transparency" and "build of continuous improvement into the process". The fundamental rationale underlying these principles is the concept of flow where production is seen as composed of waiting, transporting, inspecting and transformation (processing) activities. According to this concept, transformation activities are the only ones that actually add value. Hence, all other activities should be reduced or eliminated from the flow whilst increasing the efficiency of transformation activities.

The assessment of construction practices against the theory was carried out through six case studies, based in England and Brazil, and a complementary meta-case. Cross-case study analysis showed that construction already applies all heuristic approaches relating to the flow principles under study. However, the intra-case study analysis revealed a serious lack of integration among the literal replications identified in each of the case studies. Integration of practices matching the theory is critical since the evidence suggests that there is a correlation between production performance and the level of integration among literal replications.

An additional case study investigated the issue of how to implement these principles in the practice of construction. The interaction with the host company happened through an Action Learning set supported by the *Revans Centre for Action Learning and Research*. The experiment showed that a combination of both "push" and "pull" learning seems to be an appropriate approach for introducing the principles in study in the construction sector. Top management positive support during "gestation" period was the most important factor for motivating people to "pull" the learning after the initial 'push' learning exercise.

PREFACE

My first lessons of production management in the construction environment I received from my father, João Enedir dos Santos, a construction foreman in the South of Brazil. However, it was only during my MSc. degree, under the supervision of Professor Carlos Torres Formoso at NORIE/UFRGS, that the complex art and science of analysing production systems fascinated me. Until that stage, my mindset was strongly biased towards perpetuation and replication of traditional production practices.

In 1993 I carried out my first analysis of a production system in a construction company. In that study I began to realise how easier, faster and better could production practices in the sector be. Reviewing the literature showed me that similar findings were already present in the writings of Frank Gilbreth, in 1911. The variety of reactions in the company when I presented the findings also brought me attention to the dangers of ignoring the human factor when analysing production. Yet, my findings in this respect did not differ from the findings of the *Hawthorne* experiments carried out in the 1930's. I learnt that knowledge in production evolves slowly and we cannot ignore the developments carried out in the past.

Since this instigating experience I have been involved in the analysis of many other production systems and, time and time again, these studies present many of the same problems reported in the literature. Foremost, these experiences showed that the best construction sites had some common characteristics reported in the literature. In this context, I saw in the PhD as an excellent opportunity to understand in depth the wide problem of transforming construction into a better industry. Under the supervision of Professor James Powell, my emphasis has been on improving our understanding into the application in construction of some principles underlying current production theories.

I hope that, by contributing to our understanding of better production management theory, I am helping to set the standard in which construction practice can be compared against, thus, giving a useful contribution to industry, academia and society.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter **1**

INTRODUCTION

The larger the island of knowledge, the longer the shoreline of wonder.
Ralph W. Sockman

1.1 OVERVIEW

This thesis is concerned with the improvement of production management theory through a study of the application of some core principles in the construction context. Production managers rely on theories throughout their careers in order to generate more sensible solutions and to communicate better with their peers. However, throughout recent history this tacit knowledge has been gradually transformed into a portfolio of heuristic concepts/principles and gradual integration into newer theories. Nowadays, there is a strong demand for the consolidation of these heuristic ideas into a concise and more coherent theory.

The present Chapter outlines the research background and the fundamental questions that lead to the research objectives of this thesis and begins by discussing the need for a better understanding concerning the application of core production management ideas in the construction environment. The benefit of better theory in the context of learning is then discussed along with the presentation of the most significant sources of pressure for improving construction practice. Next, the research questions, research objectives and hypothesis set the main focus of this thesis. An outline of the research method and organisation of the thesis is then reviewed in the final sections.

1.2 BACKGROUND

1.2.1 CURRENT MISCELLANY OF THEORIES

In production management, a combination of past theories and newer theories has produced a complex portfolio of different strategies for action. The principal group of theories come as a combination of Just-in-Time (JIT) and Total Quality Control (TQC) with other theories such as Visual Management, Total Productive Maintenance, Re-engineering and Value Based Management. However, the boundaries of these theories are not always clear and, quite often, there is an overlap among the main ideas

underlying them. Researchers in the field rarely admit or point out these overlaps. In many cases, this situation results in unproductive semantic disputes, leading to confusion and conflict among researchers, consultants and practitioners.

Those trying to get agreement and, thus, consensus, between these theories often waste precious resource and brainpower trying to resolve these conflicts. Furthermore, the miscellany of terms and definitions used in current production management theories worsens this situation. Indeed, truly new ideas may be misunderstood, and not applied, due to the difficulties in communicating their actual meaning. Sadly, this situation is not confined to production management field alone. Edwards & Peppard (1994:251) give an example of a similar situation in the organisational field:

> *"Recently, there have been calls for new organisational forms: the hollow organization, the networked organization, the learning organization, the modular corporation, the virtual organization and the horizontal organization"*

Fortunately, the recent literature on production management has brought with it new prospects of clarity since it has started to show that contemporary theories and practices do have a common core (Koskela, 1992; Luhtala, Kilpinen & Antilla, 1994; Voss, 1995; Towill, 1997). It is now readily accepted that what normally varies is the way the core production theory combines to each different application in practice (Koskela, 1992). World-wide benchmarking studies, particularly within the car industry, have also consistently presented evidence that there are common characteristics observable in all best production systems. Such production systems seem to require less human effort, less space, less product development time, less investments in new tools and, at the same time, their performance often exceeds that of competitors (Womack, Jones & Roos, 1990; Sohal, 1996).

The present researcher believes that investigation into the core ideas underlying current production management theory and best practices may open new windows of opportunity for achieving higher efficiency and effectiveness in the construction industry. The usefulness of such an investigation for learning better production practices is highlighted in the next section.

1.2.2 USING A PRODUCTION THEORY TO ENABLE LEARNING

1.2.2.1 LEARNING OPPORTUNITIES IN A GLOBAL CONTEXT

The prospect of continuous reduction of both cost and time, in global transportation and communication encourages the study of how we could learn better from each other across different regions and countries around the world. Observation of current practices and literature reveals a growing volume of knowledge about production being transferred across national barriers, through direct communication (e.g.: reports, memos, telephone, video), group interaction (e.g.: meetings) and even physical relocation of complete production systems. The expansion of multinational companies, and the continuing migration of people around the world, further accelerates this flow of information (Lemer, 1992; Rebentisch & Ferretti, 1995).

International learning across cultures is a complex issue, since it is clearly affected by a large number of variables such as language itself, culture, geography, social rules, political order and even the legal system. These variables create a "distance" or "gap" that is not only physical, but also mental. The larger this "mental distance" the greater the possibility of misunderstandings (Lillrank, 1995). Despite such obstacles, the search for better production management could drive improvement in local practices through reflection upon alternative practices found elsewhere in the globe.

Intra-sector learning has also always been a 'natural' phenomenon amongst organisations working in the same region. Seminars, conferences, meetings in professional associations, and even the movement of employees between companies, are examples of channels through which knowledge has been flowing across organisations. Cross-sector learning, such as that practised within chambers of commerce, complements the 'natural' intra-sector learning. The manufacturing industry, for instance, has been a good source of innovation and a reference point of production practices for the construction industry.

In addition, there is great scope for learning between companies of developed countries from companies in developing countries, and vice-versa. It is also widely recognised that the strategy of buying or copying practices demands resources that are not always available in developing countries. At the same time, imaginative and successful

solutions for production problems, developed in the Third World, may indeed be a valuable source of ideas for developed countries.

In this context, the next section discusses a mechanism that, the present researcher believes, enables a better interpretation and subsequent successful transfer of knowledge, across different companies and different regions.

1.2.2.2 ABSTRACTION AS A MECHANISM FOR KNOWLEDGE TRANSFER

Production system represents a continuum of 'know-how' ranging from low abstract physical technology to highly abstract concepts. When 'know-how' is only understood as physical technology, its capacity to carry fundamental changes in other contexts is limited. In some situations, this mode of knowledge transfer[1] may not even be technically or economically feasible and the recipient environment may not even have the right materials, machines or personnel to make the new technology to work properly (Barrett, 1997).

Similarly, the successful transfer of a complete managerial methodology, from one place to another, may be extremely difficult, since it is rare to find an environment where complex variables and inter-relationships are equal between contexts. Cultural differences, in particular, have great impact on the knowledge transfer process since they are normally deeply embedded. This usually demands adaptation of ideas from the original managerial technology to the new context (Barrett, 1997).

In this context, Lillrank (1995) proposed that practice would be more effectively transported across different cultures if they were first translated into abstract ideas, as illustrated in Figure 1.1. An abstraction must go beyond the simple description of the directly observable processes and certainly demands a deeper understanding of the meaning and dynamics of processes related to their original context (Lillrank, 1995).

---

[1] **Knowledge transfer** is learning activity that involves the deep understanding and subsequent abstraction, transmission and absorption of knowledge across different locations.

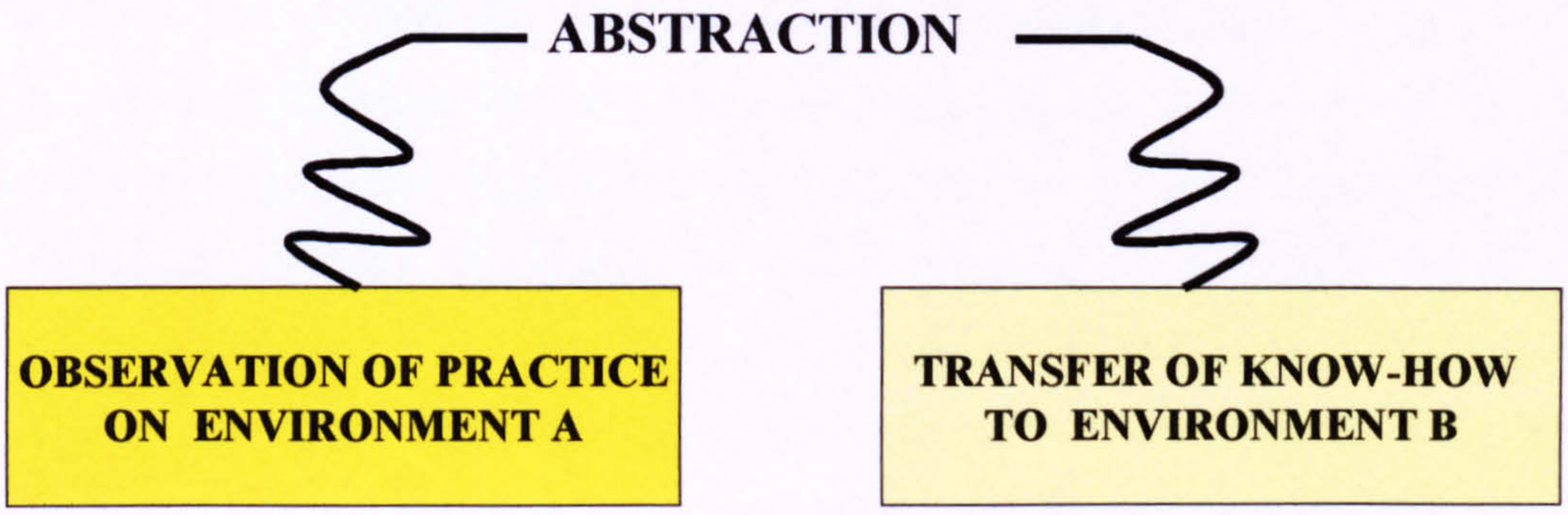


Figure 1.1 - Abstraction as a Mechanism of Knowledge Transfer (adapted from Lillrank, 1995)

However, merely understanding an abstract idea that underlies a particular production practice, and making this knowledge freely available, does not mean that learning is occurring. From a learning perspective, knowledge transfer involves not only transmission (sending or pre-sending to a potential recipient) but, above all, absorption. A successful learning (transfer) process should enable people to become more capable of dealing with unexpected production problems by themselves and, in this way, expand their own knowledge (Davenport & Prusak, 1998). Thus, abstraction of practices must be portrayed in such a way that recipients understand and own the new ideas in their own individual terms.

1.2.2.3 DEMAND DRIVEN vs. SUPPLY DRIVEN KNOWLEDGE

According to Lillrank (1995), knowledge is more effectively transferred when people demand it (demand driven knowledge) as opposed to situations when knowledge is pushed at them, or simply supplied without being wanted (supply driven knowledge), as illustrated on Figure 1.2:

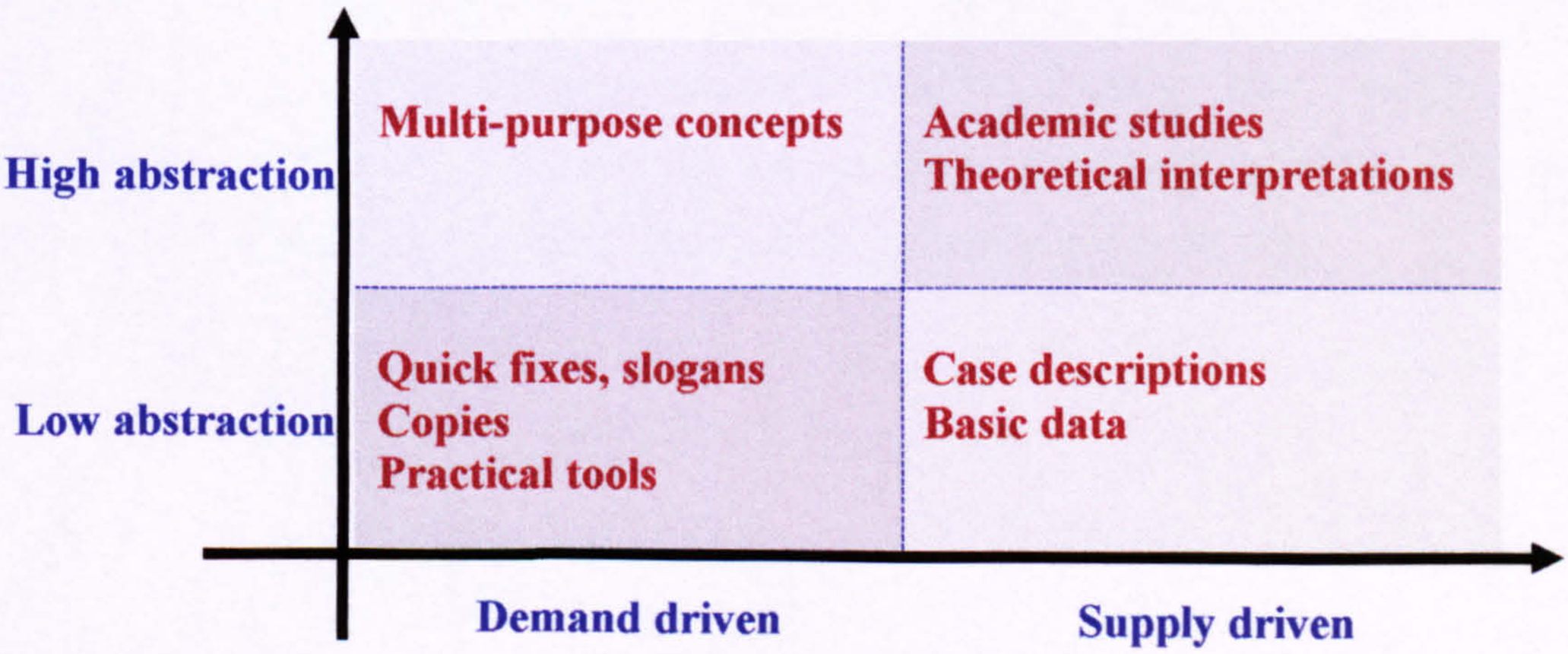


Figure 1.2 - Model of Transfer Channels (Lillrank, 1995)

In 'demands driven channels' people freely request, and more readily absorb, information according to their own wishes and idiosyncrasies. Because of this, new knowledge becomes more meaningful and more likely to be adopted and transformed into innovative solutions. In contrast, in 'supply driven channels' people may simply reject new ideas because they do not match their perception relating to their own needs. This lack of awareness of the actual needs and realities of learner recipients often results in reduced ownership and commitment to new information and, as a result, it often fail in generating 'effective solutions' or 'innovative practices'.

Transmission of information into highly abstract forms through demand-driven channels comes into use when the essence of a particular practice has been crystallised into what appears to be useful principles that have practical applications in other settings. For instance, only when the Japanese practice of Quality Control Circles (QCC) was properly presented as the principle of "continuous improvement" was it successfully applied by American and European companies. Likewise, the low abstract slogans used in "zero defects" did not create change until it was understood as the high abstract notion of "customer satisfaction". Only then, people began to develop their own solutions that, quite often, differed from traditional "zero defect programs" (Lillrank, 1995).

In the present context, to understand the multi-purpose ideas that constitute best production practices is a necessary step for enabling effective learning. Fortunately, many theories have already translated a great number of effective production practices into multi-purpose ideas that can be the basis for better knowledge transfer. Nevertheless, there is a clear lack of integration, appropriate structuring and clear definition of existing ideas within a common theoretical framework. The present research intends to make a contribution in this respect by investigating the application of some core production management ideas within the construction context.

1.2.3 PRESSURES TO IMPROVE PRODUCTION MANAGEMENT IN CONSTRUCTION

Construction is under heavy pressure to improve its present practices since it now has to compete for investments with other, increasingly sophisticated and competitive, industries. This section presents some of the most important sources of this pressure.

1.2.3.1 LOW PRODUCTIVITY

The prosperity of a nation is recognised as being dependent upon its productivity levels in comparison to other nations (Hill, 1992). In this sense, the productivity level in construction is an important indicator of prosperity since in most countries this sector represents a significant part of the Gross Domestic Product (GDP) and employment. In the UK, for example, the construction industry has averaged 7.5% of the GDP over the 5 years between 1992 and 1996, employing around 1.4 million people in 1998 (Office of National Statistics, 1997; Key Note, 1997; Egan, 1998).

Despite its great economic importance, the construction industry regularly shows lower levels of productivity when compared with the manufacturing industry. Indeed, in the USA it is reported that, between 1970 and 1995, the productivity of the sector had decreased at a rate of –1.3% per year whilst in the same period the manufacturing industry had increased at + 3.5% per year (Teicholz, 1997).

1.2.3.2 SOCIAL DEMANDS

Other pressures for increasing productivity, and value, within the construction industry are equally high in both Third World and developed nations. In Brazil, for instance, the housing shortage is estimated at 5,2 million but just a small fraction of the population able to afford current housing costs (Picchi, 1993). Changes in the population's profile, as much as their lifestyle, is bringing new demands to the construction industry world-wide. This is mainly concerned with construction modernisation, repair and maintenance works (Key Note, 1997; VTT, 1997).

1.2.3.3 HIGH LEVELS OF WASTE

Unfortunately, the levels of production waste in the sector remain high despite all the economic and social pressures mentioned above. Various studies have confirmed this

argument, repeatedly showing high levels of unproductive time in construction sites: 24% on average in Australia, Sweden, UK and Netherlands (Vershuren, 1980), 43% in Nigeria (Olomolaiye, Wahab & Price, 1987) and 26% in Brazil (Bicca, Formoso & Scardoelli, 1994).

In the UK, Skoyles & Skoyles (1987) found the wastage of materials ranging from 5 to 10% in volume. In Brazil, Soibelman (1993) monitored the waste of seven materials in five building sites and found values ranging from 5.06% to 11.62% in terms of cost. In Norway, Sjoholt (1998) estimated that the costs due to nonconformity, errors, alterations and wastage, in the course of the building process, were around 10% of the total building cost.

Analysis of data compiled by Koskela (1992) confirms the poor performance of construction regarding waste (*see* Table 1.1 below):

Table 1.1 – Compilation of Data on Construction Waste (Koskela, 1992)

Waste	Cost	Country
Quality costs (non conformance)	12% of total project costs	USA
External quality cost (during facility use)	4% of total project costs	Sweden
Lack of constructability	6-10% of total project cost	USA
Poor materials management	10-12% of labour costs	USA
Excess consumption of materials on site	10% on average	Sweden
Working time used for non-value adding activities on site	App. 2/3 of total time	USA
Lack of safety	6% of total project costs	USA

Further pressures for reducing waste come from the emergent demands of public opinion and the resulting legislation on environmental management. There is also an increased demand for the development of more environmentally benign products and processes (Browne, Sackett & Wortman, 1995). For instance, in Finland, there is a graded waste charge based on the harmfulness of the waste. This makes it economically interesting for Finnish contractors to separate waste and invest efforts in the reduction of its occurrence. Additionally, regulations in that country now require nearly a 10% average improvement in the energy efficiency of buildings (VTT, 1997).

1.2.3.4 BAD IMAGE

Construction has one of the worst public images among the industrial sectors. The sector is often perceived as being dirty, dangerous and dull, with adversarial relationships at all levels and great environmental insensitivity. This image has a seriously negative impact in the recruitment of new young talents (Ball, 1988; DTI, 1994; CIB, 1996).

The sector is also often blamed for being backward and for failing to develop into a mature and technically advanced industry. Moreover, only a fraction of the construction industry's gross revenue seems to be re-invested into applied research, let alone the basic research necessary to create real change. Construction practitioners often see construction research as a source of ideas with low practical value, and being too general and highly speculative (Barrie & Paulson, 1992).

Furthermore, construction projects are widely seen as unpredictable in terms of delivery time, budget, profitability and the standards of quality expected. In addition, investments in construction are usually seen as expensive when compared to other industries (Egan, 1998). The under-achievements of construction are reflected in the growing dissatisfaction that is found among both its private and public sector clients. All these factors make production management in construction an important and valuable area for research (Koskela, 1993).

1.3 KEY AREA OF CONCERN

This thesis focuses on the sub-discipline of operations management that is often called production management. In fact, operations management is traditionally associated with the actual production of tangible products. In different parts of the literature operations management is treated as "*production management*", "*manufacturing management*", "*industrial management*" or "*inventory management*" (Wild, 1995). Nevertheless, as far as this thesis is concerned, operations management involves all aspects of the business directly related to production, transport, supply or service activities (Schroeder, 1993; Wild, 1995).

More particularly, this thesis focuses on the management of production in the construction environment. Construction is one of oldest laboratories of the management science, particularly in the field of production management. Already in 400 BC, Ciro, in Persia, carried out studies on the use of movements, layout and transport of materials on construction sites (Chiavenato, 1983). Moreover, it was in the construction industry that Frank Gilbreth carried out his famous motion studies that laid down some of the principal foundations of scientific management (Gilbreth, 1911; Cheetham, Steel & Lewis, 1992).

1.4 RESEARCH QUESTIONS

The critical observation of practice, and the present researcher's earlier studies, allied to a careful reading of the literature suggested the emergent need to determine, verify and integrate the principles of modern production management in the context of construction. In this process, it also became clear the need for better understanding of the issue of how to transfer the knowledge from theory to practice. "*For no matter how good the theory or the information, if it is not accessed and understood by the practitioners it will be of no value for them or the industry*" (Powell, 1979).

In this context, the researcher decided to investigate three key questions with respect the practice and theory of production management in construction, as follows:

> **Question 1:** *Are there construction practices matching the production flow principles?*
>
> **Question 2:** *If so, what is the extent to which construction integrates the production flow principles in practice?*
>
> **Question 3:** *How can we create a "learning mood" in construction companies in order to effectively transfer flow principles of production management into construction practice?*

Answering these questions offers great potential for bringing innovation into construction because they will touch on deeply rooted paradigms of thinking and acting within the sector. Indeed, other research studies with similar aims have already proved

to be extremely useful in generating new ideas for both theory and practice in other sectors. James-Moore & Gibbons (1997), for instance, have investigated the validity and relevance of some core lean manufacture principles between the civil and aerospace industry. Their study resulted in indications of areas in which theory and practice should change or improve in order to enhance the performance in both industries.

1.5 OBJECTIVES AND WORKING HYPOTHESES

The researcher established the objectives for this thesis based on the above research questions. Additionally, a further literature review, and the researcher's own previous research and practical experience in the field, have enabled the generation of working research hypothesis for each of these objectives, as follows:

Objective 1: *to interpret and refine some key heuristics[2] of production flow principles based on empirical evidence obtained from the construction sector.*

Working Hypothesis: *there will be empirical evidence indicating key heuristics to be used with effect in construction.*

The peculiarities of construction are often pointed out in the literature as major barriers to the implementation of many core ideas of current production management. The lack of empirical evidence showing the contrary seems to be a key reason why such arguments have prevailed so far. In this respect, the present research will seek to find empirical evidence that fundamental heuristic principles are implemented successfully in construction in the hope of reducing controversy. Eventually, the analysis of construction practice should enable the reformulation or refinement of the theory in order to contemplate the characteristics of production in the construction environment.

Objective 2: *to determine the extent to which construction applies some key heuristics of production flow principles.*

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[2] **Heuristic**: serving to discover; using trial and error (Oxford, 1998). "Rules of thumb" used by practitioners.

Working Hypothesis: *the construction sites will present poor systemic integration among the studied heuristics.*

As with the majority of production systems operating in the manufacturing industry, it is unlikely that all heuristic principles and correspondent implementation approaches will be fully attained in a single construction site. The reasons for this conjecture mainly relates to the reported poor training of construction workforce and generalised lack of integration throughout its entire supply chain (Ball, 1988).

Objective 3: *to understand how to create a 'learning mood' within a construction company so that its staff might want to understand and apply new production practices.*

Working Hypothesis: *a composition of "push" and "pull learning" will be the most effective way to promote the creation of a "learning mood" and, thus, better practices in construction.*

This hypothesis emerged from the researcher's previous work on "intervention in construction sites". This experience indicated that a good balance between "push" and "pull" learning was an effective strategy to enable real changes in production practices. Indeed, one important outcome of the previous work was the motivation within the companies studied to continue in the challenging activity of improving production practices in construction (Santos, Hinks & Formoso, 1996).

By achieving these objectives, the present author expects to give a positive contribution to construction by consolidating the core production management theory in a language that construction people can understand. Also, the author expects to make a contribution to the improvement of understanding on how this knowledge can be introduced in the daily practice of construction companies.

1.6 SCOPE OF THE WORK

The present research is best described as an **explanatory study** since it analyses past and present production theories against construction practice in order to present an

"illuminated evaluation". One of the outcomes of this analysis will be a sharper and more insightful questioning of what is known about production management (Yin, 1994). Ultimately, using Dubin (1978) words, "*this should add knowledge to the field by increasing the realms of the known and the knowable and by pointing out more accurately the realms of the unknown*".

For ultimate success, there has to be a reciprocal flow of theory to practice and, of new ideas, from practice to theory. This study is, therefore, a combination of **theory building** and **theory verification**. It is "theory building" in the sense that it uses principles and concepts that are still evolving in the field of production management and tries to combine them in a more useful way. Therefore, the research will hopefully also improve, or change, the content of the theory itself. On the other hand, the work is also about "theory verification" since it is an investigation of the practical validity, in construction, of a number of existing general theoretical propositions. In this reciprocal way, the present research should be able to contribute to expanding the sphere of industries where the theoretical propositions are valid.

1.7 OUTLINE OF THE RESEARCH PROCESS

In order to facilitate understanding, the present study is divided into six distinct phases (see Chapter 4 for more details): *1) problem definition; 2) development of the theoretical framework; 3) data collection; 4) analysis; 5) experimental implementation of theory in practice* and *6) final discussion and conclusions*. In the first phase, the researcher made an initial literature review in order to identify the state of the art in the field. Previous research studies carried out by the researcher in Brazil, and contacts with academics and practitioners in the UK, strongly influenced this early part of the research. This phase resulted in the initial definition of the research questions described earlier in this chapter.

Having identified the main issues in the field, the second phase of this work involved a more thorough literature review focusing on some specific core principles underlying contemporary production management. The objective of this revision was to obtain the basic theoretical framework that would later be the key reference point, or benchmark, against which all the empirical data would be analysed.

In the third phase the researcher conducted an empirical investigation to validate the proposed theoretical framework in practice. Due to the type of research questions asked, and the importance of obtaining information from real-life contexts, a multiple "case study" approach was adopted. The data collection used a standardised observational protocol and was carried out in six construction sites of two different countries (Brazil and England). In addition, isolated construction "best practices", collected around the world, have been assembled into a "meta-case" to supply complementary information for those instances where the case studies did not produce sufficient empirical evidence. The case studies and the meta-case constitute the principal research material used during the validation of the theoretical framework.

The fourth phase of this work focused on the *intra-case study analysis*, with emphasis on the inter-relationships between theoretical propositions, and a *cross case study analysis*, aimed at testing the validity of each of the isolated theoretical proposition. Having tested the applicability of the theory, the fifth phase searched for insights into the creation of an appropriate "learning mood" which could open up construction companies to put these ideas into practice.

Finally, the sixth phase tied together the main aspects of the discussions carried out in the previous phases and the main conclusions concerning the research question. This phase ended with the suggestion of key topics for future research in the field.

1.8 ORGANISATION OF THE THESIS

The author has written this thesis as a series of self-contained chapters in order to allow the reader to freely explore individual ideas without losing context. However, the chapters do have a natural sequential logic that, hopefully, makes conventional serial reading the most sensible way to fully understand their contents.

Chapter 1 - Introduction

The present Chapter has introduced the background that led to the choice of research questions and their correspondent objectives. It included the need for understanding and consolidating the core ideas underlying current production management theories and an indication of the opportunities for learning in today's global economy. The text also

discussed the reasons for choosing construction as the main source of data. This Chapter also presents the working hypothesis, the research scope and an outline of the research method.

Chapter 2 - Production Management in Perspective

This Chapter points out the main aspects surrounding the context of contemporary developments in the production management theory. Initially, following a chronological order of theory development, it builds up a picture of the evolutionary progress wihin the general management and production management field. Then, it presents arguments and counter-arguments, gathered from the literature regarding the differentiation of construction from other industries and how that might affect the application of production management theory in the construction arena. It also discusses the role of production within any organisation with respect to both functional and process perspectives. The strategic role of production is highlighted, along with the need to incorporate strategic thinking into the decision making process of production managers.

Chapter 3 – Theoretical Framework

Having placed production management developments in context, this Chapter presents the structure and content of some core ideas behind current production management theories. It sets a basic theoretical framework for the thesis later used to analyse the case studies. The chapter discusses the concepts of "Flow", "Conversion" and "Value". Following this, it describes five main principles derived from the flow model as well as the correspondent approaches for implementation since they are the main focus of analysis in this research.

Chapter 4 – Research Method

Chapter 4 explains the reasons for choosing "case study" as the research strategy and describes, in some detail, the content of the research design; including the data collection techniques, the protocol for data collection, the unit of analysis and the criteria for selecting the companies. Finally, it presents the case studies themselves, the logic linking the data to the theoretical propositions and the criteria used to interpret the research findings.

Chapter 5 - Cross Case Study Analysis

This Chapter presents what is called in this thesis a cross case study analysis. It searches for empirical evidence that matches the individual heuristic implementation approaches as theoretically defined in Chapter 3. Each of the heuristic principles and corresponding implementation approaches is analysed in depth using real examples from practice in an attempt to calibrate the researcher's theoretical interpretations. Quantitative and qualitative criteria help to substantiate the research findings.

Chapter 6 - Intra Case Study Analysis

While Chapter 5 tries to draw patterns across the case studies, it is also important recognise the individuality of each case study, which is discussed in this Chapter. For, according to Yin (1994), within the multi-case design each case study must stand-alone and have a specific purpose within the overall scope of inquiry. Following this logic, this Chapter present a series of intra-case study analyses where the main focus is on the nature of the different chains of interactions among practices. This investigation intends to illuminate and bring better understanding concerning how the theoretical propositions work in practice within different contexts.

Chapter 7 – Exploratory Study on Changing Practices

This chapter describes an exploratory study aimed at bringing overarching insights for future studies involving the implementation of the theory into practice. The focus of this case study was on the creation of a "learning mood" designed to change traditional practices. It combines the use of the knowledge described in Chapter 3 (*Theoretical Framework*) as well as the data and information analysed in Chapter 5 and 6 (*Cross and Intra Case Study Analysis* respectively). This case study experimented with both "push" and "pull" learning strategies in order to understand the transfer of theory into practice.

Chapter 8 – Final Discussion

Here the researcher presents his general deliberations based on the observations of construction practice and critical analysis of literature. The aspects dicussed in this chapter include the complexity of the pattern matching analysis, the need to improve the knowledge of people in the middle and bottom line of construction organisations and,

finally, the researcher's view on the subject of learning. The last part of this Chapter discusses the potential benefits of the production management theory for driving the generation of innovations within the construction sector.

Chapter 9 – Conclusion

This Chapter simply concludes with a presentation of the major findings related to the research questions, emphasising and highlighting the most important contributions of the study succinctly. The last section of this chapter lists a number of suggestions for future research that the researcher believes are necessary for continuing the advancement of knowledge in this field.

1.9 SUMMARY

Currently, the combination of past theories with new ones has produced a complex portfolio of different strategies for action. The principal group comes as a combination of the main ideas of JIT and TQC and other newer theories such as Visual Management, Total Productive Maintenance, Re-engineering and Value Based Management. The confusing miscellany of theories demands a consolidation of the core ideas within a common theoretical platform in order to allow better communication and understanding among practitioners and academics.

The researcher understands that better understanding of the core ideas underlying current production management theories is necessary to enable effective learning. The use of abstract ideas is defended in the literature as a better way of transferring knowledge and enabling effective learning. In this context, the present research explores this hypothesis and attempts to refine some abstract production management heuristics. More particularly, it focuses on the management of production in the construction environment. Despite being one of the oldest laboratories for the management science, construction is still a wasteful, dangerous, dull and dirty industry. This bad image does not help attracting young talents to the industry and worsens the competitiveness of the sector against other industrial sectors.

One of the central hypotheses of this thesis is that construction already applies the heuristic principles presented as 'best practice' in modern production management

theories. Notwithstanding, the researcher expects to find a lack of integration of these heuristic principles in the empirical evidence collected from the sector. Indeed, exploration of the literature in the area already reveals wide structural problems in the sector and poor attention to systemic implementation of production practices. In this respect, this research also developed a study to explore the issue of how to create a "learning mood" in order to understand how to implement these abstract heuristic principles into construction practice.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter **2**

PRODUCTION MANAGEMENT IN CONTEXT

Everything has been thought of before, but the problem is to think of it again.
Johan W. von Goethe

2.1 OVERVIEW

The previous Chapter introduced the background study that motivated the choice of the research problem. This included the pressures for changing practices in the construction industry and the learning opportunities of today's global economy. Subsequently, it presented the main objectives of the present study, together with the correspondent hypotheses, the scope of the work, the principal aspects of the research method and the structure of this thesis.

The central aim of this thesis is to *interpret and refine some key flow principles of production management based on empirical evidence obtained from the construction sector.* In this context, the present Chapter tries to place production management into a wider systemic perspective, mainly regarding its history and strategic role. This will enable better understanding of the origins and history of production principles described on Chapter 3. Firstly, it presents the most important schools of thought within the managerial theory in general, from which production management cannot be dissociated. Secondly, it discusses the complexities of generalising findings in management science and the strategic role of production within any organisation. Finally, it discusses three alternatives for developing the production management theory in construction: adapting ideas from other industries, developing construction's own theory, or improving the content of a general production management theory.

2.2 RECENT HISTORY OF MANAGEMENT THEORY

2.2.1 THE IMPORTANCE OF UNDERSTANDING HISTORY

Management theory is actually a condensed diary of experiences, observations and thinking. It evolves constantly with the continuous stream of new ideas that come from the attempts to transform theory into practice, and vice-versa. Past theories are constantly revisited to obtain insights to solve current problems. When these theories do not fit in a work context, new ideas have to be developed and, consequently, this

process results in a new theory. Thus, it is important to understand the historical evolution of management in order to solid advance of knowledge in this field to be made.

The study of the management history is a complex task since the boundaries of the field are not exact and there are many different interpretations of its evolution and content. The word *management* itself does not have a universally accepted standard definition. According to McFarland (1979) the word *"manage"* seems to have come into English usage directly from the Italian word *"maneggiare"*, that means *"to handle"*. This word, in turn, traces back to the Latin word *"manus"* (hand). In the early sixteenth century the word *"manage"* was quickly extended into the common language of war situations and used in the general sense of "taking control", "taking charge", or "directing". Later, in the seventeenth and the eighteenth centuries, it became confused with the French word *"menage"*, meaning *"to use carefully"* (McFarland, 1979).

Nowadays the meaning of management is tempered by these early variations, depending on the specific situation. Management "as a process", for example, is understood as the fundamental integrating processes used to achieve organised, purposeful results. From such process managers create, direct, maintain and operate purposive organisations through co-ordinated and co-operative human effort. Management "as a discipline", is typically understood as a field of learning which is organised, researched and taught in an integrative way, bringing together aspects from various disciplines while at the same time developing its own body of theory (McFarland, 1979).

As the paragraphs above have described, understanding history can helps us to understand the actual origins and meanings of our present thinking and actions. Unfortunately, managers often ignore the importance of understanding the management history since they are more inclined to pay attention to actions occurring in the present. However, to disregard the progress of events and ideas of management throughout history is to risk repeating the same mistakes. In this context, the next sections review three of the most important theoretical movements since the Industrial Revolution, as illustrated diagrammatically in Figure 2.1:

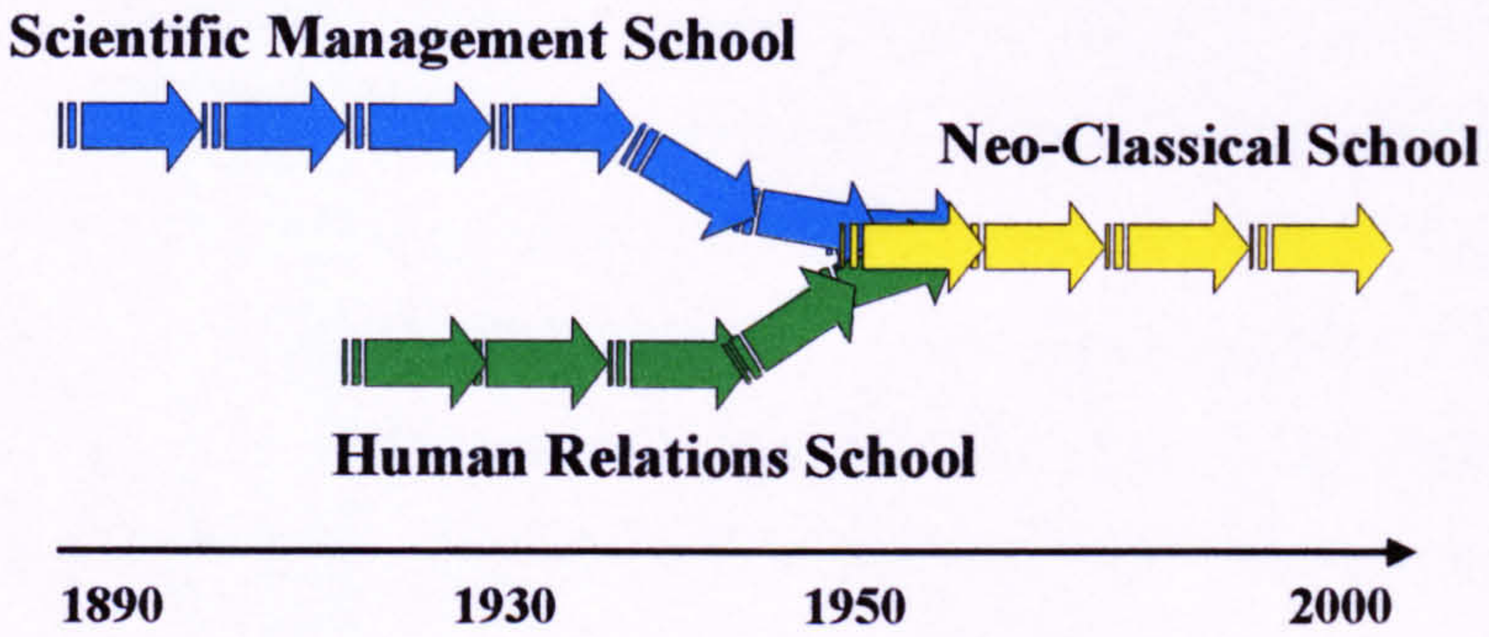


Figure 2.1 - Evolution of Management throughout History

2.2.2 THE SCIENTIFIC MANAGEMENT SCHOOL

The last decades of the nineteenth century, and the first decades of the twentieth, watched the emergence of a new managerial philosophy. Managers started to search for ways to co-ordinate and control production activities as never before. Until that time the control from top managers over operational procedures was very limited because actual production was typically directed by skilled workers who followed traditional craft customs (Wren, 1994).

Prior to this period of history, the adjustments of production to market forces and the introduction of new technologies were almost beyond executive control. However, unionism, growing cost of labour and the need for better quality and productivity forced managers to change their approach to production. Business professionals decided to mechanise and specialise in their jobs, restricting the discretion of those at the bottom of the organisation, thus, expanding the power of those at the top (Wren, 1994). This movement evolved into a complete managerial philosophy[1] that is often called the *Classical School* or *Scientific Management*.

One of the original concerns of this movement was to increase efficiency in production and, consequently, obtain lower costs and higher profits. In order to drive these ideas through to the workforce, workers were to receive pay rises corresponding to the increment in productivity. Thus, this school of thought saw increase in productivity as the answer to both higher wages and higher profits (Weihrisch & Koontz, 1993; McFarland, 1979; Wren, 1994).

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[1] **Philosophy**: the pursuit of wisdom or knowledge, especially the general causes and principles (Oxford Dictionary, 1998)

Frederick W. Taylor is acknowledged as the 'father' of scientific management, because of his famous work entitled "Principles of Scientific Management", published in 1911 . His studies concentrated on the efficient use of time in the workplace. Taylor carried his first time studies into the machine shop of the Midvale Steel Company. There he tried to discover the relationship between the "horsepower that a man exerts" and the correspondent "tiring effect that this work has on man". He concluded that the controlling factor in determining how much work a worker could do was the percentage of time that the worker was under load or resting, and the length and frequency of resting periods. In contrast, common sense at that time had led people to believe that the strength alone was the main factor in determining worker's productivity levels (Taylor, 1911; Barnes, 1980).

While conducting his experiments on work performance, Taylor used a stopwatch to obtain precise measurements of the production activities. He believed that all management judgements and decisions should be firmly based on accurate, first-hand knowledge gathered from systematic detailed observations. Guesswork, hunches and intuition wer to be rejected in his conception of effective management (Taylor, 1911; McFarland, 1979).

Another important pioneer of the scientific management movement was Frank Bunker Gilbreth. In 1885, at the age of seventeen, Gilbreth entered as an apprentice of bricklaying at Whidden Construction Company, in Boston. By the beginning of the twentieth century, Gilbreth was already managing his own construction company. Similar to Taylor, he was also interested in the search for the one best way of carrying out a given task. As a building contractor, he became interested in the study of "needless, ill-directed and ineffective motions in construction processes". In his most famous study, he analysed the bricklayer's motions, reducing them from 18 to 5. With these improvements, he doubled a bricklayer's productivity without the need for increasing the bricklayer's efforts (Barnes, 1980; Gilbreth, 1911; Weihrisch & Koontz, 1993; Cheetham, Steel & Lewis, 1992).

Scientific Management writers believed that workers would have to be taught how to do their jobs better and that they could not know this without formal instruction on how a job should be done. Furthermore, they should receive strong guidance and stern discipline (McFarland, 1979). Thus, the aim of time and motion studies was to develop,

standardise and determine the best possible practices, so that workers could be trained correctly in order to sustain these best practices. Thus, it was necessary to deduce the laws and fundamental principles of the best practices and apply them in order to standardise production activities, either for the purpose of increasing output or decreasing input (Gilbreth, 1911; Barnes, 1980). One of the consequences of this line of thinking was the division of organisations into two separate sets of people: those who think about work and plan and those who actually do the job.

Henry Ford, applied these ideas of the scientific management when developing his assembly line for producing the famous *Model T*, in 1913. The assembly line was part of an integrated production system that emphasised quality, efficient production and the avoidance of waste (Wilson, 1995; Ford, 1988). It was thought that the standard quality was guaranteed by the fact that machines were so well constructed that a piece of work could not go through them unless it followed the specifications (Encyclopaedia Britannica, 1926). The general consent is that the Ford has the credit for bringing mass production to experimental success with his assembly line. The experience of Ford with mass production made mass consumption possible through the continuous reduction of costs and prices. According to Encyclopaedia Britannica (1926) the principles of mass production were:

- Planned orderly progression of the commodity through the production system;
- The delivery of work instead of leaving it to the worker's initiative to find it;
- Systematic analysis of operations into their constituent parts.

With the assembly line, Ford took the original ideas of Gilbreth and Taylor about process control and development one step further. He moved the determination of the content and speed of production out of the hands of a direct human agent almost completely. In this sense, the production system he designed had characteristics which allowed him to recruit a low grade and highly varied workforce that was largely available to Ford at that time (Ball, 1988:30; Ford, 1988).

Taylor's contemporaries seemed to accept the efficacy of this mechanical thinking of Scientific Management, even though they rejected his techniques for establishing it. Unfortunately, many people have misunderstood his original methods and principles,

applying them unwisely. "Efficiency experts" gave the Scientific Management movement a bad reputation, especially among the workforce, due to their focus solely on the increase of productivity, with frequent tactless behaviour to the workforce (Wren, 1994; McFarland, 1979).

Despite all the criticism relating to its despotism, Scientific Management became a powerful managerial philosophy, influencing nearly all Western managerial thinking ever since. Even today, many in the management community still continue to believe that successful management and Taylor's ideas are one and the same (Wren, 1994). Additionally, new management disciplines have often derived directly from the original scientific way of thinking, such as operations research and the application of statistical principles to process control (Voss, 1995).

2.2.3 THE HUMAN RELATIONS SCHOOL

Despite its rapid dissemination and popularity among managers, the Scientific Management School created new problems even at the beginning of its development. Workers started to object to the accelerated pace of working, the restricted autonomy, the destruction of craft skills and hierarchies, the lower standard of workmanship and the substitution of man for machines (Wren, 1994).

It should not be inferred here that the Scientific Management School ignored or overlooked the importance of human factor. After all, Frank Gilbreth, one of its great theorists, had shown great regard for the human factors at the work place; a concern shaped, in part, by the influence of his wife and collaborator, Lillian Gilbreth. Lilian Gilbreth was a pioneer industrial psychologist who focused on the human aspects of work and in improving understanding about the worker's personalities and needs (Weihrisch & Koontz, 1993). Frank Gilbreth was, therefore, aware of the importance of placing man at the center of considerations regarding production analysis.

Taylor himself also considered human aspects as an important factor for achieving sustainable improvements in production. He claimed that business and labour should work together to undergo a "*complete revolution in mental attitude*" and to realise the shared benefits of maximising income through maximisation of output. He believed that when managers and workers shared this common goal it would be easier to eliminate

political controversy and make governing an organisation a purely technical matter of finding the "*one best way*" (Taylor, 1911; Wren, 1994).

However, factory owners throughout the world contributed to the bad reputation of the scientific movement by using its principles without providing complementary rewards, training and managerial support to the workforce (Weihrisch & Koontz, 1993). As a result, workers gradually realised the weaknesses in the scientific management system and started to exploit them. For example, they took advantage of the diminution of skills to increase the rate of turnover. Then, they collectively started to restrict output using strikes and demand higher wages (Wren, 1994).

The result of this situation was that, by the late 1920's, researchers and practitioners started to experiment on, and write more about, industrial psychology and social theories. In the beginning, such research focused more on helping industry find people whose mental qualities were best suited for their jobs. They also tried to find those psychological conditions that could stimulate and influence workers in such a way as to obtain the best possible results from them (Weihrisch & Koontz, 1993; McFarland, 1979).

The turning point in this human focused research came with the study carried out by Western Electric managers and Harvard University researchers at the Hawthorne works, near Chicago, from 1924 until 1932. Originally, this study sought to confirm Taylor's principle that more lighting in the workplace would result in greater productivity. However, to the amazement of the researchers, the experiment showed productivity rising still further even with a decrease in illumination. The investigation then turned its attention to the relationship between managers and workers, still aiming for the manipulation of workers to maximise the output (Mayo, 1949; Barnes, 1980:283; Wren, 1994; Weihrisch & Koontz, 1993).

After a number of experiments, they finally concluded that the improvements in productivity happened almost solely due to social factors such as moral and satisfactory inter-relationships within the production team. The study also showed that just the fact of being chosen for the study motivated workers to continually improve production regardless of the working environment (Mayo, 1949; Wren, 1994; Weihrisch & Koontz, 1993; Lee & Schniederjans, 1994).

Since the Hawthorne experiment the volume of research in the field of human resources has increased fast. In time this became a mature theoretical movement, resulting in what is called today the Human Relations School. This school of thought brought rapid advances in the sciences dealing with men/women and their behaviour in the workplace (Weihrisch & Koontz, 1993; McFarland, 1979).

The Human Relations School searched for integration among the various disciplines studying human behaviour. However, it has been difficult for human researchers in this movement to maintain a single disciplinary approach since the field is extremely complex and individual problem can be interpreted from a variety of different angles. To illustrate, the items below show a sample of disciplines in the field that emphasise different aspects of human behaviour (McFarland, 1979):

- *Industrial psychology* studies fatigue, monotony, selection and training of employees and techniques for psychological testing and measurement;

- *Industrial sociology* emphasises the study of groups, both large and small, as well as the problems of society itself;

- *Applied anthropology* studies aspects of cultures, both past and present, and the impact of culture elements on particular groups;

- *Social psychology* studies the inter-relationships between group and individual behaviour; mass communication; propaganda analysis and rumour transmission.

Unfortunately, the implementation of the Human Relations School in practice had similar problems to those faced by the Scientific Management School. Practitioners simply misunderstood and misapplied research findings because, among other reasons, they had no systemic understanding of the theory. Unfortunately, "*buzz words*" captured the attention of well-intentioned industrialists who used them inappropriately; often consultants oversold concepts of human relations that still were evolving. As a consequence the Human Relations School declined in the late 1950's because it could not solve all the problems it promised (McFarland, 1979).

2.2.4 THE NEO-CLASSIC SCHOOL

The elicitation of the Neo-Classic School dates from the mid-1950's when Litchfield first proposed a "*general theory of administration*". This school, sometimes called "*revisionist*" or "*management science*" movement, was motivated by the confusion surrounding the management field when the Scientific Management School and the Human Relations School began to integrate into practice. What was once a hostile and contradictory relationship progressed to be one of collaboration when a new model evolved incorporating ideas from both schools (Litchfield, 1956; McFarland, 1979; Weihrisch & Koontz, 1993: 44).

It can be said that the initial inspirations of the Neo-Classical School came with the seminal work of the Tavistock Institute of Human Relations on the effects of changing technology in the coal-mining industry in the 1940's. At that time, the increasing mechanisation and the introduction of coal-cutters and mechanical conveyors enabled coal to be extracted on a "longwall" method. However, the new method also meant a change in the social groupings of miners that characterised the previous system - the "single place" or "shortwall" method. Thus, despite the theoretical advantages of the new method it did not prove to be as efficient as predicted during the initial stages of implementation. This was because the social disruptions produced by the new method led to low moral and more frequent process problems (Mullins, 1993).

At this point the Tavistock researchers saw the need for a socio-technical approach in which an appropriate social system could be implemented alongside the new technology. The result was the "composite wall" method with more responsibility given to the team as a whole, and development of composite tasks and the re-introduction of multi-skilled roles. The Tavistock study concluded that the composite method was psychologically and socially more rewarding and economically more efficient than the "longwall" method (Mullins, 1993). This balanced approach between the social and technical approach became one of the hallmarks of the Neo-Classic School.

The Neo-Classical School of thought does not discard the content of early theories, but insists on rejecting ideas that have not been verified or proven in practice. According to McFarland (1979) the central characteristic of this movement is its emphasis on sophisticated research methods, empirical investigation, and rigorous testing of

propositions. Because of these characteristics, this school is praised for receiving contributions, not only from academics and consultants, but also from active practitioners. The background of the contributors is diverse, ranging from behavioural scientists, system theorists, operation research specialists, decision theorists, statisticians, computer experts, and so on.

People working under the ideas of this school of thought do not expect to find definitive answers in their search for the "*one best way*" (Forza, 1996). In fact, the phrase "*one better way*" seems to be more suitable to characterise the emphasis of process improvement in this movement. The most effective concept underlying this objective has been the need to drive continuous and relentless improvement. This, it is suggested, must be carried out in every aspect of a business by self-regulating teams through frequent and systematic problem solving activities.

2.2.5 DISCUSSION

The literature review has clearly shown that evolution of management theory mirrors the changes in the surrounding economical and social environment. There have been times when the capitalist exploitation of a cheap and non-educated workforce was acceptable. In that situation, managers focused their attention solely on the reduction of waste and increased production speed. Changes in the economy and society worldwide resulted in a workforce that no longer accepted being treated like another piece of machinery. Consequently, it brought workers' motivation and satisfaction back into the main considerations of managers.

The fusion of Scientific Management and Human Relations ideas is clearly observed in modern management literature in general. Technological knowledge is placed side by side with human considerations. Also, in high education there are a growing number of multi-disciplinary courses linking pure technical topics (e.g. alternative formwork technologies) with human topics (e.g. theories of motivation). This trend is recognised by research funding agencies that have now started to demand greater participation of social scientists in bids for research in the management field (EPSRC, 1999). The present thesis itself is best described as being part of this school of thought, since it investigates and puts together many ideas traced in both schools of thought.

2.3 GENERALISATION OF MANAGEMENT THEORIES

The generalisation of theories across industries and countries has been the subject of research since the early years of the scientific management school. Frank Gilbreth, for example, believed that the principles he was laying down from his observations of construction, were applicable to every trade and every industry (Gilbreth, 1911:xii). This section explores various aspects of developing such generalisations and starts by presenting the contrasts between technical and related findings.

2.3.1 GENERALISATION OF TECHNICAL FINDINGS

The successful generalisation of findings to different environments requires deep understanding of entire systems of variables (human + technical). Technical variables are those that have a corresponding external and tangible object in the real world. They may include mechanical, mathematical, or otherwise inanimate variables (Rosenweig, 1994). According to Rosenweig (1994) technical variables often refer to things that have entered language relatively recently, such as CIS - *Computer Information Systems* and MRP - *Material Requirement Planning*. Therefore, technical terms usually do not carry with them a social tradition that itself creates nuances and subtle differences in connotation.

Some technical findings can be simply applied directly into other sectors whilst other technical findings are only relevant to particular sectors. Sufficient understanding is necessary to determine the degree of transferability. However, it does no harm to use technical finding as a metaphorical benchmark for change since it is sometimes impossible to find ideal conditions for full replication of technical aspects of production. Purely technical findings do not depend on human behaviour. Therefore, their generalisation to other countries is not threatened by differences in individual or organisational behaviour (Rosenweig, 1994).

2.3.2 GENERALISATION OF HUMAN RELATED FINDINGS

Cheng (1994) states that a finding in the management science can only have universal applicability if it incorporates characteristics of the socio/cultural context in which it was observed as analytical variables in the explanation or prediction of that phenomenon. Alternatively, according to the same author, a research finding can only

be considered as universal if all the relationships it describes remain unchanged from one socio/cultural context to another. In this context, human related findings present themselves as far more complex to generalise than technical findings.

Human related findings include the actions of people whether as individuals, or groups, or organisations. Thus, these types of findings are often abstractions that depend on social construction and cultural understanding in order to obtain meaning. Unfortunately, differences in social and cultural characteristics themselves impose barriers to generalisation of human related findings. These differences are manifested, for instance, in particular managerial behaviours such as decision making styles, approach for learning activities, norms of participation and formality in presentations (Hofstede, 1994; Lessen, 1993).

The way organisations learn, for instance, varies considerably from one culture to another and may affect a principle or concept derived from a human related finding. According to Lessen (1993), for instance, in the more pragmatic cultures (e.g. USA, UK), knowledge is typically acquired through experience. Here, managers and workers have a strong pressure for action, and less for reflection. In the rationalist cultures (e.g. France) managers may generate bureaucratic paths of decisions throughout the company. Managers in more wholistic cultures (e.g. Germany, Japan) are more likely to be worried about the coherence of the whole system in which someone is working. In humanist environments (e.g. Italy, Spain) the social network is usually the strongest factor in decision making and learning (Lessen, 1993).

From the discussion above, it becomes clear that human related findings usually involve a far more complex number of factors than technical ones. Thus, findings of this kind offer far more difficulties to build high abstract concepts for enabling international transfer (*see* item 1.2.2 - *Using a Theory to Enable Learning* - Chapter 1). Because of this, they are very often translated into actionable consulting packages and *"how to"* books (Rosenweig, 1994; Lillrank, 1995).

2.3.3 MAIN BARRIERS FOR GENERALISATION

Cultural differences are the most commonly mentioned barriers for generalisation of theories. Because of the number of cultural variables and the difficulties to evaluate

them, the analysis of a culture is a complex task and, not surprisingly, it brings controversy. Moreover, relationships between cultural variables are difficult to hold in different environments. Even composing a research team using people from different national origins does not, in itself, guarantee the elimination of cultural biases in research findings. A lot will depend on the interpersonal dynamics within the team such as leadership and equality (Hofstede, 1994).

Hofstede (1994) gives an example of theory that does not apply to two different cultural environments: the well known Mc-Gregor's theory of management style (*Theory XY*). Mc-Gregor's theory was written from an individualistic, fairly masculine cultural background, that makes little sense, for instance, in the collectivist, moderately feminine Indonesia (Hofstede, 1994). Table 2.1 presents some of these incompatibilities.

Table 2.1 - Problems on Generalising the Theory XY (Hofstede, 1994)

West	East
♦ Work is good for people	♦ Work is necessary, but not a goal in itself
♦ People's capacities should be maximally utilised	♦ People should find their rightful place, in peace and harmony with their environment
♦ There are 'organisational objectives' that exist apart from people	♦ Absolute objectives exist only with God. In the world persons in authority positions represent God, so their objective should be followed
♦ People in organisations behave as unattached individuals	♦ People behave as members of a family and/or group. Those who do not are rejected by society.

Other arguments against the generalisations of the management theory include:

♦ *Language*: unfortunately, there is not a universally accepted language, with shared definitions, that could be a basis for a universal contingency management theory. Thus, even a translation with literal exactness from one language to another is not a guarantee of conceptual equivalence since it may not operationalise the variable in a way that leads to valid interpretation of data (Rosenweig, 1994). For example, what is viewed as aggressive behaviour in China may receive different interpretation in Holland though one can find an exact translation of the word for both countries;

♦ *Observer or response bias*: the systematic error or bias in data collection and analysis is another threat to obtaining external validity of studies carried out across

countries. Rosenweig (1994) distinguishes two different biases: *observer bias* - when the selection of data for study reflects the researcher's culturally based assumptions and *response bias* - when cultural differences produce societal-specific response biases;

- *Peculiarities of each industry:* the literature of each industry tends to emphasise the uniqueness of its practices. This act as a barrier to generalising research findings from other industrial sectors or other countries;

- *Links to external conditions*: sometimes managerial practices may rely on particular features of the external environment which may vary among countries, making any generalisation more difficult (Rosenweig, 1994).

Adding to the barriers presented above are the doubts about the usefulness of searching for any theoretical generalisation. The study of theory is not always clearly worthwhile for people in industry since the meaning of the word "theory" to them is usually associated with speculation or with a mental distance from the real world (Koskela, 1996). Hence, Hofstede (1994) argues that the search for a universal, timeless, world-wide management theory is futile since it is a never-ending quest. Even when it is found that a particular piece of knowledge is universally valid, it may still not be universally relevant (Rosenweig, 1994; Aharoni & Burton, 1994).

2.3.4 DISCUSSION

In the author's view, one of the most important results of searching for the theoretical meanings of best practices is to expand the creativity of people and drive their corresponding reflection in the practices of their industry. Therefore, it is not simply enough to ask whether the research findings of one country are valid, or not valid, in another country but used that to promote useful reflections. Promoting learning and enhancing creativity are sufficient reasons why both industry and academia should strive for better theories that lead to better practices and vice-versa. Exploring opportunities posed by different cultures is one way to achieve this objective.

The side benefits in terms of continuous learning is often more important than the generalisations themselves. Thus, despite the cultural relativity of generalisations present in a theory, there are great possibilities of using it as an enabler for international

and cross-organisational learning. After all, inter-cultural co-operation demands a common theoretical ground in order to permit the exchange of ideas. Hence, the study of the theory underlying best practices (*theory-in-action*) can play an important role as an instrument for communication and reflection in practice.

2.4 THE PRODUCTION MANAGEMENT CASE

The previous sections explained the historical evolution from which production management cannot be dissociated. They also presented the pitfalls of generalising about management theories. Having put the management field in context, the next section shows the dynamic relationships between production practice and theory, and discusses some of the current research topics dominating the field.

2.4.1 DYNAMIC FLOW BETWEEN PRACTICE AND THEORY

In the past hundred years production management has evolved from a set of heuristic ideas to a portfolio of somewhat developed concepts and principles. This has followed the typical path of knowledge development illustrated in Figure 2.2. "Just-in-time" and "Total Quality Management" integrate most of the modern concepts and principles in the field. However, new heuristics and principles constantly flow from practice to theory as we deepen our understanding about practices from the 'best plants' world-wide (Schonberger, 1985; Koskela, 1992; Womack & Jones, 1996)

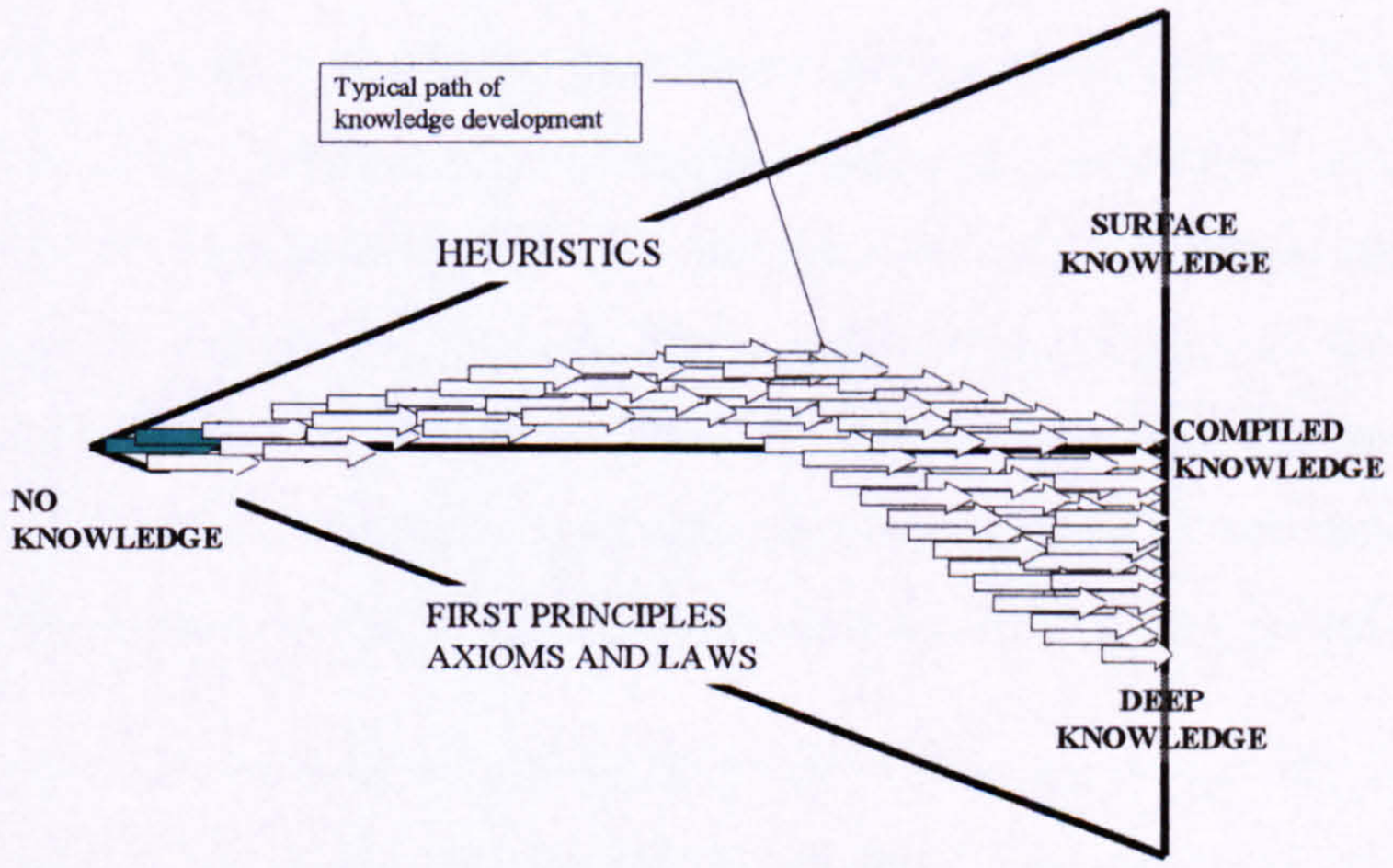


Figure 2.2 – Evolution of Domain Knowledge (after Harmon & King, 1985)

Companies operating in competitive environments are constantly trying new ideas in order to cope with an increasing complex business environment. They now realise that keeping in touch with, or developing new knowledge, is a key factor in guaranteeing their survival. The constant shift of management emphasis during the last few decades demonstrates the eagerness of companies for new knowledge in this respect, as Figure 2.3 illustrates. Furthermore, this shift of emphasis is part of a continuous and cumulative learning process that affects what is known, and practised, in the field of production management. Indeed, from the narrow view of work study, there has been a gradual evolution of emphasis towards issues involving the entire organisation (e.g. Total Quality Management) and, now, to even wider issues such as the organisation with the external environment (e.g. Environmental Management).

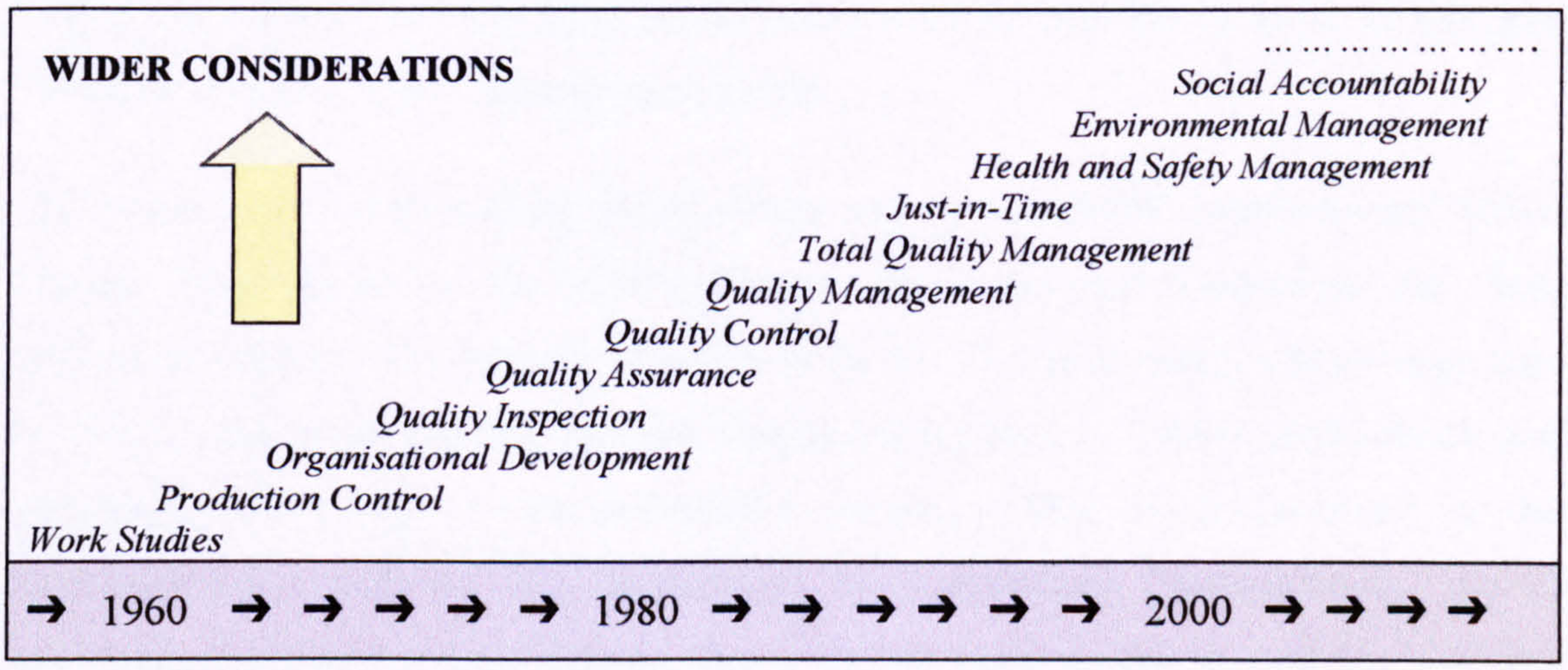


Figure 2.3 - Change of Management Emphasis Through Time (after Sjoholt, 1998)

This dynamic flow between practice and theory, and vice-versa, is also one of the key virtues of disciplines relating to production management. Academics and consultants are continually developing new ways for solving production problems and marketing these solutions to practitioners through books and training programs, for instance. In other situations the active experimentation of practitioners leads to new ideas and insights that are themselves gradually transformed into theories. These theories, in turn, help the communication of their solutions to other practitioners facing similar problems.

If a new theory, or some of its elements, proves to be successful elsewhere it may become the new imperative in the manager's agenda. However, in the case of failure, this new theory is likely to become one more ineffective "*buzzword*" to be criticised by

industry and academia. Unfortunately, due to the lack of proper testing of theory in practise, or due to deficient implementation, this happens all too often.

2.4.2 PRODUCTION MANAGEMENT RESEARCH AGENDA

Current production research is characterised by a wide and integrative perspective about production, including social and environmental issues. In particular, there is a growing volume of research focusing on the consolidation of "Just-in-Time" with "Total Quality Management" and an array of other theories/practices such as "Total Productive Maintenance" (TPM), "Visual Management" and "Re-engineering". Recent investigations seek to develop the content and structure of the core ideas underlying these theories. In particular, "World-class manufacturing", "Lean Production" and "Agile Production"[2] are the most recent terms used to describe research in this area (Womack & Jones, 1996; Schonberger, 1996).

The world-wide benchmarking study carried out by the IMVP (*International Motor Vehicle Programme*) in the 1980's has propelled research concerning the "lean production" subject. The primary objective of the IMVP was to create a knowledge base to allow better understanding of what constitutes superior industrial performance and competitive advantage in the automobile industry. With its headquarters at the *Massachussetts Institute of Technology* in Cambridge, Massachusetts, IMVP investigated companies from Europe, Japan and North America, as well as Australia, Brazil, Korea, and South Africa. One of their main findings was that the 'best plants' worldwide had common characteristics and practices that result in lean production systems. In short, these companies were able to produce more products, with higher quality but with fewer resources (Womack, Jones & Ross, 1990).

As a result from the IMVP work, the interest of industry and academia in the subject of "lean production" has grown faster ever since. Global competitiveness became associated with the practice of lean production. Techniques and views on how to achieve world-class/lean production are now the subject of many conferences, workshops and seminars around the world. Universities are proposing an increasing

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[2] Due to similarities the present research will use the term lean production when referring to wold-class manufacturing, agile production or correlated topics.

number of research projects and programmes designed to be of relevance to production managers in the establishment of lean practices.

The growing publication rate and higher quality of publications on lean production, identified by Voss (1995) in the *International Journal of Operations and Production Management*, already indicate a growing interest of academia on the subject (see Table 2. 2 below):

Table 2. 2 – Level and trend of publication rate in the *International Journal of Operations and Production Management* by topic (Voss, 1995)

	Level of Publication		
Trend in the Rate of Publications	**Low**	**Medium**	**High**
Up	Maintenance Research Methodology	Quality Practice performance Cellular manufacturing, Flexibility Performance measurement	**Lean production** **Just-in-time** **Manufacturing strategy** **Implementation**
Static		Service Flexible Manufacturing Systems Advanced Technology, Computer Integrated Manufacturing	Models Simulation Production Planning and Inventory Control
Down	Economic Order Quantity Buffer Stocks Optimised Production Technology Robotics	Manufacturing Resource Planning	

Researchers now continuously review the current state of lean production approaches, including the testing of propositions and evaluations of their relationship with performance. Industry now requires universities to participate in industrially supported research projects aimed at accelerating the adoption of lean production practices (e.g. WCMRT, 1999; CEMM, 1999; DVIRC, 1999; LESDI, 1999; MMTI, 1999). Benchmarking studies try to position the practice and performance of industries in an international context with regard to lean production practices. The focus of these studies is namely on the contrasting patterns across countries and the identification of common characteristics among leading competitors. Hence, governments increasingly include

"lean production" ideas as the underlying topics for policy-making in industrial development (Latham, 1994; Egan, 1998; COMRP, 1999).

2.4.3 DISCUSSION

Production management theory, as any other managerial theory, could be interpreted as *"condensed learning"*[3] since it incorporates many of the core ideas and cumulative experiences that have led to current best known production practices. Thus, production management theory should be considered as the result of a natural learning process of companies searching for ways to become more competitive. The constant shift of managerial emphasis in industry should provoke reflection and drive further improvements in the theory. Unfortunately, the constant and unstructured generation of new terms and "new theories" witnessed nowadays does not help either industry or academia to consolidate existing ideas or developing truly new ideas.

In general, newer theories do borrow concepts and principles already developed from previous works and, therefore, usually contain only a fraction of truly new knowledge. Often the main body of these 'new' theories is only a re-interpretation and re-configuration of previous theories in order to allow the application of them in a particular context and for a particular problem. Furthermore, even if it is clear that a 'new theory' does not have actual new knowledge, companies often adopt them if it conforms to their way of seeing the world or working on it. The novelty factor of a brand new name also seems to help them to provoke change and reflection among production personnel.

The fact that the current research agenda, such as world-class manufacturing and lean production, increasingly focuses on the study of comprehensive and integrating theories indicates that production management has began to be a mature field of knowledge. This is not to say that practitioners, consultants and academics in the field should disregard previous theories. In fact, without adequate understanding of previous theories, there is a risk of overlooking important operational knowledge. So, for instance, the successful implementation of "Just-in-Time" and "Total Quality

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[3] Idea presented by Lauri Koskela at the Conference ENTAC - *Encontro Nacional de Tecnologia do Ambiente Construido*, Florianopolis, Brazil, May 1998.

Management" depends on the adequate knowledge of specific topics such as work-study and quality control.

The next section explores the context of the development of production management in construction, since this industry will be the main source of empirical evidence in this research.

2.5 DEVELOPING PRODUCTION MANAGEMENT IN CONSTRUCTION

2.5.1 CHARACTERISTICS OF THE CONSTRUCTION INDUSTRY

The development of production management theory in construction requires an adequate understanding of the main characteristics of the sector and the implications of these characteristics in production practices. In this sense, some of the most common factors used to characterise construction are:

- *Spatial fixity of buildings*: unlike any other industry, the end product of construction is generally spatially fixed, large and immobile. This physical characteristic influences fundamentally the structure of all construction organisations (Ball, 1988);

- *On site production*: the construction industry is distinguished by the physical nature of its production process. In general, a large proportion of the work takes place at the site where the product will be used. As a consequence of this on-site production, the workforce, tools and equipment have to move from site to site to undertake a sequence of tasks that, to a certain degree at least, vary from project to project (Ball, 1988:40);

- *Workstations moving around a fixed product*: the objects of construction are wholes assembled from 'parts' (*fixed position manufacturing*). During the assembly process, the parts themselves become too large and heavy to move through workstations. Thus, the workstations have to move through the emerging wholes, adding pieces as they move (Ballard & Howell, 1998);

- *Land dependence*: land speculation takes a great share of the resources for the construction business process. The continual need to pay ground rent, or the high

prices that developers have to pay to acquire building plots, limits the incentive for construction companies to invest in new techniques. Thus, this factor hinders technological and managerial development in the sector (Ball, 1988);

- *One of a kind product*: construction is, in general, a "make-to-order" industry where the majority of projects are "one-off" and "tailor-made" to a particular client's requirements (Fellows et al., 1983);

- *Long life expectancy required*: a building is usually more expensive than most other manufactured goods and, because of that, it has to be more durable (Gann, 1996). Moreover, many clients may also prefer not to change their living/working place throughout their life, which confers to the life expectancy of a building an extra psychological and social dimension;

- *Non-experienced clients*: typically, the construction client normally has little or no experience in buying a house or other product from construction. This situation contributes to their inability to clarify their requirements and poor discernment with respect to the level of quality supplied by construction companies. In short, it is only when they inhabit a building that they realise its inadequacies;

- *Merchant/producer role of construction companies*: this factor has implications in all phases of the business process. Sometimes, the most profitable construction companies may not be the ones with the best production performance. Rather, they are often the ones that achieve the best portfolio of contracts. Eventually, this situation creates a paradox where the "least-cost producers" are forced out of business because they are not the ones with the most favourable portfolio. In such an environment, innovation is likely to come from other sources rather than different practices in the production system (Ball, 1988:97);

- *Overwhelmingly domestic industry*: in most countries, imports constitute a relatively small, though growing proportion of the construction input. Many of the construction materials are too heavy or awkward, in relation to their value, to make extensive international trade viable. This sort of trade usually only occurs when there is a lack of indigenous construction technology or management skills or, when domestic prices rise above foreign prices. In some cases, governments can influence the rules of

international competition in favour of a country's construction firms by direct subsidies, cheap project finance or even "diplomatic muscle". However, overseas work, though significant for some individual firms, generally represents only a small percentage of a country's output. Furthermore, this usually only happens when a firm's domestic market has collapsed or is saturated (Ball, 1988);

- *Masculine stereotype*: it could be claimed that the construction industry has a masculine stereotype. Actually, the workforce in construction is predominantly male. The social psychology of building workers, therefore, has its emphasis on the masculine bravado and in individual risk taking that, in turn, contributes to the high levels of accidents in the sector (Fellows et al., 1983; Ball, 1988);

- *Long period for design-production*: in general, there is a long period between the decision to implement a construction project and the actual commencement of the works on site. In major jobs the entire project may take years to be completed (Ball, 1988);

- *High cost of the projects*: the cost of a construction project confers a structural rigidity to the business process. Cancellation may be prohibitively expensive once contracts have started, or when extensive pre-planning and design has been done, or when the project is semi-completed (Ball, 1988);

- *Amplified reaction in economic crisis*: the high cost and the long cycle time for producing a construction product tends to amplify the effect of variations in the economy. Hence, the typical strategy of the sector has been to push the risk areas externally to the firm. One example of this behaviour is the practice of hiring equipment rather than buying it. This reduces the idle time of machines and reduces the need to retain a skilled workforce to operate it since many hiring firms are now providing trained operatives (Ball, 1988);

- *High proportion of subcontractors:* in order to avoid the risk of having high indirect costs of employment (e.g. pensions, sickness and holiday pay, clerical and administrative costs, etc.) and to be more flexible in times of variations in the economy, construction companies subcontract workers, or encourage them to be self-employed. Subcontracting adds considerable flexibility in terms of adjusting

workloads and the ability to undertake different types of work. Subcontracting is feature of most of industries, but what is distinctive in the construction industry is the extent of its use and, most importantly, that it takes place at one point of production, the building site (Ball, 1988);

- *Labour intensive*: the financial risk caused by the high cost and long duration of projects, associated with the fragility in downturns of the economy, results in a culture of avoidance of those technologies which require substantial investment on fixed assets. The wide use of production systems that demand the intense use of labour and few machines reflects this culture;

- *Fragmented*: construction is essentially a large and fragmented industry, with significant differences between firms in terms of size and scope of their work.

The unique and complex environment represented by the combination of these, and other, characteristics represents a challenge for production management research in construction. The overall opinion among academics and practitioners with respect to how to develop better production practices in the construction sector varies considerably. In this context, the next sections report the most common strategies identified in the literature.

2.5.2 USUAL STRATEGIES FOR DEVELOPING PRODUCTION MANAGEMENT IN CONSTRUCTION

2.5.2.1 ADAPTATION OF IDEAS FROM OTHER INDUSTRIES

Today, the applicability and transfer of practices and theories from other sectors is the constant subject of discussion within the construction industry. Manufacturing, in particular, have been a reference point, and a source of innovation to construction, over the years. Hence, defenders of directly transfer of manufacturing practices to construction constantly challenge the arguments in favour of the differentiation of the sector (IMI, 1996). Indeed, there are now major research programmes that aim to transform construction into a manufacturing process. In the UK, the Construction Task Force's report on the scope of improving the quality and efficiency of the construction industry says (Egan, 1998):

> *'...we see that construction has two choices: ignore all this in the belief that construction is unique that there are no lessons to be learned; or seek improvement through re-engineering construction, learning as much as possible from those who have done it elsewhere...'*

The defenders of the transfer of practices from other industries question the conventional assumptions of the construction process itself. Traditionally, because of the characteristics of construction, it has been claimed that the "project" process approach is the only suitable option for the sector. However, according to the supporters of the idea of moving construction towards a manufacturing mode, the sector can progress towards alternative process configurations. As Figure 2.4 illustrates, construction can evolve from the production based on projects to job-shop, batch flow, assembly line or, in certain cases, continuous flow of production.

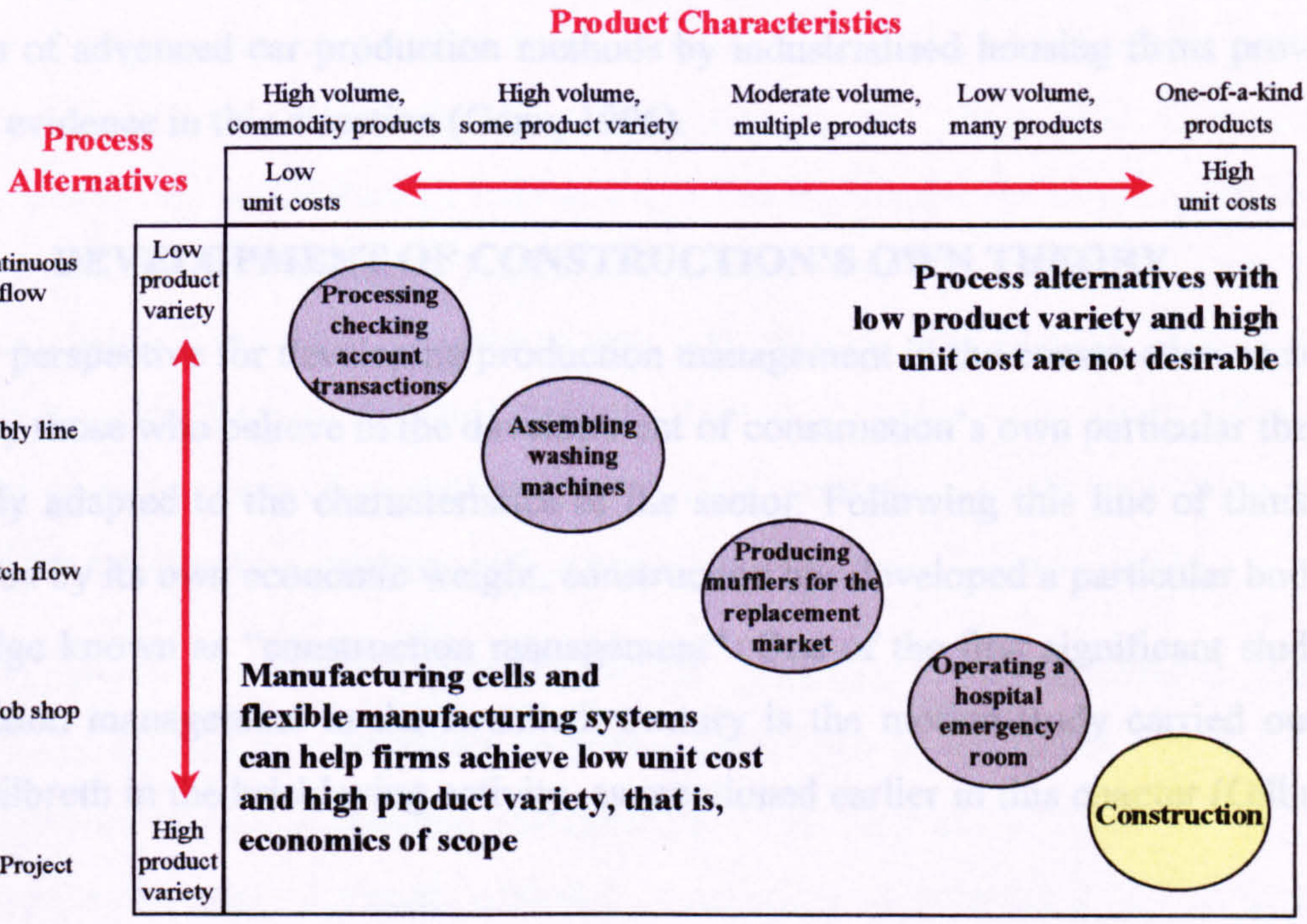


Figure 2.4 - Process Alternatives versus Product Characteristics [adapted from Hayes & Wheelwright (1979) and Vonderembse & White (1996:260)]

According to the logic of Figure 2.4, product characteristics in the construction sector can evolve from "one-of-a-kind" product to a high volume/commodity product. The same Figure shows that the type of production process adopted will depend on a relationship between product maturation and technological innovations (Hayes & Wheelwright, 1979; Vonderembse & White, 1996:260). Ideally, construction should

evolve to become a "manufacturing cell" or a "flexible process" where production has a high variety of products and low unit costs. Most high performance production systems reported in the literature benefit from the economies of scope offered by this type of process.

The Construction Task Force (UK) argues that many buildings, such as houses, are essentially products with components that can be continuously improved. Furthermore, the construction business process itself is partially repeated in its essentials from project to project. Therefore, even the construction business process should be subject to the same successful practices found in manufacturing (Egan, 1998). Ball (1988) goes even further by saying that building production should be designed to be almost identical to the conveyor-belt model, except that it is the workers and not the products who would move down the line. Certainly, for some particular types of construction this direct transfer of practices has already proved to be possible. In Japan, for example, the adoption of advanced car production methods by industrialised housing firms provides positive evidence in this direction (Gann, 1996).

2.5.2.2 DEVELOPMENT OF CONSTRUCTION'S OWN THEORY

Another perspective for developing production management in the construction sector is shared by those who believe in the development of construction's own particular theory, especially adapted to the characteristics of the sector. Following this line of thinking, and driven by its own economic weight, construction has developed a particular body of knowledge known as "construction management". One of the first significant study in construction management in the twentieth century is the motion-study carried out by Frank Gilbreth in the bricklaying activity, as mentioned earlier in this chapter (Gilbreth, 1911)

Studies at the Building Research Establishment (UK), Construction Industry Institute (USA) and other research institutes across the globe have contributed to improve our understanding on the sources of problems in the construction industry and methods to deal with that (Bishop, 1965; Grigg, 1991; Littlefair, 1995). The Construction Industry Institute, for instance, maintains eight-five research groups in fields ranging from High Performance Work Teams, Reduction of Cycle Time, Craft Productivity Improvement, Modularization and Total Quality Management.

Total Quality Management, in particular, has received great attention since the mid 1980's. In the UK, the CIOB - Chartered Institute of Building has invested great efforts in this area through the development of guidelines for the sector. One of these initiatives, for instance, was the production of instructions for the sector regarding Quality Assurance (CIOB, 1987). The pressure for better quality in the sector has increased so much that by the early 1990's, many firms in the UK construction industry had put in place quality management systems to BS 5750 (now ISO 9000) and achieved third party certification. A range of publications were available on quality management in construction, including a significant series of reports from CIRIA – Construction Industry Research and Information Association (CIRIA, 1996).

Some of the major themes of current construction conferences and seminars include value management, automation of construction systems, electronic data management, process management, team building and partnering. In the UK, the Contruction Industry Board is trying to put these ideas into practice through the involvement and co-ordination of all stakeholders in the construction supply chain. The Construction Industry Board was established in February 1995 to implement the thrust of the report *'Constructing the Team'* (Latham Report). Fourteen Working Groups were set up to develop a code of practice for construction and prepare best practice guidance for clients on briefing, and on selecting consultants and specialist contractors. They also addressed wider issues such as qualification systems, education, equal opportunities, the image of the construction industry, and liability and insurance (Latham, 1994).

However, despite all these efforts, there are clear gaps in the theories under discussion in the current construction literature regarding production management. There are few articles discussing core production management ideas such as the reduction of batch sizes, implementation of visual controls, installation of mistake-proof devices or reduction of work-in-progress. Furthermore, the construction industry has a poor record of continuous professional development and life long learning, especially regarding better practices for managing production (Powell, 1999). A clear consequence of this situation lies in the fact that many of the developments carried out by Frank Gilbreth are still poorly applied in construction companies. In contrast, the same developments are now part of the normal practices of other industrial sectors (Gilbreth, 1911; Weihrisch & Koontz, 1993; Cheetham, Steel & Lewis, 1992). In the UK, the same production

problems in construction have been charted with regularity since the Second World War, in reports of the Ministry of Public Buildings and Works (1964) and several other studies, and latterly by Latham (1994) and Egan (1997).

A brief look some of the contents of operations and construction management books presented in Table 2.3 illustrates the difference of emphasis in both disciplines. The construction management books used as reference in Table 2.3 are: *"Construction Management in Practice"* (Fellows et al. (1983) and *"Professional Construction Management"* (Barrie & Paulson, 1992). Both books are widely used nowadays in most undergraduate courses relating to construction management. The operations management books used as benchmark in this table are *"Operations management: decision making in the operations function"* (Schroeder, 1993), *"Production and Operations Management"* (Wild, 1995) and *"Operations Management"* (Lees & Schniederjans, 1994). Researchers working in other industries regularly mention these three textbooks in the bibliographic references.

Table 2.3- Comparison of Contents among Key Operations and Construction Management Books

AREA	GENERAL OPERATIONS MANAGEMENT	CONSTRUCTION MANAGEMENT
Purchasing	♦ Logistics; Specifications and quotations; Awarding contracts; Expediting; Just-in-time purchasing; Follow-ups	♦ Definition of documents; ♦ Purchasing and contracting; Control of procurement; Budgeting, Estimating[4]
Material/ Inventory	♦ Management methods: Just-in-time, ABC system, Kanban, MRP I, MRP II; ♦ Material handling technologies; Integration of Management Resources;	♦ Operational research methods: cost models, probability, linear regression, stock control; network analysis, linear programming; queuing.
Quality	♦ Quality Management (TQM), ISO 9000; ♦ Techniques: Quality circles, Taguchi Methods, Pareto, etc.;	♦ Economics of quality; ♦ Organisation for quality assurance; ♦ Quality control;
Human Resources	♦ Job design, Payment and incentives, Worker's motivation.	♦ Health and safety: legislation, costs, safety policies and organisation; implementation guidelines ♦ Recruitment and selection, Education and training, Communication.

Source: Fellows, Langford, Newcombe & Urry, 1983; Barrie & Paulson, 1992, Schroeder, 1993; Lee & Schniederjans, 1994; Wild, 1995)

[4] **Estimating includes**: detailed estimates, definitive estimates; cost control and cost engineering, work breakdown structure, cost codes, control budgets, engineering economy, life cycle costing

The construction management literature claims to be more suitable for the sector because it is based on the practices and peculiarities of the sector. According to the defenders of this strategy, the combination of the various characteristics of construction confers a "peculiar" mode of production to it (Ball, 1988:39; Towill, 1997; Ballard & Howell, 1998). When this "peculiar" mode of production is placed in *dynamic construction projects*, characterised for quickness, uncertainty and complexity, construction shows constant reminders that it cannot be transformed into manufacturing. These reminders, in turn, cannot be ignored or overlooked when developing a consistent and coherent theory of production. For this reason, Ballard & Howell, (1998) argue that there is a need to develop techniques customised for the construction sector.

2.5.3 DISCUSSION: AN ALTERNATIVE STRATEGY

Following Lillrank's (1995) concepts of knowledge transfer (*see* Chapter 1), practices of different industries can be effectively transferred across industries if they are translated into highly abstract ideas. Thus, an alternative strategy for developing a production management theory suitable to construction is to search for common abstract definitions that enable the effective exchange of ideas with other industries. This means widening the scope, abstracting and improving the core ideas of production management theory in order to contemplate and consider even the construction's peculiarities.

Certainly, construction, as any other industry, has its own particular mix of peculiarities. However, to place these peculiarities at a level where they are all determining seems both logically and historically false. Technical change can continuously transform the physical content of any production process, making previous seemingly insuperable barriers either non-existent or easier to overcome (Ball, 1988). Koskela (1996) argues that most of the peculiarities of construction also exist in other domains of engineering and, thus, they are subject to the same theoretical advancements[5].

[5] It is worth emphasising that many important thinkers in production management, such as Frank Gilbreth and Taichi Ohno, began their careers working in the construction industry (Gilbreth, 1911; Ohno, 1988).

Furthermore, companies in other sectors, facing some of the peculiarities faced by construction have managed to overtake them and reach excellent levels of performance as Table 2.4 shows:

Table 2.4 - Excellent Companies with Similar Characteristics of Construction

CONSTRUCTION	OTHER SECTORS
One of a kind product	Shipbuilders
On site production	Car Repair (AA Patrol)
Fixed position manufacturing[7]	Aeroplanes (Boeing)
Land dependence	High Street Retailers (Benetton)
Long life expectancy required	Elevator Manufacturers (Otis, Kone)
Non-experienced clients	Ambulance (999 Service)
Merchant/producer role of companies	Car Factories (Toyota, Nissan)
Overwhelmingly domestic industry	Fast Food (McDonald's)
Temporary Organisation	Sport Events (World Cup - FIFA)
Masculine stereotype	Mining (Minnesota Mining & Manufacturing)*
Long period for design-production	Car Factories (Toyota, Nissan)
High cost of the project	Chemical Industries (Du Pont)*
Amplified reaction in economic crisis	Entertainment (Disney Productions)*
Labour intensive	Fast Food (McDonald's)
Fragmented Industry	Cloth Producers (Levi Strauss)*
Spatial fixity of the end product	None

* Companies with excellent performance in all aspects of the business according to Peters & Waterman (1982)

"*Spatial fixity of the end product*" is the only truly special characteristic of construction compared to other sectors. Spatial fixity brings with it various sources of uncertainty such as soil conditions, wind load, seismic conditions and the discretion implicit in the application of codes and regulations. Moreover, because the product is 'rooted in place', its relationship with clients also becomes different since it is more difficult in construction to find alternative customers in other geographical areas (Ballard & Howell, 1998).

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[7] Ballard & Howell (1998) argue that the uniqueness of construction comes from the combination of fixed position manufacturing and the fact that the product is rooted in place.

Spatial fixity invariably results in some sort of site production or final assembly. Industrialisation initiatives have tried to handle this problem by advocating the transformation of site activities into off-site production where the construction site would be restricted to final assembly and testing. This implies moving production activities, as much as possible, to a factory environment, away from the site, where they can be done more efficiently (Sarja & Hannus, 1995; Ballard & Howell, 1998).

These industrialisation ideas sound adequate to apply in slow, certain and simple construction projects. However, enormous difficulties appear when people try to apply such industrialisation ideas in dynamic construction projects, characterised by high uncertainty and complexity. Hence, the strategy of making construction more like manufacturing in *dynamic projects* requires construction characteristics to be softened, or explained away. Indeed, the transfer of practices from manufacturing usually falls into a "vicious cycle", often resulting in small, but important, reminders that construction has not yet been transformed into a manufacturing process (Ballard & Howell, 1998)

If only certain types of construction can be fully transformed in manufacturing, there will always be certain misfits between the manufacturing literature and the construction practice with respect to production. In fact, this is one of the main arguments for those defending the development of a particular theory for construction. However, as the literature review revealed, while construction management has dedicated a great amount of effort to develop its own body of knowledge, it has often done so whilst being unaware of the recent and useful advances in general operations/production management (*see* Table 2.3). Intra-sector development of concepts and techniques in construction can offer the risk of alienation and increased difficulties in communicating and exchanging ideas with people from other industries.

In this context, the strategy of widening the scope of production management theory is seen as a viable alternative to effectively avoid the inaccuracies of copying manufacturing practices, or the risks of alienation caused by the search for a special construction management theory. This theory should provide a useful filter for construction, by means of which it would be possible to consider the applicability of ideas generated in other contexts, thus, enabling cross-industry learning. For this reason,

during the literature review the researcher tried to avoid special focus to construction or any other industry.

2.6 INTERACTIONS OF PRODUCTION WITHIN THE ORGANISATION

The previous sections presented the context in which production management theory is being developed and, particularly, the complexities of considering construction characteristics in its theoretical development. This section turns its attention to how production interacts with the other activities within general organisations.

2.6.1 THE FUNCTIONAL PERSPECTIVE

An organisational function can be defined as a subsystem of processes that share common inputs and aims for common outputs. Figure 2.5 shows some of the most common functions present in the literature. Under the functional perspective production is an organisational function that receives material, equipment, personnel and information and transforms it into specified products. Hence, some form of production clearly exists in all companies, regardless of size or structure (Fayol, 1967).

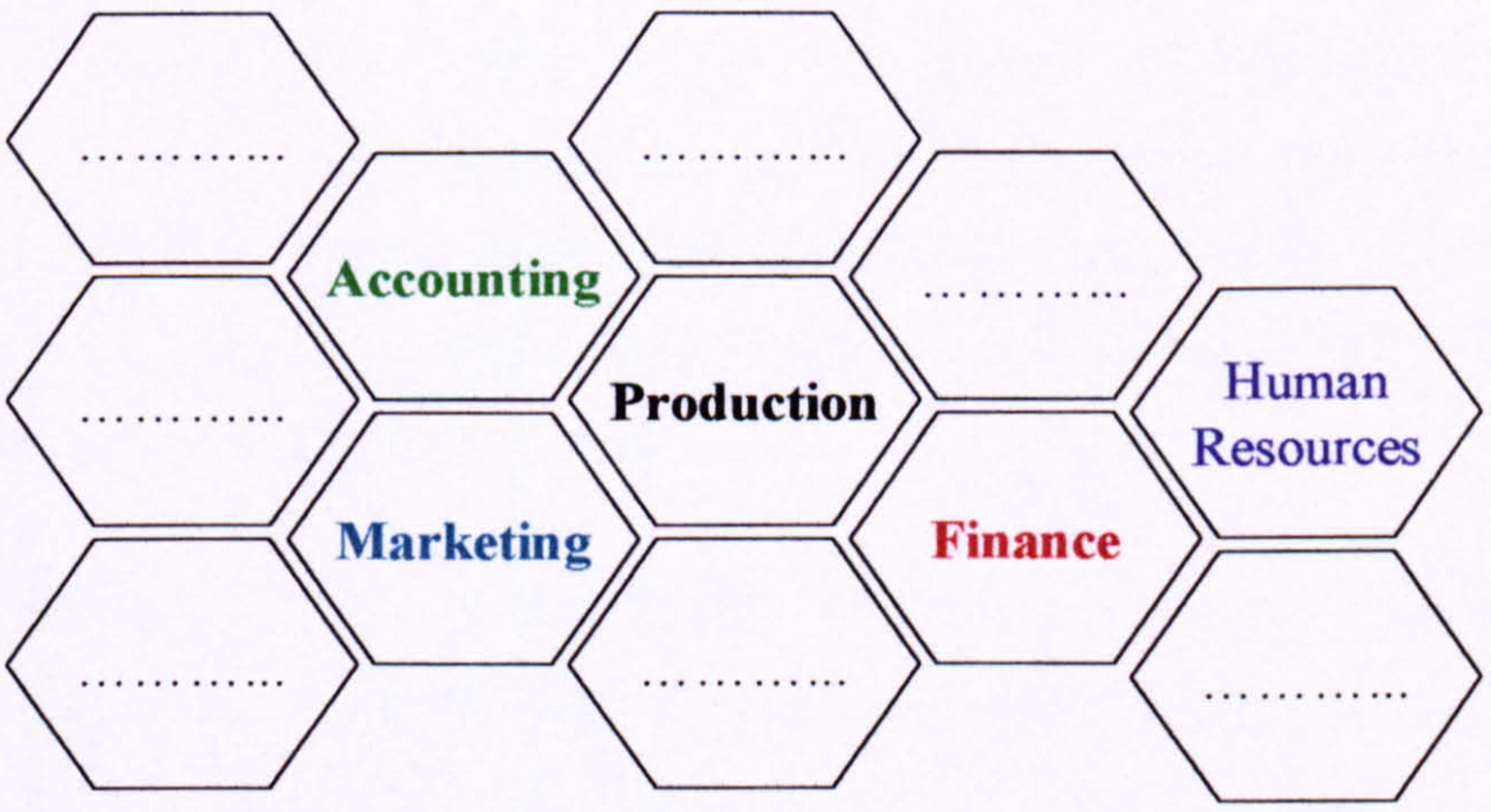


Figure 2.5 – Production as one of the Organisational Functions

In large companies, a complete department may represent a *'production function'*. In contrast, small companies may have production, and other organisational functions, concentrated in a single person. Therefore, the notion of *'production function'* is not the same as the traditional notion of a *'production department'*. Traditional organisations

often use a functional perspective as the logic behind the organisation of production. The organisational charts in these companies confirm such practises by showing the hierarchical levels within the production function, as well as the limits of those functions within the organisation. However, production has a far more complex dynamic than any organisational chart could possibly represent. Some of its typical interactions are described below (Vonderembse & White, 1994; Skinner, 1992:23/24):

- *Accounting:* the production manager receives cost information and budgets from the 'account function' in matters related to human resources, materials, and other inputs and, subsequently, uses that information to establish new directions to production. The main interest of accounting is to get the correct information out as fast as possible, while meeting all technical requirements. Production managers, in turn, have to provide accounting with all the transactional data necessary to describe financial and fiscal aspects of the production activities. This continuous need for control between is often seen as a burden by production managers;

- *Marketing*: this organisational function monitors customer needs, promotes the company's image and helps to sell the services and products of the company. Therefore, the main interest of this function is to increase market share by promoting an increase in sales. In general, the 'production function' receives information from the 'marketing function'; this normally includes the number, quantity and characteristics of all the products that should be produced. Marketing expects, from the production manager, information on the capabilities of the production system to meet customer demands and expectations. Conflicts arise when increases in sales are not synchronised with the capacity of the production system;

- *Human Resources*: this organisational function is usually responsible for all activities related to personnel, such as recruiting and training. As the production receives workers and logistical support from the 'human resources function', production managers have to provide information on the quantity, timing, and profile of personnel required. One of the human resource's main underlying interests is, therefore, to "keep the peace" among the workforce, trying to avoid unnecessary disputes and unfortunate precedents. This human resource posture often conflicts with the need that the 'production function' has for unleashing innovative ideas and

increases the motivation of the workforce through continuous experimentation in practice.

From a systemic point of view production interacts with, and is dependent on, all other sub-systems (organisational functions) of a larger system. These include all interest groups, even those well beyond the organisation's normal boundaries. Such groups are often called "stakeholders" because they are affected by, and affect, the decisions taken in production. The stakeholders include, for example, the unions, the shareholders, the workforce, the customers, the suppliers and the public in general.

The interactions of the production function with the external stakeholders are constantly changing. Technological and social changes bring about new demands to production from time to time. For instance, in the 1920's and 1930's the pollution issue was not considered to be a problem because few people fully understood the consequences of such an environmental issue. Thus, waste from production could then be disposed using cost as the only business decision criteria (Vonderembse & White, 1994). In contrast, today new demands and legislation are emerging from public opinion in terms of environmental issues. As a result, environmental management is an essential topic in the agenda of the most competitive companies. This condition has increased the pressure for those involved with production to use more environmentally benign products and processes.

2.6.2 THE PROCESS PERSPECTIVE

Nowadays, the pressures for faster and better answers to market needs and demands is such that in many companies traditional departmental barriers are being eliminated as managers try to create cross-functional teams to tackle difficult and complex problems. One of the core issues from this is a fundamental change in a company from organising it by departments, to organising it by business processes, such as strategy formulation, product development, and order fulfilment (Hammer, 1990; Davenport, 1993; Kawalek, 1994; Vonderembse & White, 1994).

Figure 2.6 illustrates a business process crossing various organisational functions.

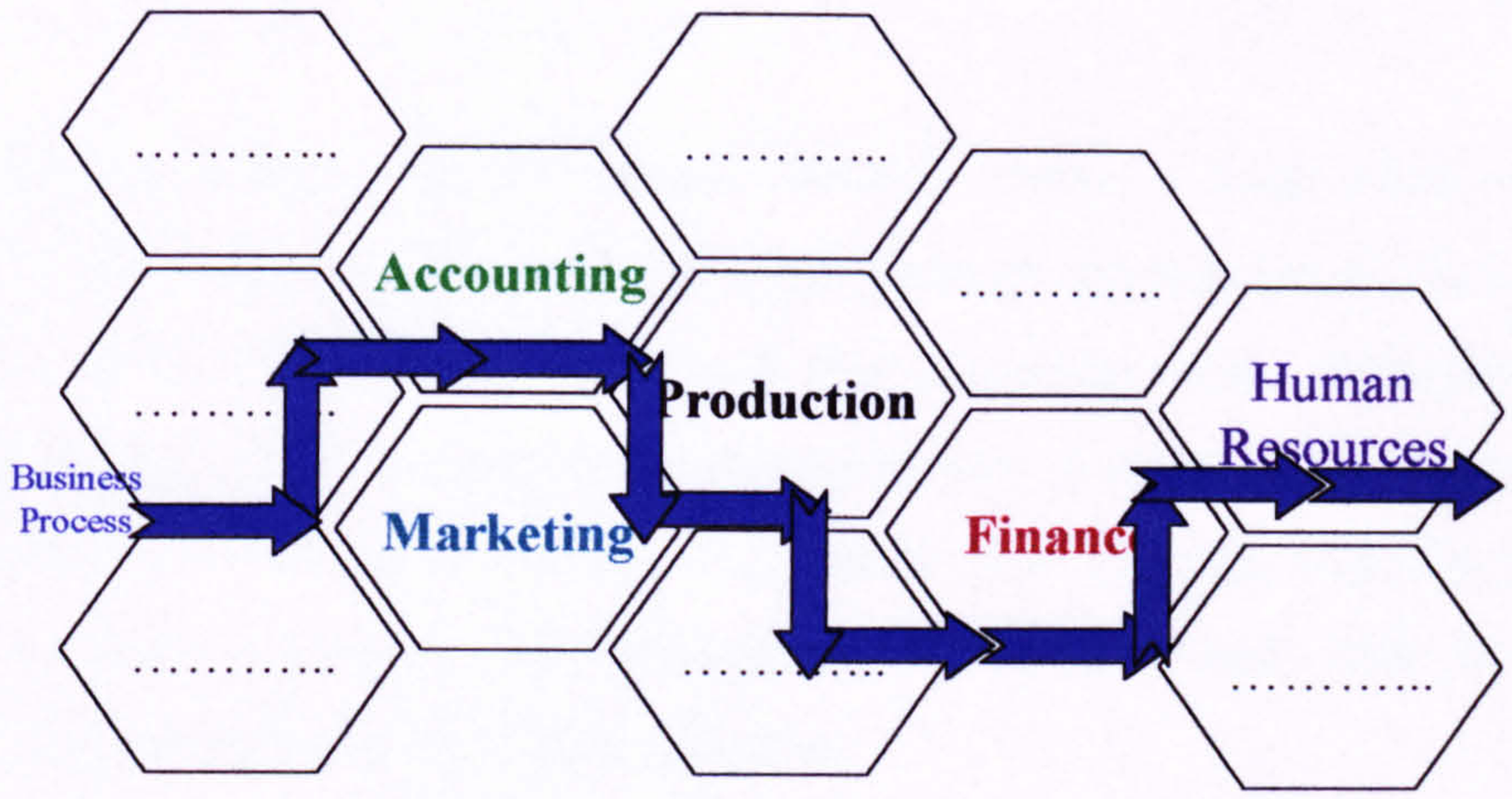


Figure 2.6 – Production as Part of the Business Process

Business processes have always existed in organisations but often they are not recognised as such by managers because of superimposed departmental structure (Edward & Peppard, 1994). Yet, as the process driven perspective begins to permeate into all industries, the benefits of reorganising activities around the main value adding flows becomes more evident. This approach increases the focus of decisions to clients needs, reduces waste of resources and, thus, promotes better internal synergy.

The production function has an important role within all business processes since throughout its activities pass most of the company resources. However, it is clear that the earlier a decision is taken in any business process, the higher is its impact on the overall project performance. The impact of reviewing the client's need at the "*briefing stage*", for instance, may have greater impact on cost and time than arduous efforts during the production stage (Norton, 1995). Indeed, correcting mistakes during the production stage is far more costly since it usually involves rework and waste of materials.

The process perspective emphasises the strategic importance of involving production expertise already from the early stages of the business process in order to achieve a substantial reduction of waste and increased value in the subsequent stages of the business process. In this context, production can, and must, give a significant contribution to the achievement of higher levels of performance in the business process.

2.6.3 DISCUSSION

The literature associated with the present research reveals a clear trend towards the inclusion of production in the context of wider business process issues (e.g. Norton & McElligott, 1995). The common feature of this movement is an emphasis on waste reduction and increase of value through integration and synergy of production with the entire organisation and supply chain. Integration and synergy requires production managers to have a greater multi-disciplinary background and, with it, a greater willingness to participate in teamwork activities.

Although there is a growing volume of multidisciplinary research in the field, it is likely that production management will continue to have its own experts and disciplines, since the industry needs people with profound understanding of this field. However, the researcher understands that the literature lacks the critical debate needed on right connection between production decisions and decisions throughout the business process. The strategic implication of production decisions is the theme of the next section.

2.7 THE STRATEGIC ROLE OF PRODUCTION

2.7.1 DIFFERENTIATING STRATEGIC, TACTICAL AND OPERATIONAL DECISIONS

Conventionally the translation of a company's needs into actions follows three levels of decision-making: strategic, tactical and operational. Strategic decision-making gives more emphasis to "*wished events*" while tactical decision-making emphasises "*planned events*" and, finally, the operational decision-making focuses on "*current events*". The paragraphs below present some examples of typical information handled at each of these decision levels:

- Strategic (*wished events*): market penetration, consolidation, liquidation, market development, diversification, internal development, acquisition, joint venture (Porter, 1986; Bowman & Asch, 1987), new opportunities, new products, new management systems, new manufacturing processes, new production channels;

- Tactical (*planned events*): re-arrangement of schedules in order to get a better balance of resources; preparation of training courses to introduce new technology;

- Operational (*current events*): the processing times, labour absenteeism, reduction of machine breakdowns, material shortages, layout changes.

A very important difference between strategic decisions and other type of decisions is their clear search for competitive advantage. A good strategy sets the development path along which the key organisation capabilities will evolve to achieve business objectives (Galbraith, 1986).

One example of implications of a strategic decision is the option for 'outsourcing'. Normally outsourcing is used when a firm has neither a critical strategic need nor special capabilities to produce or supply a particular product or service. Companies using this strategy can lower their long-term capital investment and leverage their key internal competencies significantly. Therefore, outsourcing can provide greater flexibility, especially in the purchase of rapidly developing new technologies, fashion goods, or the myriad of components for complex systems (Quinn, 1994).

In practice, the boundaries between strategic, tactic and operational decisions are not clearly defined. However, this rather abstract division does not mean the use of a Taylorist approach to strategic development since the same person could be found making decisions at different levels of the decision-making process (Cheng & Simmons, 1994).

2.7.2 THE CONTEXT OF STRATEGIC THINKING IN PRODUCTION

With the globalisation and opening of market barriers, customers are becoming more discerning in terms of price, quality, cost, delivery and the availability of customised features. After all, nowadays customers have the power and ability to choose the best product or service that their money can buy from anywhere in the world. In this context, competitiveness rests more and more on the anticipation of market trends and in the quick response to the ever-changing customer needs and demands (Browne, Sackett & Wortman, 1995; Stalk, Evans & Shulman, 1992). These, and other changes in the competitive environment in the last decades, have brought significant changes in the strategic role of production within any organisation, as explained next:

- *1945 - mid 1960's*: during this period the focus was on the efficiency of the production function due to the positive balance between production capacity and demand after the 2nd World War. Industries that were producing artefacts for the war turned their attention to the production of goods in virtually untouched markets (Hill, 1992);

- *mid 1960's - mid 1970's*: the focus then moved towards marketing, as a result of companies' redressing of the relation between production capacity and demand that was caused by the saturation of existing markets. Companies started to search for new markets in other regions and countries with far more intensity (Hill, 1992);

- *mid 1970's - mid 1980's*: companies shifted their focus to the accounting/finance function, mainly because of the effects of the oil crisis of 1974 (Hill, 1992);

- *mid 1980's – 1990's*: the emphasis in the current period is on the achievement of "lean business processes". This results from various factors, such as global competition, the over capacity of the industry, the scarcity of key resources, the drastic reduction of product cycles and the new developments in Information Technology. As a result, there is a strong need for synergy and strategic focus across the various organisational functions.

Strategic and holistic thinking among production personnel is a fundamental requirement for enabling production to give an effective contribution to competitive advantage. However, it is still often the case that operational decisions and actions within production do not agree with the strategic needs of the company. In this context, the next sections discuss the development of strategic thinking into production decisions.

2.7.3 THE MISSING LINK BETWEEN PRODUCTION DECISIONS AND THE BUSINESS STRATEGY

Galbraith (1986) argued that organisations are "packages of mosaics" in which all the pieces must fit together. In line with this, coherence of decision-making between production and other organisational functions, specifically concerning the business process, is a fundamental requirement for achieving a company's strategic objectives.

Internal fights within a company, to satisfy fragmented objectives, are counterproductive and only lead to sub-optimisation and waste of resources.

Production managers risk being affected by "cognitive nearsightedness" if they do not get involved in strategic planning. Short-term decisions may sacrifice a long-term strategic advantage. Bowman & Asch (1987) define "cognitive nearsightedness" as the tendency to pay more attention to physically observable, quantitative and immediate factors, at the expense of intangible dimensions of a problem that are remote in time and space. In other words, production managers may place too much emphasis on direct operational decisions and give little attention to their implications on the business strategy[8].

In this context, production may opt for one of the following strategic postures with respect to the business needs (Hayes & Wheelwright, 1984; Schroedder, Anderson & Cleveland, 1986; Adler, McDonald & McDonald, 1992):

- *Internally neutral*: production that is simply reactive to the internal business demands. The function has few links with the rest of the business and makes a minimal contribution to increase the company's competitiveness;

- *Externally neutral*: production that is able to meet the standards imposed by the major competitors. It responds to problems encountered in the rest of the business, but never establishes its own long term strategy;

- *Internally supportive*: production that is tailored to the specific business strategy. In this case, the production function generates many new ideas and has a long term strategy, but it may not be well tuned to other functions needs or expectations;

- *Externally supportive*: production that aims to be as good as any other competitor in the world. In this case production supports both the current business priorities, and other organisational functions, thus, creating new opportunities for increased competitiveness.

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[8] The need for coherence between business strategy and the production was first brought to attention on the seminal paper written by Skinner (1969) – *Manufacturing: the missing link in corporate strategy*.

Unfortunately, production is often found playing only an internally neutral role in many organisations. Production's usual response to competitive pressure has been a simple directive to "cut costs" which, in turn, results in the decision to reduce capital investment, minimise research and development, cut back preventive maintenance and to lay off workers (Wisner & Fawcett, 1991). In some instances, production managers try to transfer and adopt the same "best practices" of other successful production systems. However, Mills, Platts & Gregory (1995) argue that "*the implementation of the best practices alone is unlikely to develop the production function ability to create and understand its own strategy*".

According to Skinner (1992), one of the main barriers for moving the production towards a more strategic role is the lack of a leadership that understands and accepts the idea of developing strategic thinking in the production function. Hill (1992) adds some other reasons for the poor participation of production at the business strategic debate:

- *The production manager's view of themselves*: strategic implications of the production decisions are not fully understood even by the production managers themselves;

- *The company view of the production manager's role*: business strategic decisions are formulated assuming the production manager has few strategic contributions to give;

- *Production managers are late into the corporate debate*: very often production managers have their first contact with the content of the strategic decisions only after they have already been defined;

- *The "can't say no" syndrome to orders*: a result from the fear of losing face or being accused of incompetence in relation to other functions within the company;

- *Lack of language*: production managers rarely understand the language and practice at the corporate level because of their operational background (the lack of strategic management in the curriculum of undergraduate courses is also often a serious gap in higher education in this field);

- *Functional goals and measures*: the link between production goals and actions in the business performance is not always clearly made.

Nowadays, production managers and workforce must have a clear strategic orientation in order to allow them to understand the link and impact of their own actions on the strategic needs of the company. In this sense, the adoption of a process for continuous formulation and revisions of a production strategy is a fundamental step in bringing strategic focus and, therefore, consistency to all production decisions and actions.

2.7.4 DEFINING PRODUCTION STRATEGY

According to Roth, Giffi & Seal (1992), production strategy is a critical component of world class companies. Skinner (1992) argues that one of the basic ideas of a production strategy is that production must be a powerful source of competitiveness. It can be defined as those collective and co-ordinated decisions that are used in the formulation and deployment of production resources in order to provide competitive advantage (Swamidass and Newell, 1987; Marucheck, Pannesi and Anderson, 1992:93). A production strategy must be able to cope with the paradox of promoting consistency of decision-making in highly competitive environments and, at the same time, guaranteeing future adaptability in the case of changes in the environment (Marucheck, Pannesi & Anderson, 1992).

The content of any production strategy may vary from company to company, but the literature constantly refers to a number of 'decision fields' that should be considered when formulating it. The most commonly referred to are: capacity, facilities, technology, vertical integration, quality management, human resource management, production planning, scheduling and control systems (Hayes and Wheelwright, 1984; Anderson, Cleveland & Schroeder, 1989; Marucheck, Pannesi & Anderson, 1992; Skinner, 1992). The next section presents the competitive criteria utilised to evaluate the content of decisions within these 'decisions fields'.

2.7.5 COMPETITIVE CRITERIA IN PRODUCTION DECISIONS

A production strategy must be formulated in accordance with competitive criteria defined by business requirements. The literature lists a number of competitive criteria in this respect such as speed, consistency, acuity, agility, innovativeness (Stalk, Evans & Shulman, 1992), diversity, speed of production changes (De Meyer, 1992: 225) uniqueness (Fleury, 1995), safety and morale (Ishiwata, 1991). However, the most basic

competitive criteria are cost, quality, time and flexibility since from their combination can be developed most of the other competitive criteria (Skinner, 1969; Porter, 1980; Buffa, 1977; De Meyer, 1992; Stalk, Evans & Shulman, 1992; Minor, Hensley & Wood, 1994; Stalk, 1994; Fleury, 1995; Ishiwata, 1991). The next sections describe these four basic competitive criteria;

2.7.5.1 QUALITY

Quality, as a production competitive criterion, has a variety of different connotations and interpretations for production. From a strict operational point of view, the most practical and straightforwardly visible way of detecting quality in any production system is the level of process variability. Strategic decisions, using this interpretation, usually focus on actions aimed at continuously reducing the root cause of process problems in the long-term[9] (Imai, 1986; Shingo, 1988). However, one of the shortcomings of this internally oriented definition of quality is the assumption that production is already working under a specifications that matches to customer's requirements. This may not always be the case. In this context, a more comprehensive interpretation of quality defines it as "fitness for use", or the capacity to consistently meet, or exceed, the customer needs and expectations (Juran, 1989; Deming, 1986; Vonderembse & White, 1996; Schroeder, 1993).

2.7.5.2 TIME

In today's highly competitive business environment, time has become a precious commodity (Jackson & Hall, 1992). Time cannot be stored, borrowed, purchased, traded, or changed. Still, it is permeating every facet of businesses today, from research and development, through to marketing and distribution. In strategic decision-making, time is a more useful and universal metric than cost or quality because it can drive improvement in both variables (Hall & Jackson, 1992; Stalk, 1989; Krupka, 1992; Vonderembse & White, 1996).

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[9] According to Imai (1986), the Japanese managers have found that seeking improvement for improvement's sake, is the surest way to strengthen a company's overall competitiveness in the medium and long term.

2.7.5.3 COST

In poorly competitive environments, where the formula *"cost + profit = price"* is valid, people's attentions tend to go away from improvements in the production system (Shingo, 1988). However, this formula is no longer applicable in today's competitive environment and many companies are realising this rather late. In the current context, price is becoming market led and, because of that, profit now is severely affected by the final cost (*"price - cost = profit"* or *"price - profit = cost"*). Thus, achieving a competitive production cost is the aim of the majority of production managers nowadays. A sustainable reduction in cost implies improvements in performance against both quality and time competitive criteria.

2.7.5.4 FLEXIBILITY

The growing volume of more sophisticated buyers, the emergence of volatile markets and the short life cycles of products are examples of factors that demand greater flexibility from today's organisations. Hence, flexibility is a hybrid competitive criterion since it is a composition of other competitive criteria. Suarez, Cusumano and Fine (1995) suggest that all types of flexibility are variants of four basic types of flexibility:

- *Mix flexibility*: measured by the number of different products that a system is able to produce at any point in time;
- *New product flexibility*: measured by the ability of rapidly introducing new products;
- *Volume flexibility*: measured by the ability to vary production with no detrimental effect on efficiency and quality;
- *Delivery time flexibility*: measured by the ability to vary delivery times.

A production system cannot retain sustainable levels of flexibility without improving quality, cost and time. Obviously, a production manager can decide to buy brand new machines in order to acquire immediate flexibility. Nevertheless, such an increase in flexibility will certainly lead to corresponding increases in cost. However, the literature shows that high flexibility can also be achieved without costly decisions. In other

words, the simultaneous reduction of production cost and time and parallel improvements in quality are possible. The next section discusses this new paradigm.

2.7.6 THE FALL OF THE TRADE-OFF PARADIGM

The literature on production strategy traditionally recommends focusing decisions on one or two competitive variables at a time. The practical reasons for choosing such strategic focus lies in the need for a more coherent and focused use of resources in relation to business needs. Hence, a company which chooses to compete on time, for instance, could also decide to speed up the introduction of new products, operate "Just-in-time", or respond promptly to customer complaints (Skinner, 1992; Stalk, Evans & Shulman, 1992). Unfortunately, one of the underlying problems of this way of thinking is the idea of static *"trade-offs"* (compromise) among these main competitive criteria.

The "trade-off" paradigm can be defined as "the notion of rigid compromise relationships between competitive criteria" (*see* illustration in Figure 2.7). Mapes, New & Szwejczewski (1997) state that, within this "trade-off" paradigm, the achievement of performance in one or more competitive criterion can only be obtained at the expense of performance in one or more other competitive criterion.

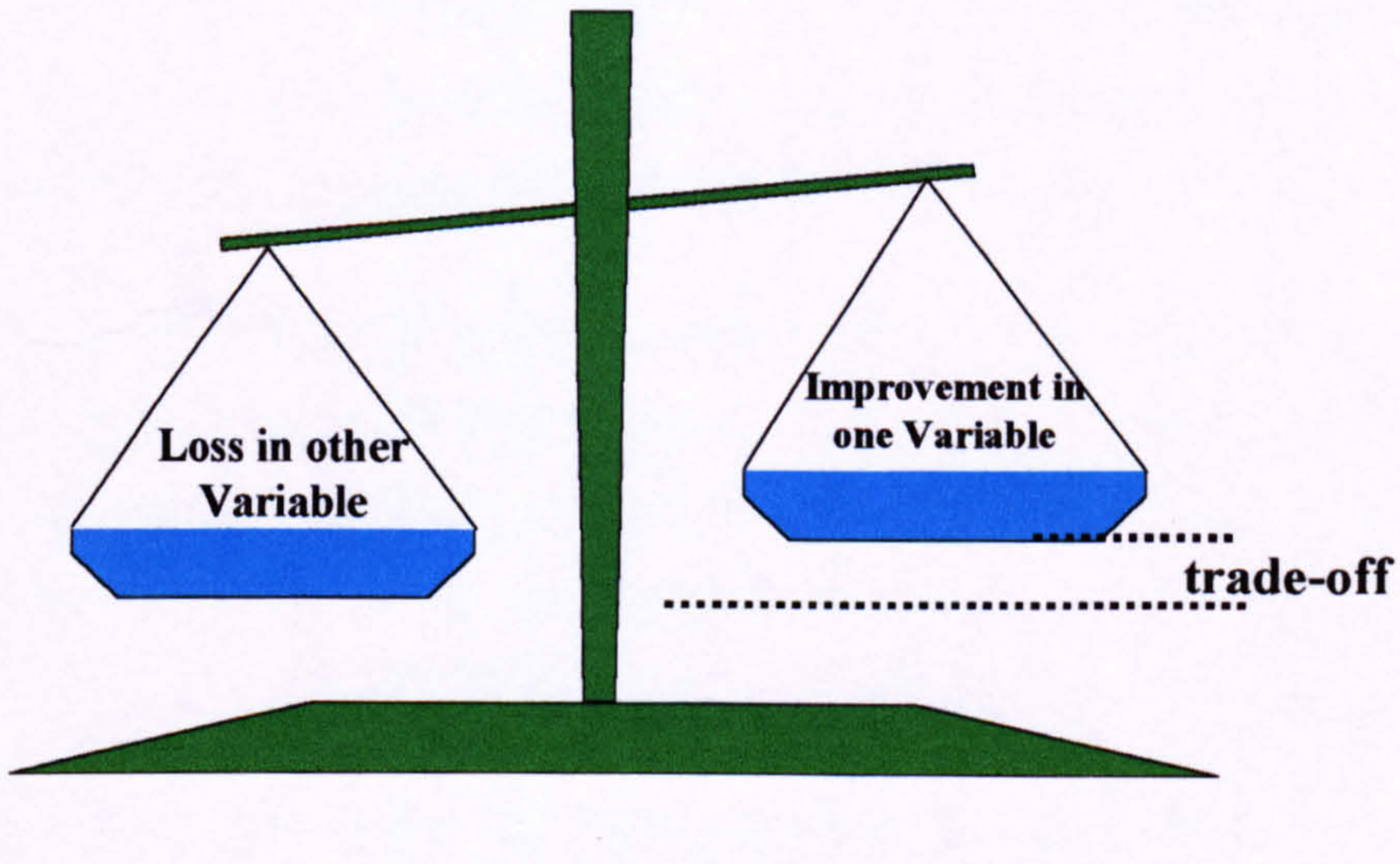


Figure 2.7 – The Trade-Off Paradigm

Several authors have criticised this trade-off paradigm arguing that it is possible for organisations to excel at differentiation and have low cost at the same time (Jackson, Stoltman & Taylor, 1994; Schonberger, 1986; Mapes, New & Szwejczewski, 1997). Mapes, New & Szwejczewski (1997), for instance, have investigated the validity of the

trade-off notion using a database of 782 UK companies, entered for the *Best Factory Award*. One of the main findings from their study was that there is an absence of trade-offs among those companies and, further, that good performance in one measure seemed to lead to good performance in many other measures.

Unfortunately, the trade-off paradigm is still underlying the decision-making and actions of many people involved within production. Reitsperger & Daniel (1991) provide evidence for the resilience for such a narrow paradigm when comparing American with Japanese managers. Rank analyses of variance between different management levels showed that *"quality is free"* propositions was strongly understood at top management levels, somewhat less at middle management levels, and significantly less at lower management levels. In other words, managers at the lower levels still believed in rigid compromise between performance criteria.

At one time many consumers believed strictly in the old adage *"You get what you pay for"*. Consequently, consumers used to believe that they had to pay more to get high quality. Despite the intuitive appeal of this idea, recent history shows that high quality can be achieved while holding down costs or even reducing them (Vonderembse & White, 1996). According to Schonberger (1990), the world-class companies are squeezing out the trade-off notion from production. Higher competition and the scarcity of resources are also simultaneously pushing these companies towards more lean, agile, effective and flexible production systems (Schonberger, 1990).

In this context, Skinner (1992) suggests a change of the trade-off paradigm towards the notion of "*performance relationship*" among competitive variables. According to this notion, the gap between different competitive criteria may still continue to exist but it can be constantly reduced by continuously improving production from different perspectives.

Additionally, the observation of best practices suggests that achieving good performance in all competitive variables may have a logical path. This logical path starts with quality, then goes to delivery time and, finally, to cost and/or flexibility (Nakane, 1989; Roth, Giffi & Seal, 1992:145; Minor, Hensley & Wood, 1994). This notion has support from practice since "quality" is becoming a *"qualifying criteria"* of production systems operating in the most competitive markets (Hill, 1992:10).

2.7.7 DISCUSSION

The key issue in a production strategy is to develop the awareness of every individual at all levels in an organisation about the impact of his/her individual actions and decisions on the strategic objectives. Yet, there are some seriously conflicting views among authors with respect to the relevant "competitive criteria" to be used in the development of a successful production strategy. Most of the *"production strategy"* literature still argues that production must focus in only one or two of the competitive criteria (quality, time, cost or flexibility). Their fundamental argument is that it is impossible for a production system to excel in all variables at the same time. On the other hand, the *"world class manufacturing"* literature argues that the trade-offs between these criteria are reducing and that a production system has to strive to excel in all criteria simultaneously.

The researcher understands the position of the "*world-class manufacturing*" literature to be more appropriate since it reduces the complacency that so often drives low levels of performance in any production system. A simple focus in one or two competitive variables carries the risk of reinforcing the trade-off paradigm. Nevertheless, it is clear that excellence in all competitive criteria may not be feasible in the short term and like any change in culture, it requires an incremental approach. Like Nakane (1989), the researcher understands that improvements in production performance have to pass through a naturally evolutionary process, starting from improvements in quality and time and then progressing towards lower cost and higher flexibility. Therefore, while the production function may still need a good production strategy to give better coherence and focus in decision making, it also needs to consider this logical evolutionary sequence when formulating other decisions.

The evolution in strategic thinking among production personnel has to be complemented by a parallel evolution in the knowledge underlying their own operational practices. Otherwise, a production strategy may fail due to the lack of structure and personnel with adequate expertise needed to support and guarantee the successful implementation and maintenance of strategic decisions in practice.

2.8 CONCLUDING REMARKS

Widening the scope of production management is the main strategy underlying the objectives of this research. This strategy means, in practical terms, the development of a multi-purpose theory, applicable to different industries in order to allow better communication and transfer of production knowledge across different settings. Better communication, in turn, can promote a more dynamic flow of ideas and experiences among researchers and practitioners across different industries. Thus, it is important to develop a multi-purpose theory of production management that enables the construction industry to use the scarce resources available for research development more efficiently and effectively.

In general terms, widening the scope of the production management theory follow the Neo-Classical School way of thinking, as described at the beginning of this chapter. Indeed, this strategy does not discard knowledge available in both manufacturing or construction literature. However, it does reject that which is not verified in practice. Furthermore, it includes ideas developed in various disciplines of management, ranging from psychology to statistics.

2.9 SUMMARY

The current theories of production management reflect the ideas of the recent Neo-Classical School of Thought. Thus, current theories incorporate ideas from both Scientific and Human Relations School of thought. Nevertheless, the implementation of these new ideas still faces many barriers such as the departmental view of organisations and a lack of coherence of the production strategy with other organisational strategies. These problems can be reduced if production is managed according to the business strategy and if there is a continuous process for formulating and revising the production strategy. It is also important that the resulting decisions take into consideration the reduction of the trade-offs among competitive variables (quality, time, cost and flexibility) and the logical path of their development in production systems.

Finally, the literature reveals that production management has two main veins of development in construction: the adaptation of ideas from other industries or the development of a construction's own particular theory. The analysis of both strategies

presents weaknesses that often are overlooked or not considered by the majority of authors. In this context, the alternative strategy conceived by the researcher is to widen the scope and improve the content of production management theories in order to make them valuable even for dynamic construction projects.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter **3**

THEORETICAL FRAMEWORK

The man who becomes interested in making this kind of study (motion studies) *will become so fascinated by it that it will be on his mind almost all the time.*

Frank Bunker Gilbreth (1911)

3.1 OVERVIEW

Chapter 2 placed production management in perspective regarding the historical evolution of the managerial theories, current organisation's strategic needs and the construction industry. It reviewed the three most important schools of thought in the recent history of management theory: Scientific Management School, Human Relations School and the Neo-Classical School. Subsequently, it presented some of the most common arguments and counter-arguments in relation to the peculiarities of construction and their implications in theory development. The last part of the chapter discussed the role of production in terms of its contribution to the business strategy needs.

The present Chapter focuses on the structure and content of four flow principles of modern production management that will be used as a "theoretical framework" or "benchmark of practice" to analyse empirical evidence obtained in construction. It starts with a presentation of the three basic concepts of conversion, flow and value. The framework then continues with a more in-depth review of the principles that will be analysed in this research. There is a discussion at the end of each section where the author expresses his views on these principles based on a critical analysis of the literature.

3.2 POSITIONING THE THEORETICAL FRAMEWORK

3.2.1 IMPORTANCE OF A THEORETICAL FRAMEWORK

Koskela (1999) argues that the practical power, and significance of, a theory of production is that it provides **the** ultimate benchmark of practice. In his view, the application of the theory in practice should lead to improved performance and, in the same way, the lack of application of the theory should result in inferior performance.

Using this logic, this chapter dedicates itself to setting the structure and describing the segment of theory that will be used as a 'benchmark of best practice' in the field research.

An explicit 'theoretical framework' is the logic and necessary steps used in making sense of integrating and re-arranging the ideas in core production management. Without it, it is virtually impossible to codify existing knowledge in the field in a coherent manner. Indeed, according to Litchfield (1956), a theoretical framework can help people discern the gaps between existing knowledge and ongoing research or their own individual needs. It is particularly important to develop such a framework because the growing volume of cross-national research. Globalisation has brought a strong need for common theoretical terms, definitions and a coherent structure in order to allow better communication, and more precise detection of gaps, of the production management theory and practice across regions and nations.

A theoretical framework has to explain the basic concepts and constructs that should be considered as part of the explanation of the phenomena of interest in order to effectively contribute to the consolidation of production management theory. Also, it has to show how factors relate to each other and the boundaries of any generalisations (Whetten, 1989).

Setting up such a theoretical structure is a challenging task if it takes fully into consideration the complexity and eclectic content of existing production management theories (*see* 2.3 Generalisation of Theories - Chapter 2). The introduction of a great number of new production management theories in the past thirty years adds further complexity to this task (*see* 1.2.1 Current Miscellany of Theories - Chapter 1*)*. For completeness, a framework is required which should draw together complementary ideas from various disciplines of knowledge such as strategy, industrial relations, design, process design, legal affairs, finance, purchasing, planning, quality management and human resources.

The strategy adopted in this research for developing this chapter, has been the classification and structuring of the core ideas underpinning current theories coded according to their different levels of abstraction. The next section describes in some detail this strategy.

3.2.2 ABSTRACT LEVELS WITHIN THE FRAMEWORK

An attempt to give a logical structure to the core content underlying existing production management theory is illustrated in Figure 3.1, following Koskela's (1992) original proposition. The layers of the pyramid follow the hierarchical progression from high abstract to low abstract knowledge. Thus, the top of the pyramid contains multi-purpose concepts having high levels of abstraction. These multi-purpose concepts determine and define all other components of a production management theory. At the other extreme are the low abstract tools and techniques used in practice for developing, implementing or evaluating multi-purposes concepts.

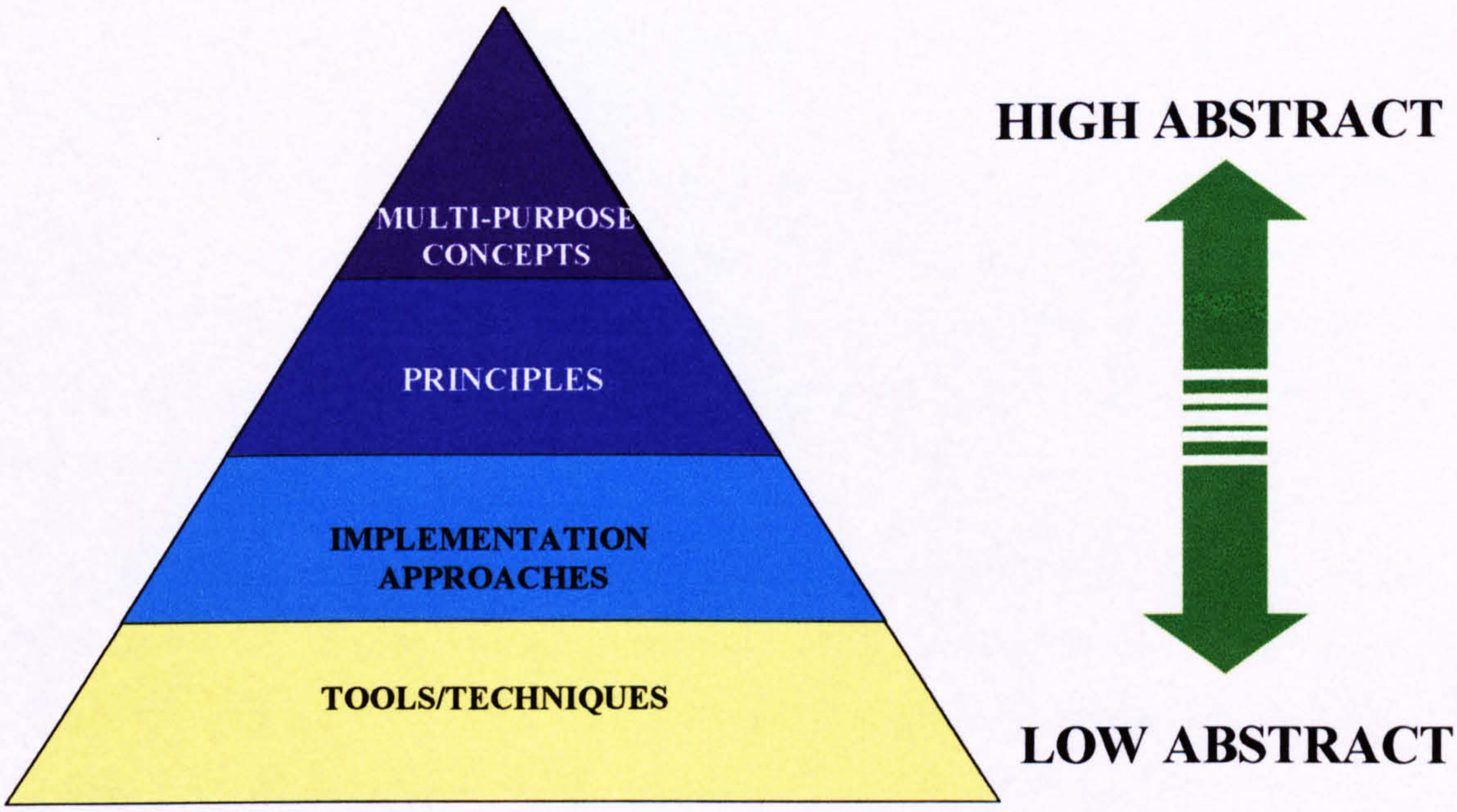


Figure 3.1 - Abstract Levels within the Production Management Theory (based on Koskela, 1992)

According to Koskela (1996), the uppermost levels of this structure roughly corresponds to the scientific notion of a theory. This is because many of the "concepts", "principles" and heuristic "implementation approaches" came from the abstraction of empirical observations of best practices (*theory-in-action*). A "multi-purpose concept" can be defined as the mental image of anything formed by generalisation from the particular (Weihrisch & Koontz, 1993). It should set the fundamental structure of our thinking and, hence, it can be used as the filter to understand and analyse reality. Thus, the

description of a concept has to be precise enough to avoid ambiguity and, paradoxically, flexible enough to allow adaptation to different purposes.

According to McFarlan (1979:10), adequate management concepts are needed before useful principles can be developed. Concepts supply the unifying structure that is essential for building a theory, allowing description and an explanation of empirically observable situations (McFarlan, 1979:10). Furthermore, according to Koskela (1996), the modelling power of concepts supplies the foundations for all decision-making. Thus, one cannot hope for innovative ideas in better theory and practice of production management without first having a solid understanding of the concepts involved.

Based on each concept it is possible to generate a number of "principles" that are, also, highly abstract and multi-purpose in their definition. In general, a principle is declared when the generalisations or hypotheses have been tested or observed in practice. Although not always unquestionably, nor invariably true, principles have to reflect reality, and be valid enough, to be used to predict events (Weihrisch & Koontz, 1993). In short, a principle describes the pathway to transform existing reality through the basic idea set by a multi-purpose concept.

An "implementation approach" is the direct and pragmatic answer to the question: "*How does one implement any principle?*" Thus, in the theoretical framework an implementation approach has a much lower level of abstraction than either concepts or principles. It has a straightforward application and, in many instances, the expected result is already in the definition of the approach itself.

The development and application of the theory in practice is supported by a number of "tools and techniques" that are specifically designed to help the determination of specific answers to specific problems. This level of abstraction includes data collection techniques (e.g. control charts) and methods for structuring and analysing data (e.g. Pareto, Ishikawa graph, etc.). Therefore, tools and techniques are located at the lowest level of abstraction in the theoretical framework.

In practice, "concepts", "principles", "implementation approaches" are mixed in different ways in the making of, what is called in this thesis, methodology or 'theory-in-

action'[1]. Theories-in-action may be found in practice as knowledge embedded in a particular practice, or underlying an entire production system, such as the case with the Toyota Production System (Monden, 1998). "Just-in-time" and "Total Quality Management" are examples of theory-in-action according to this definition.

Since practice and theory are continuously improving, the content and meanings within the various abstract levels of this theoretical framework are also under continuous transformation. However, enough development has been made to date to enable the author to describe some of the core concepts and principles underlying current "theories-in-action". In this context, the next section presents the three main concepts underlying current production management theories. Subsequently, the author will describe and discuss the heuristic implementation approaches that are the main focus of this research. The principal source of ideas for these description is the seminal report "*Application of the New Production Philosophy to Construction*", produced by *Lauri Koskela*, from the VTT - Technical Research Centre of Finland, while visiting the Center for Integrated Facility Engineering, Stanford University.

3.3 INTRODUCTION TO CORE CONCEPTS

3.3.1 PRODUCTION AS A CONVERSION ACTIVITY

3.3.1.1 DESCRIPTION

Within the conversion concept, a production system is a set of conversions of inputs into outputs, as Figure 3.2 illustrates. A production process receives inputs, transforms them, and exports the outputs to the environment, or into the next process (Koskela, 1992; Weihrisch & Koontz, 1993:17; Schroeder 1993:14; Wild, 1995:12; Vonderembse & White, 1996:3). Furthermore, the inputs, conversions or outputs may be integrated with control elements that monitor and correct system behaviour (Lee & Schniederjans, 1994).

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1 **Theory**: supposition or system of ideas explaining something; sphere of abstract knowledge or speculative thought; exposition of principles of a science (Oxford Dictionary, 1986). A ***"theory-in-action"*** is a system of heuristic ideas that have already been proven to be valid elsewhere in practice.



Figure 3.2 - Concept of Production as a Conversion Activity (Koskela, 1992)

According to Koskela (1992), the conversion model accepts that:

- production can be divided into sub-processes, which are also conversion activities in themselves (analytical reductionism;
- cost can be minimised by minimising the cost of each sub-process; and
- the output value of a process is associated with the costs (or value) of its input.

The conversion concept has very deep roots in present Western thinking about production. Often the conversion concept underlies many production manager's thoughts and, hence, it is implicit in their actions in practice (Koskela, 1999). Even in philosophy, Descarte's famous "Second Rule" proposed the division of a problem into as many parts as possible in order to devise a solution for it (Checkland, 1981). Indeed, dividing production systems into small parts and, then, focusing into the inputs and outputs is largely common practice in production management, though not always acknowledged or admitted.

3.3.1.2 PRACTICAL IMPLICATIONS OF THE CONVERSION MODEL

The application of the conversion model in practice generally involves a hierarchical decomposition of activities in order to allow control and optimisation of elemental resources (Koskela, 1999). Particularly in project management, a work breakdown structure is one of the first steps taken in order to define individual activities that must be performed as part of a project and the precedence order and relationships among them (Vonderembse & White, 1996).

The conversion model has been an extremely useful aid for researchers and practitioners alike when developing with analysis or taking decisions concerning macro-processes.

Indeed, the effective planning and operation of each individual process can only be effective when there is careful consideration of macro-processes taken as a whole, from the customer's incoming orders to their final satisfaction (Choppin, 1997; Vonderembse & White, 1996).

Furthermore, process problems are interconnected which often makes the analysis and solution of a given situation too complex and burdensome, especially if attempts are being made to explain all activities occurring between conversion activities (Alkass; Mazerolle & Harris, 1995). Based on a broad understanding of the overall system (inputs/outputs) one can re-position or eliminate process stages. Furthermore, such analysis enables the establishment of more holistic control criteria for inputs and outputs of each phase (Kagioglou et al., 1998). In this respect, the literature shows various examples of applications in the conversion model:

- *New Product Development*: the conversion model has been applied in the representation of alternative process models for design[2] (Kagioglou, 1998);

- *Project Management*: representation of a project's overall processes and its various inputs and outputs (Barrie & Paulson, 1992);

- *Logistic Management*: as a fundamental aid to understanding all relations of order-delivery throughout the supply chain (Wegelius-Lehtonen, 1995).

Nevertheless, one of the most important criticisms of the conversion model lies in its excessive emphasis upon processing activities and, hence, its lack of attention to non-value adding activities. Typically, production improvements using the conversion model focus on the implementation of new technology and primarily on value adding activities (Koskela, 1999). The direct consequence of this is the generation of large quantities of waste, since non-value adding activities usually involve great volumes of resource. Waste, in turn, is not compatible with today's highly competitive business conditions or with the emergent environmental awareness of public opinion. Therefore, the

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[2] According to Kagioglou (1998) the new product development process mainstreams are: sequential, overlapping and stage-gate or phase review.

conversion model by itself cannot be the only model to guide the thoughts and actions of people working in production.

3.3.1.3 DISCUSSION

The literature review showed that the conversion model is now dominant in traditional production management. The analysis of the management history indicates that the origins of this paradigm trace back to misinterpretations of the Scientific Management School concepts and principles. With the rise of "green markets" available at that time, scientific management ideas evolved with emphasis on the development of complete new workstations, for new production systems, in new factories (*see* item 2.2 Recent History of Management).

However, when the scientific management ideas where transferred to the context of other existing facilities the focus moved from "time study" to "time setting". The production managers' main task then became to keep up the pace of production in accordance with pre-specified schedules and procedures. Often, standard procedures were defined without a proper study of the whole production activity and were often simply copied from other plants. Consequently, people began to pay more attention to process inputs and outputs rather than the flows that were so important for the founders of scientific management.

3.3.2 PRODUCTION AS A FLOW

3.3.2.1 DESCRIPTION

According to the 'flow model', production is a flow constituted of processing, waiting, inspecting and transporting activities, as illustrated on Figure 3.3 (Gilbreth, 1911; Koskela, 1992). Within this model, processing activities are the only ones that can add value to the customer and, therefore, waiting, inspecting and transporting are considered non-value-adding activities and should be eliminated from the main process flow.

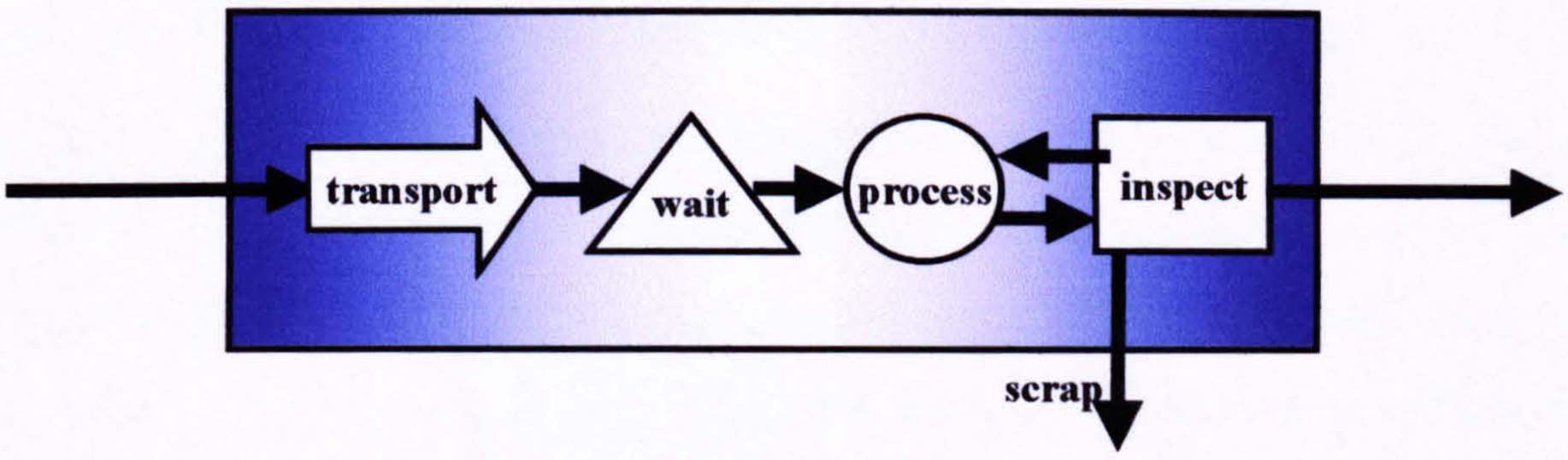


Figure 3.3 - Concept of Production as a Flow

Based on this model, a production system could be further described as a network of *process flows* and *operations flows*, lying along intersecting axes. A **process flow** is the designation for the flow of materials (or information) and represents the pathway in which raw material is transformed into semi-processed components and then into a finished product (Shingo, 1989). In car production, the 'process flow' can be further divided into the flow of components to the workstations, and then flow of the car body through the assembly line. In industries such as construction, an additional process flow may occur with the movement of material within and across workstations (Birrel, 1980; Koskela, 1999)

An **operations flow** is the designation for the flow of humans or machines that carry on the work over each stage of the process flow. Operations are very diverse and dynamic in terms of content and position in time and space. Thus, in order to facilitate the analysis of production systems, operations can be further classified as (Shingo, 1989):

- *Set-up operations*: preparation of the workstation before and after the principal operations (e.g. installing a scaffolding);

- *Principal operations*: actions which actually accomplish the essential operation (e.g. launching concrete on the formwork) and, also, those actions that help to achieve the essential operation (e.g. loading and unloading material);

- *External operations*: activities indirectly related to the principal operation, or common to a number of different operations (e.g. lubricating);

- *Personal allowance*: activities that serve the needs of the worker in terms of fatigue and biological needs (e.g. rest, drinking water).

3.3.2.2 PRACTICAL IMPLICATIONS OF THE FLOW MODEL

The strategy to improve performance in the flow model sharply contrasts with the conversion model where the focus is on the replacement of human labour with new technology (Koskela, 1997). In the flow model the aim of production managers and workers alike is different and aims to eliminate the inherent non-value adding activities (*inspecting, waiting and transporting*) and improve the efficiency of value adding activities (*processing*) (Koskela, 1992).

The aim of the flow model is, therefore, to obtain "lean production systems", with little or no waste of resources. Therefore, identifying and eliminating sources of waste is a constant preoccupation on the minds of people using this paradigm in their every day activities. According to Imai (1997) and Shingo (1989), sources of waste (*muda*) are classified according to seven main categories:

- *Overproduction*: this type of waste results from "getting ahead" with respect to production schedules. Here the required number of products is disregarded in favour of efficient utilisation of the production capacity;

- *Inventory*: final products, semi-finished products, or parts kept in storage do not add any value. Even worse, they normally add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities and manpower;

- *Repair/rejects*: rejects interrupt production and, in general, require expensive rework. Moreover, they may end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints;

- *Motion*: any motion not related to adding value is unproductive;

- *Transport*: although sometimes this activity seems to be an essential part of production, moving materials or products adds no value at all;

- *Processing*: this waste happens when the use of inadequate technology or poor design results in inefficient processing activities. Sometimes this waste may appear as a consequence of a failure to synchronise processes, where workers achieve performance levels beyond or below the requirements of downstream processes;

- *Waiting*: this waste occurs when the hands of a worker are idle such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job.

This classification could extend further with the inclusion of vandalism, theft and other sources of waste. Koskela (1999) proposes the inclusion of a type of waste that occurs frequently in construction when production operates under 'sub-optimal conditions'. Congestion of a workstation in small places, work out-of-sequence and excessive stops in the flow are examples of these conditions that lead to production having sub-optimal performance (Ballard & Howell, 1998; Koskela, 1999). Formoso et al. (1999) adds that on building sites it is possible to find waste due to 'substitution'. This waste happens when, for instance, there is a monetary loss caused by the substitution of a material by a more expensive one or when the execution of a simple task uses over qualified workers.

Another important aspect of the flow model is the importance of the differentiation between '*process* and *operations* flow', particularly for those searching for improvements in production systems. 'Process flows' (material/information) should always receive top priority in improvement activities within production systems. For example, and conventionally, most people simply think that improving transport efficiency refers to the adoption of forklifts or installing conveyors, etc. However, within the process/operation model, improving transport can also mean reducing or even eliminating the transport altogether. It is only after this broader analysis has been carried out in the entire 'process' that improvements should be devoted to the actual operation of "transport" (Shingo, 1988; Edward & Peppard, 1994).

In the case of 'operations flow', the objective of managers/workers involved in the analysis of production should be to reduce the amount of set-up, external and personal operations involved or interfering in the principal operations. At the same time, the analysts should attempt to increase the efficiency of the principal operations. Activities such as adjustments, rest or lubrication, for instance, should be moved out of the main process flow in order to allow a smoother and faster process cycle time.

There are many techniques available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behaviour, sequence, proportion and variability of inspecting, waiting, processing and

transporting activities. Many of them were invented in the early days of Scientific Management School, such as time-lapse video recording, work sampling and flow charts.

3.3.2.3 DISCUSSION

The idea of production as a network of processes and operations was first introduced by Frank and Lillian Gilbreth in 1921 at a meeting of the American Society of Mechanical Engineers (ASME) (Shingo, 1988). However, as time progressed, both "process" and "operations" began to be mixed on the same axis. The notion of 'operation' changed its meaning to become the smallest unit of analysis of a production activity. Thus, the differentiation between process and operation began to be associated with a particular level of granularity during analysis. The macro level of a production system used the term 'process' and the micro level began to use the term 'operation' or 'task'. This misunderstanding persists in many of the recent books and papers reviewed by the researcher.

Paradoxically, this confusion traces back to the early applications of the Scientific Movement. At the beginning of this movement, with the large demand for new factories, emphasis was less on improving current methods and more on designing ideal methods right from the beginning of the job (*see* item 2.2 - Recent History of Management). Later, studies became more focused on the physical actions of workers and how managers could control and reformulate their actions through an ever more complex divisions of labour[3]. It was also at this stage that "operations" and "processes" were no longer treated as two different analytical dimensions of production systems.

A detailed and graphical representation of operations and process flows simultaneously is virtually impossible when it comes to a complete production system. Each step of the process may involve a great number of operations, each one following different routes throughout time. In this respect, Information Technology is likely to grow in importance in production analysis as computing capabilities is evolving fast nowadays.

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[3] In the eighteenth century, the industrial revolution discussed in Adam Smith's *Wealth of Nations* already rested on the dramatic increase in productivity through the division of labour (Barnes, 1980).

Critical analysis of practice and theory showed that production systems could be classified according to the relative movement between processes and the operations carried out by workstations, as follows:

- *Production system with fixed workstations*: operations move in time and space but only within the limits of the workstation. The movement of the "principal operation" is restricted to the physical position of the corresponding part of the process (e.g. assembly line of computers);

- *Production systems with mobile workstations:* the sub-product and materials have a fixed position once they get into the production system. However, in this case the workstation has to move across the various workplaces in order to carry out the "principal operation" (e.g. shipbuilding, construction);

- *Production systems with mobile processes and workstation (mixed):* represent the most complex type. In this type of production, components and materials may change position in time, and the workstations will follow this movement in order to accomplish the "principal operation" (e.g. ice-cream maker).

Whilst the last type of flow may have been conceived like that from the design stage, it often happens because of a lack of synchrony between the process flow and the "principal operations". A typical consequence of this lack of synchrony is the presence of double handling and large batch sizes throughout the process. Excess of transportation happens, for instance, when the operator moves the workstation without having completely finished the "principal operation" in the previous sub-products. Material and sub-products already organised in the workstation have to be removed and transported back to previous locations in order to complete the job

3.3.3 PRODUCTION AS A VALUE GENERATING PROCESS

3.3.3.1 DESCRIPTION

Value is a central concept in many modern theories of production management. Indeed, nowadays there is an increasing need to expand the customer's perception of a product's worth vis-à-vis its price. This increase of value is obtained through a systematic analysis

of customer wishes and subsequent transformation of this information into product and service specifications, as illustrated in Figure 3.4 :

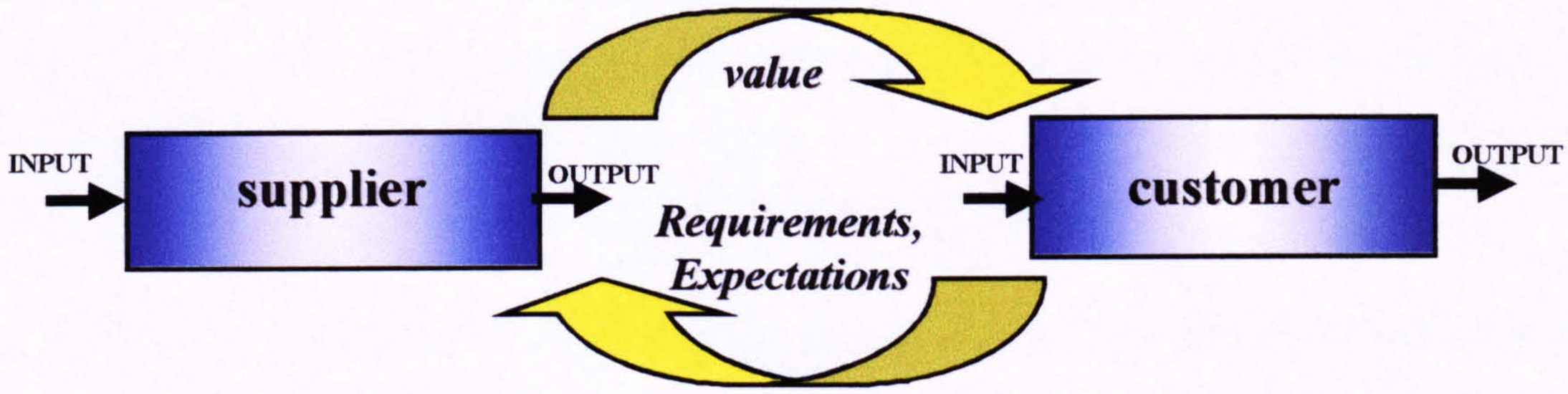


Figure 3.4 - Concept of Production as a Value Generating Activity

Value can only be defined by the customer and it is only meaningful when expressed in terms of a specific product or service, at a specific price and at a specific delivery time (Womack & Jones, 1996). The definition of value should affect all aspects of the way the entire production system is run and customer's perception of value should be one of the main inputs to define production strategic priorities (see *2.6.5 Competitive Criteria in Production Decisions - Chapter 2*).

One of the first known uses of value as a clear central managerial concept is claimed to be at the General Electric Company, in the USA, during the World War II. At that time, with a shortage of materials caused by the war effort, General Electric was forced to use substitute materials in many of their products. Over a period of time, it became evident that this forced substitution was resulting in cheaper products, as well as products with better performance. This has been the idea of developing systematic studies in product and processes in order to increase value. This idea evolved into Value Planning, Value Analysis, Value Engineering and, in the blanket term that covers all value techniques, Value Management[4] (Norton, 1995).

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[4] **Value Management** (VM): a structured approach to define what value means to a client in meeting a perceived need by establishing a clear consensus about project objectives and how they can be achieved (Connaughton & Green, 1996); **Value Planning** (VP): title given to the value techniques applied during the planning phases of a project (Norton, 1995); **Value Engineering** (VE): value techniques applied during the design or engineering phases of a project (Norton, 1995);**Value Analysis** (VA): title given to value techniques applied retrospectively to completed projects to analyse or audit the post-production period (Norton, 1995). The combined growth of practice and theory of Value Engineering led to the establishment of the Society of American Value Engineers (SAVE), in 1958 (Norton, 1995).

3.3.3.2 PRACTICAL IMPLICATIONS

The closer the production function is to the client the better it is able to improve the understanding of his/her requirements. Consequently, the generation of ideas to increase value is more likely to occur with such closeness. This factor reinforces the need to involve production during the early stages of the business process development, as described in Chapter 2 (see *item 2.5.2 The Process Perspective*).

The value model can also be interpreted as the reduction of the difference between the achieved value against to the best possible – value loss (Koskela, 1995). Quite often, deficient tracking of decisions and actions throughout a business process leads to poor consideration of value attributes that have been detected at the briefing stage. Within this view, production efforts should try to guarantee customer requirements are really understood and to ensure that this understanding is embedded into the processes throughout all production phases.

Tools and techniques are already available to implement the value concept. Most of them were developed within the field of Value Management. Quality Function Deployment - QFD - for example, is a technique created to ensure that each step of the production process is linked to the fulfilment of a specific customer's requirement. It involves constructing one or more matrices linking attributes of value to characteristics of the products and processes. These matrices help translating the customer needs into information that can be managed by the design and production team, and facilitates the use of benchmarking (Akao, 1990; Zairi, 1996). Nowadays, this and other techniques have become increasingly more sophisticated, mainly with the incorporation of Information Technology as a supporting tool.

3.3.3.3 DISCUSSION

The recent production management literature shows a heavy emphasis on reducing non value-adding activities and in increasing the efficiency of value adding ones (flow model). This literature focuses mostly on the potential competitive gains of cost and speed by reducing wastage of resources. However, there are fewer publications discussing the reduction of value loss within the production processes. One of the apparent difficulties of reducing value loss is the translation of value into an

understandable production language. The production strategy literature approaches the problem but, still, there are few studies into how to promote the transmission and tracking, in real time, of client requirements throughout the entire production process.

The interpretation and transformation of customer requirements into value is traditionally understood to be the exclusive responsibility of people working in stages prior to production. However, production personnel can, and must, give a significant contribution to design in terms of discovering new alternatives for increasing value. For instance, alternative production techniques could be developed in order to enable easier maintenance and faster visual understanding by anyone involved in future re-development of a building. Unfortunately, as described in Chapter 2, production often plays only an internally neutral role in organisations and, because of that, usually supplies only a few ideas for enhancing value of the end product.

3.3.4 INTERACTION AMONG CONCEPTS

The three core concepts presented in this section (conversion, flow and value) are complementary parts of a coherent whole, as illustrated in Figure 3.5. The adequate understanding of the deep meanings of these three concepts and corresponding principles should enable people to free themselves from traditional paradigms and, hence, enable them to create their own particular solutions for their own problems. When people have mastered the content of these concepts they should be able to manage and improve, effectively and efficiently, the entire production system.

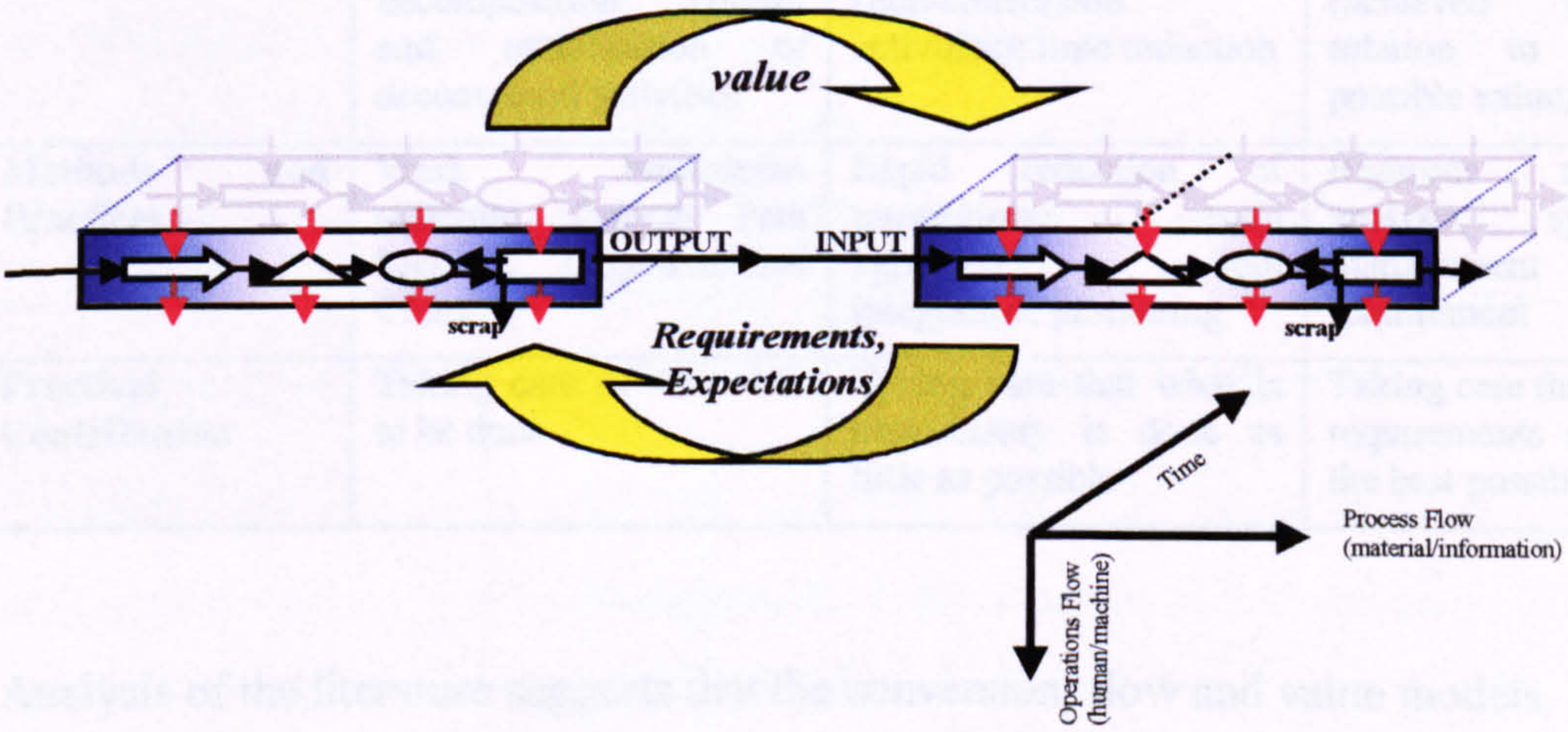


Figure 3.5 - Interconnection of the Three Concepts

Traditional techniques used in the management of production usually cover the use of the conversion model, which is very useful for organising and managing the entire network of production processes. Indeed, the conversion model appears to be more appropriate for controlling macro-processes, making sure that what has to be done starts and finishes within the time, and to the quality and cost expected. However, managing production only from a wider perspective is not enough in today's business environment that is characterised by reduction in profit margins and an increase in customer awareness regarding quality. Thus, the flow and value concepts have to be understood and incorporated into the portfolio of ideas used by practitioners and researchers. Reduction of waste is often overlooked by production managers using the conversion model and, similarly, an increase in value is not generally among the main preoccupations (Koskela, 1998; Koskela, 1999).

In engineering, Koskela (1998) gives further arguments regarding the complementary role of the three core concepts when comparing their various characteristics, as Table 3.1 summarises:

Table 3.1 - The Different Views of Engineering According to Koskela (1999)

	Conversion View	**Flow View**	**Value Generating View**
Conceptualisation of Engineering	As a conversion of requirements into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfilment of his requirements
Main Principles	Hierarchical decomposition; control and optimisation of decomposed activities	Elimination of waste (non-conversion activities); time reduction	Elimination of value loss (achieved value in relation to the best possible value)
Methods and Practices	Work breakdown structure, Critical Path Method, Organisational Chart	Rapid reduction of uncertainty, team approach, tool integration, partnering	Rigorous requirement analysis, systematised management of requirement
Practical Contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner

Analysis of the literature suggests that the conversion, flow and value models, should be used in an integrated manner in order to offer the best results. The Toyota Production System is one of the most notorious examples of coherent integration of heuristic

implementation approaches derived from all three conceptual models. In the main framework of that system it is possible to distinguish the intense application of standardisation, continuous improvement, production smoothing and many other complementary practices that clearly relate to the 'flow model'. The work-breakdown structure is used to analyse, describe, co-ordinate and establish the sequence of processes and operations and this practices clearly related to the conversion model. In addition, production personnel have a direct say on the transformation of customer requirement into characteristics of the product and process, which characterises the value model (Ohno, 1988; Monden, 1998).

3.4 EMERGING HEURISTIC PRINCIPLES

3.4.1 INTRODUCTION

Like structural engineers that apply physical principles to design structures, those who work with production management need clear principles to effectively guide their activities (Koskela, 1996). According to Weihrisch & Koontz (1993), principles in management are the fundamental truths or, at least, what was thought to be the truth at a given time. They may be descriptive or predictive, but not prescriptive, since they must not prescribe what people should do since that will inevitably depend on the context (Weihrisch & Koontz, 1993).

Principles in production management have been intensively developed since the time of the Scientific Management and the Human Relations School, as described in Chapter 2. Nowadays, empirical observations of 'best practices' world-wide has produced a range of new and valuable principles. Following the approach of the Neo-Classical School, these principles have been assembled into new theories that contain both Scientific Management and Human Relations' thinking (see *item 2.2 - Chapter 2*).

Currently, the combination of JIT and TQC allied to many other complementary approaches such as Visual Management, Total Productive Maintenance, Time-Based Competition, Re-engineering and Value Based Management represent what is known about best production practices. Fortunately, it is possible to identify a number of common heuristic principles among these theories. Table 3.2 summarises the main body

of evolving principles, based on the proposal of Koskela (1992, 1999)[5].

Koskela (1999) argues that most "buzzword approaches" of current theories have originated around some of these heuristic principles. Thus, for example, "Visual Management" has "transparency" as its core principle; "Time Based Management" aims to reduce cycle times; "Value Based Management" searches for increases in the output value. However, these new theories rarely integrate or acknowledge all other principles and, therefore, they are usually partial in defining what constitutes best production practices (Koskela, 1992).

Table 3.2 - Evolving Heuristic Principles of Production Management (Koskela, 1992/1999):

	CONCEPT		
	CONVERSION	**FLOW**	**VALUE**
HEURISTIC PRINCIPLE	**Primary Principle:** Wide view, planning, controlling and scheduling of the complete process **Secondary Principles:** Focus on Process Bottlenecks Focus on Complete Processes Hierarchical decomposition; control and optimisation of decomposed activities	**Primary Principle:** Increase the efficiency of value adding activities **Secondary Principle:** Improve production technology available **Primary Principle:** Reduce the share of non-value adding activities* **Secondary Principles:** Reduce cycle time * Reduce variability * Increase Transparency * Continuous improvement * Simplify Increase Flexibility Focus on Process Bottlenecks Focus on Complete Processes Benchmarking	**Primary Principle:** Improve customer value **Secondary Principles:** Ensure capture of all requirements Ensure flow-down of requirements Reduce trade-offs Continuous improvement Benchmarking

* Heuristic principles investigated in this thesis

Writers in the International Group for Lean Construction (IGLC) conferences consistently acknowledge the dominance of the heuristic principles related to the conversion model in traditional construction practice. They also argue that the dominance of the conversion model is one of the fundamental reasons for the large

[5] 'Primary principles' in this table are those that present the highest possible level of Generalisation under each concept. 'Secondary principles', in turn, derive directly from the primary principles.

volume of waste in the sector (Koskela, 1994; Ballard & Howell, 1994; Isatto & Formoso, 1998).

Hence, it is the present author's view that construction needs to incorporate flow and value heuristic principles into practice in order to change its poor level of efficiency and efficacy. The next section presents the principles from Table 3.2 that will be investigated in depth by this research, and the reasons for their choice. The subsequent sections will describe these principles in detail, in order to establish a reference for analysing construction practice.

3.4.2 FOCUS OF THIS RESEARCH

From the outset of this research, strong need was felt to develop a better understanding of the relationship between theory and practice of the heuristic principles related to the flow concept, as presented on Table 3.2. Indeed, Koskela (1992) argued that production managers and workers in the construction sector should pay more attention to the high proportion of storage, transporting, waiting and inspecting activities present in most construction processes.

In particular, the 'primary' principle *'reduce the share of non-value adding activities'* was felt to be extremely valuable for investigation due to the large volume of waste attributed to construction (*see* item 1.2.3.3). Non-value adding activities include all activities that take time and resources but do not add value to the customer. Within the flow concept, waiting, transporting and inspecting activities are most fundamental non-value adding activities (Koskela, 1992).

It is important to notice that among the non-value adding activities there are those auxiliary activities that do not add value but are instrumental in enabling the operation of the value adding activities (e.g. measurement). Value-adding activity, on the other hand, includes all those activities that effectively add value to the final product or service (Heineck, 1983).

Since in a doctoral thesis it is necessary to explore ideas in sufficient depth to come to rigorous conclusions, it was not possible to study all the heuristic principles related to the concept of flow due to the amount of time available. Thus, the researcher decided to

concentrate the investigation on just four 'secondary' but key principles and corresponding heuristic implementation approaches. These principles are: *reduction of cycle time, reduction of variability, increase of transparency and building of continuous improvement into the process*. Figure 3.6 graphically illustrates the position of these four principles in relation to the general theoretical structure. At the right of this Figure are the three core concepts, then follows to the left the 'primary principles', 'secondary principles' and 'implementation approaches' derived from the 'flow concept'.

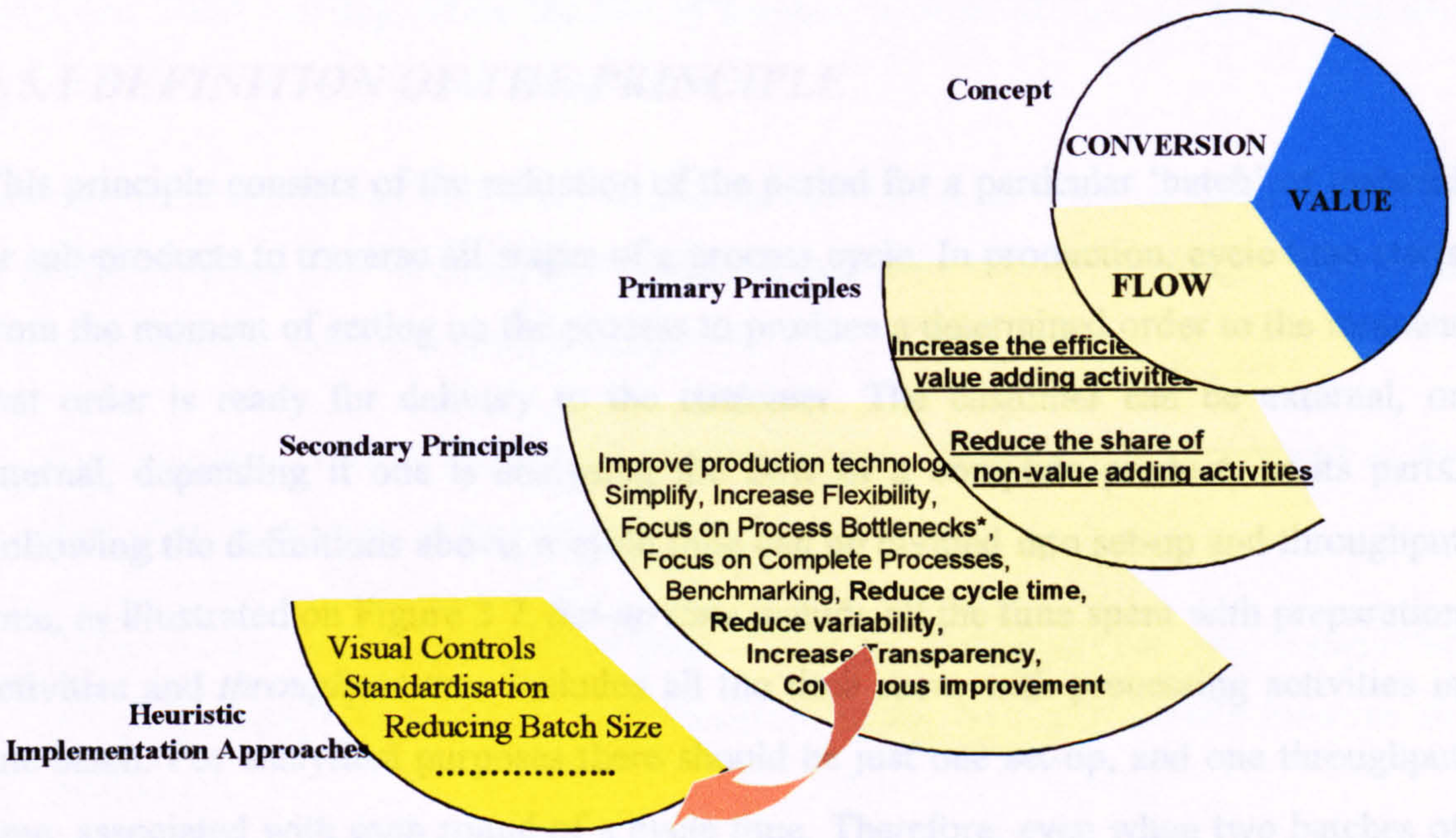


Figure 3.6 – A Perspective of the Abstract Layers Related to the Flow Concept

The four principles chosen for study were the most frequently mentioned in the literature and they seemed to be more directly connected with the key problems faced in the construction industry. Furthermore, the amount and frequency of papers and books covering these principles suggested the existence of a reasonable theoretical maturity. Papers and books produced in the manufacturing industry revealed that these principles were largely applied in the most competitive companies. In addition, these principles seemed to be strongly interdependent which could make this thesis more interesting from concerning the integration of practices and, also, facilitate the focus of data collection and analysis.

The following sections will review the key ideas found in current literature regarding these four principles, as well as their corresponding heuristic 'implementation approaches'. On one hand, this literature review covers authors from different industries in order to get a wider spectrum of ideas. On the other hand, the discussions focus on relevant aspects to the construction industry.

3.5 REDUCTION OF PROCESS CYCLE TIME

3.5.1 DEFINITION OF THE PRINCIPLE

This principle consists of the reduction of the period for a particular 'batch' of material or sub-products to traverse all stages of a process cycle. In production, cycle time starts from the moment of setting up the process to produce a determined order to the moment that order is ready for delivery to the customer. The customer can be external, or internal, depending if one is analysing the flow of a complete product, or its parts. Following the definitions above, a cycle time can be divided into set-up and throughput time, as illustrated on Figure 3.7. *Set-up time* include all the time spent with preparation activities and *throughput time* includes all the time spent with processing activities in one batch. For analytical purposes there should be just one set-up, and one throughput time, associated with each round of a cycle time. Therefore, even when two batches of the same product use the same set-up, measurement of a cycle time need to consider them as two separated entities.

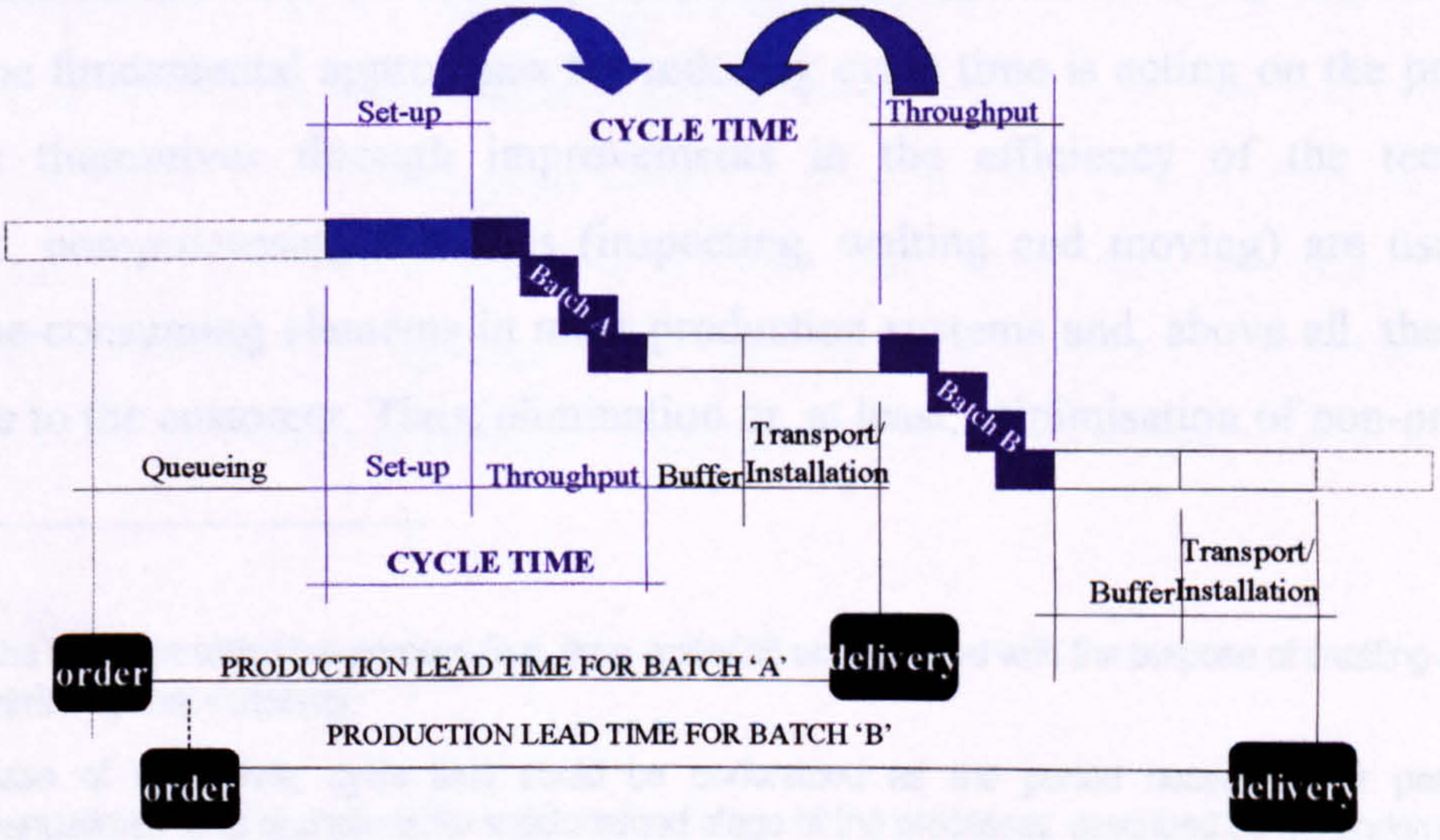


Figure 3.7 – Cycle Time Within Production

One of the main justifications for the emphasis on 'process cycle' is the advantage of replicating improvements from one cycle to another. Nevertheless, the heuristics for reducing cycle time are also valid for other activities located externally to the process cycle. Hence, cycle time has to be considered under a holistic view of the entire flow throughout the organisation. Figure 3.7 shows that the total time between the arrival of an order in production to the time when this order is actually delivered to the client (*lead-time*). It includes the time material/sub-products spend on queues, transportation/installation of the order and the buffer[6] time. Thus, the lead-time for a particular batch will depend on the size of batches, number of batches, buffer size and on the speed of processing and set-up activities.

Luhtala, Kilpinen & Antila (1994) extend further the description of flows within an organisation when they describe two additional activities that usually occur before and after a production lead-time, respectively:

- *Levelling time*: period between the point where a client's order is received to the start of order processing and engineering;
- *Delivery time*: period between the point where the product (s) has been transported out of production or installed, to the moment when the client actually receives the product (s).

It is worth remind the reader that, according to the flow model, a process cycle time[7] is composed of transformation, inspection, waiting and moving activities and that transformation activities are the only ones that really add value to the customer. Thus, one of the fundamental approaches for reducing cycle time is acting on the processing activities themselves through improvements in the efficiency of the technology. However, non-processing activities (inspecting, waiting and moving) are usually the most time-consuming elements in most production systems and, above all, they do not add value to the customer. Thus, elimination or, at least, minimisation of non-processing

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[6] **Buffer** is the resource within the process (e.g. time, material) usually used with the purpose of creating a protective barrier against variability.

[7] In the case of operations, cycle time could be understood as the period necessary for performing all manual/mechanic operations for a determined stage of the processes described by a standard procedure, including moving time.

activities is another fundamental approach used to reduce cycle time (Koskela, 1992; Vonderembse & White, 1996).

3.5.2 IMPACT ON PRODUCTION SYSTEMS

Compression of cycle time can drive the reduction of waste in production systems since the cycle of deviation-detection-correction becomes shorter[8] (Koskela, 1992). As a result, people perceive the results of their actions sooner and, consequently, they can act sooner if any correction is necessary (Senge, 1990; Koskela, 1992; Luhtala, Kilpinen & Anttila, 1994). Additionally, Koskela (1992) recognises the following benefits of reducing cycle time:

- Faster delivery to the customer;
- Reduced need to make forecasts about future demand;
- Decrease in the disruption of the production process due to changed orders;
- Easier management because there are fewer orders to keep track of.

3.5.3 IMPLEMENTATION APPROACHES

The literature shows various different strategies and guidelines for reducing cycle time. Tom Peters, for instance, in his article *Time-Obsessed Competition,* lists some important steps towards reduction of cycle time at the organisational level such as linking communication between all parties; flattening the organisational structure; redesigning the business process to reduce delays and promoting trust with new partners (Peters, 1990). Although many of these ideas certainly have an effect on time, they do not focus entirely, and directly, on the reduction of cycle time. Thus, these heuristic approaches can be easily confused as implementation approaches for other principles having other aims. This lack of precision is likely to cause confusion and disagreements in practical situations.

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[8] Parkinson's law states that work tends to expand to fill the time available (Weihrisch & Koontz, 1993). In general, such expansion brings waste due to excessive movements, waiting and reworking.

In this context, the structure of approaches proposed by Koskela (1992) seems to offer a better alternative description since it has a more straightforward relationship with time compression. For this reason, this and the other principles investigated in this research have adopted Koskela's list of heuristic implementation approaches as the basic framework to be used, namely:

- Reduction of Batch Size;
- Reduction of Work-in-Progress;
- Minimisation of Distances;
- Isolation of Value Adding Activities from Supporting Activities;
- Changing the Order of the Process;
- Synchronisation and Smoothness of Flows;
- Solution of Control Problems and Constraints to a Speedy Flow;
- Reduction of Variability.

The next section explore each of these heuristic implementation approaches and establishes the pattern of practice to be used as benchmarking to analyse the empirical evidence of this thesis. It is worth emphasising that 'reduction of variability' is also a principle in itself and is treated as such in this thesis. In this respect, this chapter dedicates a separate section to present the principle 'reduction of variability' and correspondent heuristic implementation approaches.

3.5.3.1 Reducing the Batch Size

When the batch size of a given process is reduced, material or information can flow much faster across various process stages and, thus, it can reach the end customer earlier. There is less waiting time between workstations and workers can initiate the operation immediately. Therefore, the transformation of a classic production system using large batches into value streams of small batches, flowing continuously as they

are pulled by the customer, can significantly raise production performance (Womack & Jones, 1996).

With small batches the forecasting horizon is shortened and, consequently, the forecasting error is reduced. The frequency for delivering materials and components often changes from a weekly to a daily basis. Therefore, safety stock and buffer time designed to absorb uncertainty can also be reduced (Park, 1994; Umble, 1990; Sohal, Samson & Ramsay, 1993). Additionally, with small batches flowing fast throughout a production system, production flexibility increases and, certainly, will require high quality supplies along with high production quality (Jackson & Hall, 1992). This is a perfect invitation for a continuous learning process since process problems will certainly arise with the reduction of stocks. People will have to learn quickly how to detect and solve problems, otherwise their process will come to a halt.

Notwithstanding the above knowledge, production managers usually give many reasons for maintaining high levels of stock, such as: the need to replace defective items immediately; the need to respond promptly to customer orders; and the need for a safeguard when equipment fails or absenteeism stops production (Shingo, 1988:231). At the heart of this argument is complacency with low levels of production efficiency. Furthermore, managers who thinks in that way usually believe that the reduction of batch size necessarily increases time and cost spent on transportation. However, the literature shows that this problem has been solved in many companies through creative transportation solutions (e.g. multiple delivery trucks) and improvements in the packing system (Shingo, 1988; Monden, 1998).

Another common argument against small batch sizes is the increase in the number of set-ups (preparation of the workstation to initiate the processing activity). Underlying this thinking is the assumption that time and cost spent in set-up is fixed. Indeed, one of the traditional rules of lot sizing is the trade-off between a fixed set-up cost and the additional holding costs that would be incurred in increasing inventory levels (Shingo, 1988; Toelle, 1996; Benjaafar, 1996). By using a classical economical lot sizing logic, the traditional thinking believes in a fixed breakpoint in the relationship between the number of set-ups and the total production cost, as Figure 3.8 illustrates (Monden, 1998; Shingo, 1988):

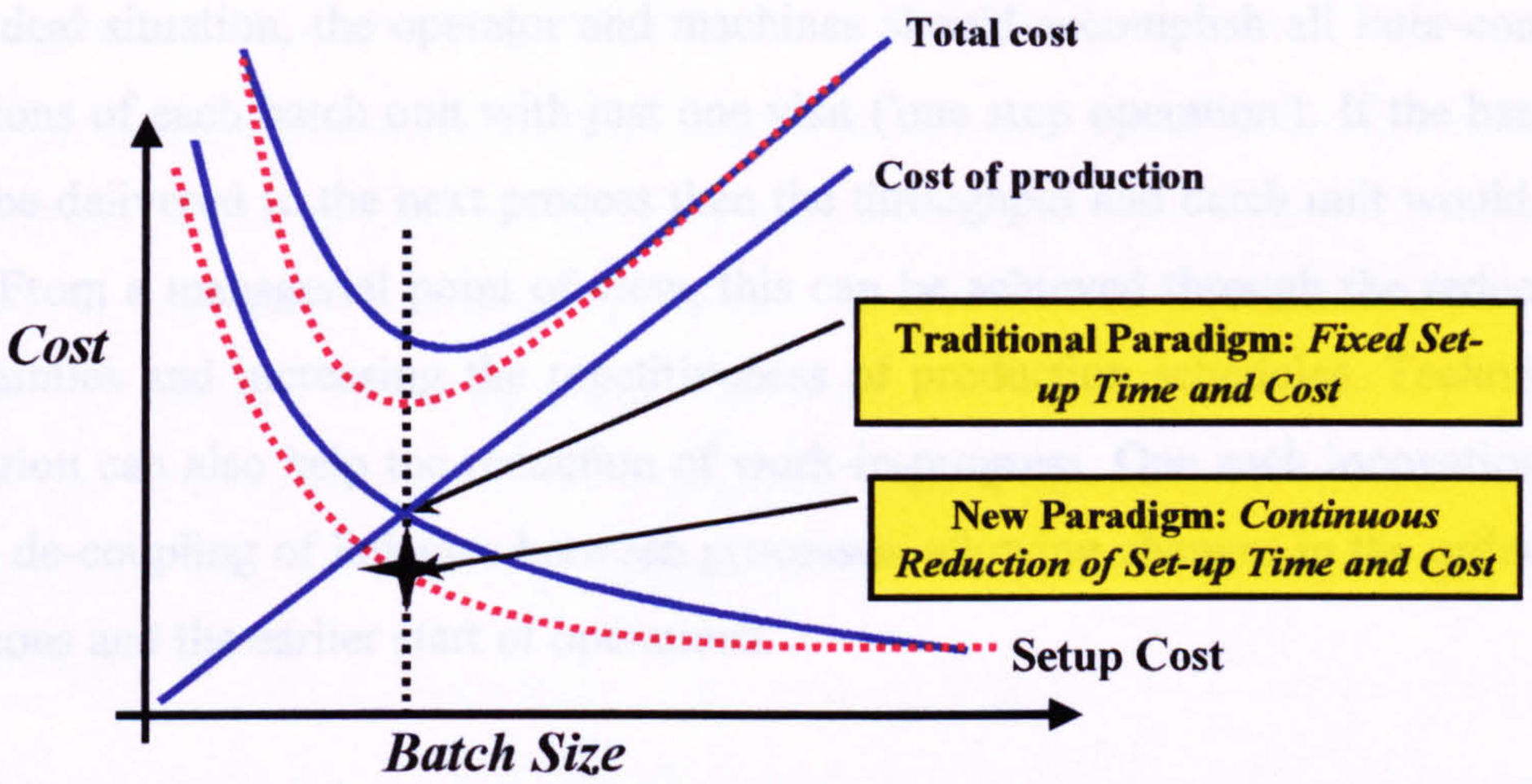


Figure 3.8 - Traditional Paradigm of Fixed Set-up Time

Nowadays, companies world-wide has started to search for reductions in the set-up time to even less than a single digit number. There are even examples of *one-touch set-ups* where no time whatsoever is spent on such an activity. The reduction of set-up time is at the heart of flexibility in both the service and the manufacturing industry and one of the fundamental pre-requisites for reducing batch sizes in 'Just-in-Time'. With this in place a company can adapt promptly to changes in customer orders and, thus, increase the utilisation of the production structure to its full capacity (Monden, 1998; Shingo, 1989).

3.5.3.2 Reducing the Work-in-Progress

The reduction of work-in-progress is one of the fundamental Just-in-Time approaches to reduce cycle time (Akintoye, 1995). In short, the existence of work-in-progress means that a material or information is waiting for an operation (flow of machine or worker) to be accomplished in order to continue its flow. Following Little's law, cycle time is reduced by reducing the work-in-progress, provided throughput remains constant [Little (1961) apud Koskela (1999)]. Therefore, the shortest cycle time happens when work-in-progress is equal to the throughput. Little's law presents the following formula to measure cycle time:

$$\text{Cycle time} = \frac{\text{Work-in-progress}}{\text{Throughput}} \qquad \{\text{e.g. Cycle Time} = \frac{400\ \text{m2}}{40\ \text{m2/hour}} = 10\ \text{hour}\}$$

In an ideal situation, the operator and machines should accomplish all inter-connected operations of each batch unit with just one visit ('one stop operation'). If the batch unit could be delivered to the next process then the throughput and batch unit would be the same. From a managerial point of view, this can be achieved through the reduction of uncertainties and increasing the repetitiveness of production schedules. Technological innovation can also help the reduction of work-in-progress. One such innovation is the simple de-coupling of linkages between processes, allowing changes in the order of the operations and the earlier start of operations.

3.5.3.3 Minimising Distances

The transport and storage of materials is one of the most time consuming activities in production systems, despite not adding value to the end customer product. It is also blamed for being the origin of a great part of the safety and ergonomic problems in production (Bishop, 1965; Forbes, 1971; Niskanen & Lauttalammi, 1989; Thomas, Sanvido & Sanders, 1989). Because transport and storage activities affect practically all production activities, improvements in their efficiency are likely to bring a positive impact to the overall production system efficiency.

The most common strategies of action in this area are ergonomic studies and layout planning. Ergonomic studies develop new workstations, or adapt existing ones, in order to make them more physically secure for operatives and, at the same time, more efficient. Layout planning, on the other hand, usually tries to minimise distances in order to allow a smooth and safe flow of people, materials and machines within the production system. One of the most efficient placements in a layout is the one that aligns workstations with the physical flow of processes in order to accelerate that flow. Thus, the study of a layout begins by understanding how the process and operations actually flow. In cellular manufacturing[9], for instance, there is a combination of people and machines in a single operational sequence that puts the start of a process as close as possible to the end of that process (known as U-shaped processes) (Galsworth, 1997).

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[9] Cells (or work-cells) is a group of closely linked, dissimilar workstations (automatic or manual) that are dedicated to performing a sequence of production on families of similar parts or products (Steudell & Desruelle (1992:264).

3.5.3.4 Isolating Value Adding Activities from Support Activities

Ideally, processing activities should be aligned in time and space, allowing a continuous flow of materials since they are the only ones that actually add value. However, it is often found that many non-essential operations obstruct the direct circulation of the main flow of material and components. Therefore, efforts to improve production should include the externalisation of all supporting activities from the main flow. This externalisation may follow similar steps to those used to reduce set-up time (Monden, 1998; Shingo, 1989):

- *Separate the value adding activities (principal operations) from the supporting activities (set-up operation, personal allowance, external operations)* (*see* item 3.3.3.1): supporting activity involves the actions that can be taken separately while the processing activity is being carried out;

- *Convert the activities in the main flow to supporting activities as much as possible*;

- *Elimination or reduction of the supporting activity itself*: elimination or reduction can be achieved in two different ways. First is the use of uniform sub-product design or the use of the same supporting activity for various different sub-products. Second is the production of various different sub-products at the same time, using the same supporting activity.

Total Productive Maintenance (TPM) is one of the current theories that intensively use such an approach by removing maintenance from the main flow and, at the same time, searching for elimination of this activity from the process. Therefore, the dual goal of TPM is zero breakdowns and zero defects (Nakajima, 1988). When breakdowns and defects are eliminated, the production efficiency rates improve, and consequently, cycle time is reduced. Furthermore, because maintenance is out of the main flow, the value adding activities can flow with fewer interruptions.

3.5.3.5 Changing the Order of the Process

Perhaps one of the most difficult approaches for reducing cycle time in production systems is to challenge the order of the current processes. In general, this heuristic approach means moving all activities to a parallel order. Therefore, it usually challenges

traditional beliefs regarding to process sequence. Notwithstanding, this ability to reduce cycle time is developed by giving up the belief that there is no other way to perform a given task.

At the project level, *concurrent engineering* uses this approach by viewing design and production as a series of simultaneous processes where the basic thrust is to eliminate waste (Huovila, Koskela & Lautanala, 1994; Koskela & Houvila, 1996). Substantial timesaving is achieved by providing a team of people with different talents to work concurrently on defined problems. The team can also accelerate the process by receiving and processing information in small batches. Likewise, *re-engineering* theories (such as business process re-engineering, business redesign, process redesign, and business process transformation) emphasise the change of order in processes as one of its core implementation approaches (Edward & Peppard, 1994).

A more aggressive use of such an approach is found under *fast tracking* ideas. Practices associated with the overlapping of design, tendering and production contribute to the achievement of early delivery in fast track projects. However, fast-track relies partially in the conversion model since it depends on the application of innovations in management of procurement and the intense use of recent technological advances and, also, "on the shelf" technologies[10] (Kwakye, 1991; Russel & Ranasinghe, 1991). Huovila, Koskela & Lautanala (1994) argue that the application of fast track increases the total cost of projects since there is an increase in the level of uncertainty in comparison to conventional sequences. Hence, concurrent engineering may be more relevant and worthwhile in those environments characterised by high uncertainty.

3.5.3.6 Synchronising and Smoothing the Flows

Synchronisation and smooth flows are among the most fundamental practical implementation approaches underlying lean production systems. The final aim in this approach is to reach a stage where each element produces the exact quantity requested by the next element in the production chain (Shingo, 1989). Therefore, synchronisation

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[10] One of the additions of fast track in relation to concurrent engineering is the arrangement of construction into work packages and the overlapping of those work packages to enable construction of sections of the project to proceed while the design for other sections is being considered or progressed. Thus, fast track needs the intense use of standardised or well known solutions (Kwakye, 1991)

and smooth flows are closely related to the way in which materials are ordered since more emphasis is placed on "pull" instead of "push" production.

One of the ways to evaluate the application of such an approach is to determine the number of production stages operating against customer's orders (Karlsson & Ahlstrom, 1996). At Toyota, recognised as one of the leanest companies in the world, they strive to make production such that all processes produce products according to the sales velocity of the market. The most direct reflex of this effort is the reduction of waste through overproduction (see *item 3.3.3.2*) and an increase in the production capacity available (Monden, 1998).

One key strategy to obtain this level of flow is to place more effort into planning and design in order to obtain the most repetitive schedules and standard processes possible. In planning, such synchronisation is accomplished by levelling the excess capacity and by co-ordinating starting and end times (Shingo, 1988). In the Theory of Constraints (also known as synchronous manufacturing) this idea is put into practice through the concept of *Drum-Buffer-Rope* (DBR). When DBR is in place, the production rate at a bottleneck serves as the drumbeat for the entire production system (Goldratt, 1986; Ashcroft, 1988).

Ashcroft (1988) list some general practical guidelines of obtaining synchronised production system:

- *Balance flow, not capacity*: focusing on capacity often results in resource wastage since variations may bring idle time to production systems operating with capacity adjusted to peak periods;

- *Keep bottlenecks operating continuously*: bottlenecks determine the flow of all the production system. Therefore, a lost bottleneck hour is a lost system's hour and, hence, a saved bottleneck hour has no meaning;

- *Overall view when setting schedules*: schedules should be set after careful examination of all constraints in the system simultaneously;

- *The production system constraints determine the level of non-bottleneck utilisation*;

- *Activation is not synonymous with utilisation*: the fact that a workstation is activated does not mean that it is adding value. If there is no guaranteed order from downstream operations the result of activation is likely to be a generation of waste with 'overproduction' and 'processing'.

The ideas described above contrast with the traditional approach of production management. Traditionally, the guarantee of a smooth process flow is obtained through the addition of capacity to existing facilities. This, in turn, increases cost and often ends up in idle resources. In contrast, in the new production management theories, physical production capacity is maintained whilst extra capacity is acquired through continuous analysis and improvement of the production system (e.g. reducing changeover time, reducing transportation distances).

Furthermore, managers dealing with synchronisation and smoothing of processes traditionally place buffer stocks of products or raw materials between workstations. As a result, the balance between workstations becomes unclear as double handling and quality defects stay hidden behind large stocks (Umble, 1990). In contrast, a central idea in the new paradigms regarding synchronisation is to uncover all problems by reducing buffers and batch sizes.

3.5.3.7 Solving the Control Problems and Constraints to a Speedy Flow

New or even well established practices may contain constraints that avoid a speedy flow of value adding activities. "Constraints" usually relate to the physical characteristics of equipment, products or materials and, thus, they are themselves subject to continuous improvement. An example of such constraints is equipment that demands too much effort to move because it is too heavy, too big, or beyond the needs of the job. Eliminating such problems will depend heavily on a clear understanding of the exact technical requirements of any job.

Another common barrier for a speedy flow in production is the presence of time consuming controls. In general, controls are necessary because they specify the conditions for production and make sure that these conditions are in place, such as the quality of the product or the delivery time of a component on the specified date. 'Production control' includes various practices such as aggregate production planning,

material co-ordination, workload control, work order release, workload acceptance, detailed work order planning, resource capacity allocation, material distribution and work distribution (Melles & Wamelick, 1993).

In modern practice, the operation and use of controls is not a managerial privilege. Workers are increasingly independent of management in terms of controlling their own activities and in taking contingent operational decisions. Nevertheless, since control is a non-value adding activity, improvements should be directed into eliminating or, at least, reducing it. In situations where controls are seen as unavoidable or as important drivers for improvement, they should be designed to allow speedy flow. Ideally, controls should be built into the production process and take absolutely no time from the workforce and main process flow.

3.5.3.8 Reduction of Variability

Koskela (1992) treats variability simultaneously as a principle in itself and as an implementation approach to reduce cycle time. The basic heuristic approaches to reduce variability are 'standardisation', 'installing poka-yoke devices' and 'measuring, detecting and eliminating the root cause of a problem'. Thus, the researcher decided to present the reduction of variability in a separate section (item 3.4.3).

3.5.4 DISCUSSION

The approaches presented in this section are very useful and straightforward guidelines to reduce cycle time. However, they may require high abstraction when it comes to implementations in practice. The theoretical definitions of cycle time identified in the literature are clearly based on the assumption that processes are repetitive and stable. However, in dynamic production systems, such as construction sites, the actual cycle time is likely to be less clear and extremely variable.

In modern production ideas the aim is to develop production systems with the capability of producing only one production unit per set-up, like in traditional construction. The difference lies in the fact that these theories also aim to reduce the set-up time to a single digit or, when possible, to zero. With this practice in place the production system is able to produce customised products with high flexibility, moving from the

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that process will also vary. Even slight variations in quality can influence the customer's perception of the overall quality, cost or delivery time of a product or service. In cases where the variation is extreme, the product or service can become unacceptable to the customer (Vonderembse & White, 1996; Sjoholt, 1998).

There are normally two causes of variability in production. The first type includes the *random factors* that are inherent in a process and very difficult, or expensive, to control or eliminate. They are often beyond the operative's control and include factors such as the number of customer orders per day. The other type of variability is due to causes that can be identified. These are easier to control and, because of that, they are called *controllable causes*. Although both causes will always be present in production systems, it is possible to have procedures in place aimed at reducing or avoiding their occurrence (Vonderembse & White, 1996; Hopp & Spearman, 1996).

"Process time variability" and "flow variability" are the building blocks for characterise the effects of variability within production systems. "**Flow Variability**" occurs when variability at one workstation affects the behaviour of another workstations in a line, i.e. it refers to the variability found in the flows between workstations. It is worth emphasising that processing time usually represent only a small fraction of the actual production flow. Greater quantity of time is spent waiting for various resources such as personnel, material, machines and so on. Therefore, a fundamental issue in production management is to understand the causes of waiting and how to reduce or eliminate it. The science that tries to characterise performance measures in terms of descriptive parameters is called *Queueing Theory* (Hopp & Spearman, 1996).

The term "Queueing Theory" is often used to describe the more specialised mathematical theory of that study waiting times. This theory can be used to describe real world queues, or more abstract queues, such as are often found in many branches of computer science, for example in operating system design (Ravindran, Phillips & Solberg, 1987; Bunday, 1996). The focus must be on the process bottlenecks of production since they are the ones that determine the flow and capacity required of the entire production system ("Theory of Constraints") (Goldtratt, 1986; Ashcroft, 1988). Much of "Queueing Theory" is very complex and almost all of it relies heavily on mathematics, especially statistics. In production, the Queueing Theory deals with the investigation of situations where units of a production lot arrive at the workstation for

receiving the main operation but some of the units have to wait for that operation (Ravindran, Phillips & Solberg, 1987; Bunday, 1996; Hopp & Spearman, 1996; Hlynka, 1999).

Hopp & Spearman (1996) call "**process time variability**" those effects that are confined to the workstation. This type of variability includes, for instance, machine breakdowns or deviations in the planned set-up times. In both situations the capacity and efficiency of the entire production system can be affected. In this respect, Taguchi & Clausing (1990) proposed the use of the idea of *"loss function"* in order to measure the loss to society caused by deviations of the process from a *"target value"*. In general, this loss is far bigger than the isolated cost of the variation itself because of the large number of inter-related links throughout the supply chain.

Within the idea of "loss function", a distribution of frequency presenting low variability in relation to target attributes, but contained within tolerance limits (process A in Figure 3.9), is much better for production than one centred at the target value but presenting high variability (process B in Figure 3.9). The fundamental reason is the fact that the effects of variations are amplified when processes are combined. Furthermore, when deviations from the target are consistent and have low variability (process A), the adjustments are easy and likely to be successful (Taguchi & Clausing, 1990).

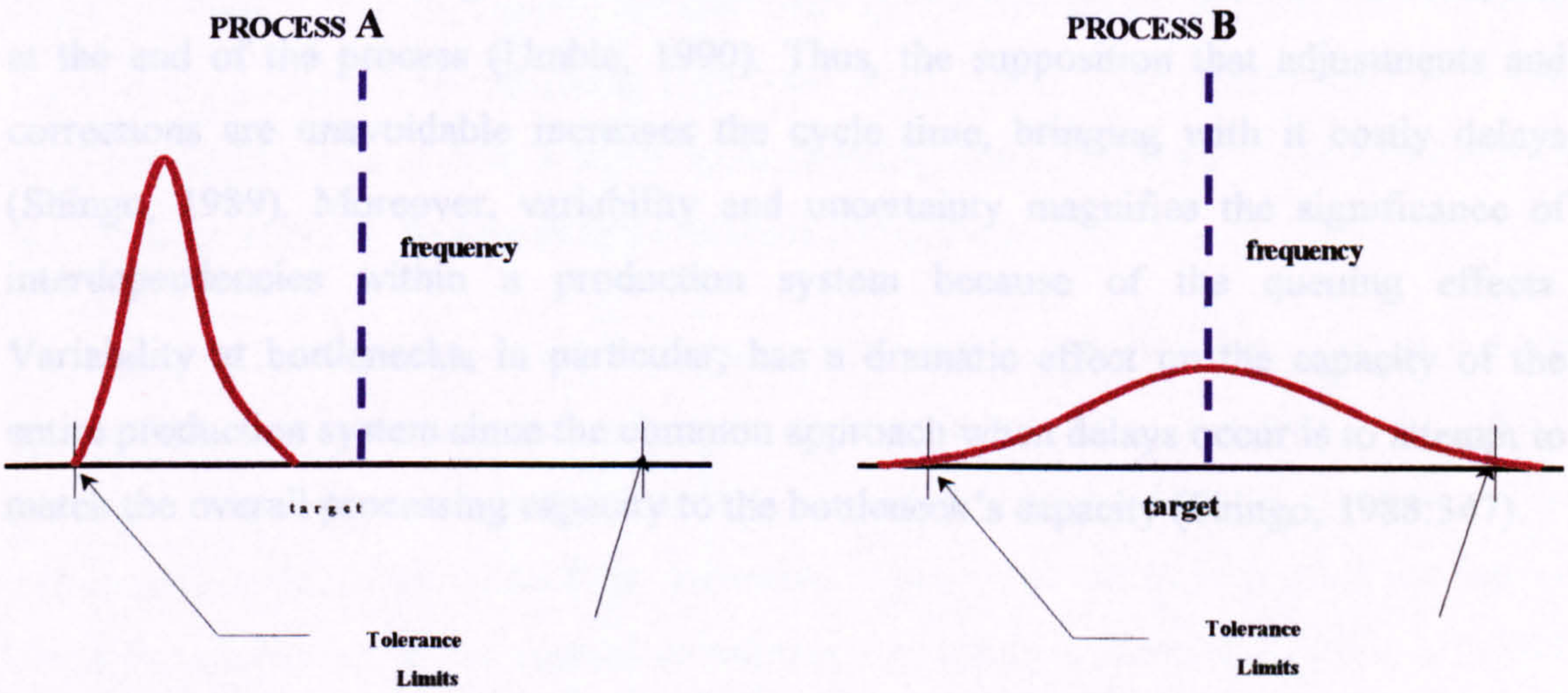


Figure 3.9 - Frequency Distribution from Two Different Processes

Taguchi & Clausing (1990) argue that designing products in a way so that the output is minimally influenced by external factors can be an effective strategy to reduce the effect of *random causes* of variations. *Robust design* requires the identification of the principal controllable factors that can influence the process output and the use of information to develop preventive solutions (Taguchi & Clausing, 1990). This notion is important for production management because quality losses often result from product failure after sale. The reduction of these failures is more dependent on product design than stringent control in the production system.

3.6.2 IMPACT ON PRODUCTION SYSTEMS

The cost of variability to society is, in general, much bigger than the cost of the variation in production alone. It can include, for instance, guarantee and repair costs and the time clients have lost waiting for those repairs (*loss function*) (Tagushi & Clausing, 1990). Particularly, in production systems that are implementing 'Just-in-Time', reduction of variability is a fundamental requirement to enable the reduction of batch sizes. In such systems, everything can come to a halt if one sub-product is not within the tolerance limits (Vonderembse & White, 1996).

When variability occurs it makes planning and programming a mere conjecture. Delays tend to accumulate leading to the installation of time buffers between workstations, and at the end of the process (Umble, 1990). Thus, the supposition that adjustments and corrections are unavoidable increases the cycle time, bringing with it costly delays (Shingo, 1989). Moreover, variability and uncertainty magnifies the significance of interdependencies within a production system because of the queuing effects. Variability at bottlenecks, in particular, has a dramatic effect on the capacity of the entire production system since the common approach when delays occur is to attempt to match the overall processing capacity to the bottleneck's capacity (Shingo, 1988:347).

3.6.3 IMPLEMENTATION APPROACHES

3.6.3.1 Measuring, Finding and Eliminating the Root Cause of Problems

One of the foundations for an effective reduction of variability in a production system is to make decisions based on facts, instead of intuition. Of course, many problems in production can be solved quite readily using a combination of production management heuristic principles and common sense, without any sort of data collection. However, non-trivial situations, such as the solution of complex engineering difficulties, or the introduction of new technologies, requires substantial preparation and planning. In these cases, data from all possible angles is a fundamental requisite to obtain effective solutions (Imai, 1997)

Systematic measurement helps to detect problems as they occur, or at least, give an early indication of critical situations before they actually become a problem. This is so that the systematic identification of root causes of process problems is a common practice among the most competitive companies. In some of these companies such detection is even carried out in real time, using sophisticated computer systems.

Measurements linked to problem solving activities are so important that they are a fundamental requirement of quality awards such as the "Malcolm Baldridge National Quality Award", "NASA Quality Award" and "European Quality Award", as well as in the auditing processes for obtaining ISO 9000 certification (Zairi, 1996). ISO 9001, for instance, applies this principle when recommending the identification and reduction of non-conformances in deliveries and customer complaints.

Nevertheless, to be of any value, measurement and monitoring have to be quickly interpreted and converted into solutions as soon as possible (see also *item 3.5.3.7 Solving Control Problems and Constraints to a Speedy Flow*). Defects in products and processes are frequently caused by corrective actions that are implemented too late or through deficiencies in the control or monitoring activities themselves (Shingo, 1988; Woodgate, 1991). In traditional companies, with rigid departments and many organisational layers, the cycle time between deviation, detection and correction is sometimes extremely large. This happens due to a lack of communication, when no

message is passed, or due to the existence of long channels of communication which often also produce distortion in the content of messages (Koskela, 1992).

One important factor which enables the systematic elimination of the root cause of problems is the shift the control of plans closer to process owners. Unfortunately, plans and schedules are often based on the premise that everything is going to work as planned. This belief is strongly suggested in the conversion model where production is divided into various "black boxes" and where what really matters for management is the control of inputs and outputs to and from these "black boxes". Within this paradigm production control gives emphasis to variables like "finishing dates" and "budget limits". However, delays are often accepted within the original schedules and waste is already included within the normal rates of consumption relating to such processes. Therefore, by ignoring the existence of variations in production, the traditional paradigm leads to ineffective planning and encourages sub-optimisation (Ballard, 1993; Ballard, 1994).

If traditional planning worked perfectly, *"what can be done"* should always match with *"what should be done"*. The *"completed work"* would be a mirror of the project *"objectives"*. However, this situation is more the exception than the rule (Ballard & Howell, 1994). Actual measurements in case studies carried out by Ballard & Howell (1994) showed that what was actually done differed markedly from what was supposed to be done by roughly one third of the time.

Ballard (1993) proposes a method for planning that strongly use this idea of shifting the control of planning closer to process owners. The essential elements of his *Last Planner* method is to determine "*what should be done*", "*what can be done*", "*what will be done*" and systematically work on the sources of failures to achieve the original objectives. The first step to implement the *Last Planner* approach is to stabilise the production flow by shielding a process from upstream process variations and uncertainties that management has not yet been able to prevent. This shield may be translated into a space of time between processes. Within this shield, it becomes possible to gradually move upstream processes in front of the shield and, thus, reduce inflow variation. At the same time, the downstream processes can move behind the shield to improve performance (Ballard & Howell, 1994). The shield works as a temporary buffer that gives an opportunity to reduce variability of a process (es).

During the application of *Last Planner* the Percentage of Plans Complete (PPC) is measured regularly. The PPC rises when people analyse and act on the causes of failures to accomplish their plan. Consequently, variability is reduced, productivity rises and there is a reduction in the amount of non-value adding activities. In short, "can" and "should" get closer through a higher level of involvement, motivation and commitment of the process owner themselves (Ballard & Howell, 1994).

3.6.3.2 Standardisation

Standardisation involves the development of pre-set procedures and referential material for performing a particular process or operation. Such standards are usually presented in writing. However, at times, pictures, sketches, and photos may facilitate understanding (Vonderembse & White, 1996; Imai, 1997). In this context, standards have the following features (Imai, 1997):

- they represent the best, easiest and safest way to do an activity;
- they offer the best way to preserve know-how and expertise: with standardisation and institutionalisation of its content, the know-how stays in the company regardless of the comings and goings of employees;
- the standards offer a fair way to evaluate performance;
- they provide a basis for both maintenance and improvement activities;
- they provide a basis for training, audit and diagnosis.

Whenever there are problems in production, such as producing rejects or rework, people should seek the root causes, act to remedy the situation, and change the standard to eliminate the problem. Without standards, there is no way of knowing whether an activity is performed correctly or not. In this sense, Imai (1997) argues that maintenance of standards is one of the management's primary duties. If variability occurs because of lack of standards he argues that one should develop new standards. If variability occurs even when people have adopted standards, it will be necessary to determine the causes and, either revise/upgrade the existing standards, or verify that the existing standards are clear to the workforce (Imai, 1997).

3.6.3.3 Poka-Yoke

In the early days of the quality control, there was a strong belief that high quality would necessarily imply one hundred percent inspection. After all, most production systems are complex organisations and some errors can go through the production process without being noticed. However, people started to realise that this level of inspection was burdensome and time consuming and, hence, incompatible with a business environment where time began to be a competitive battleground. So, production systems started to adopt the SPC - Statistical Process Control - methods, replacing 100 percent inspection with sampling inspection and statistics (NKS, 1987; Monden, 1998). In a short period of time, SPC become the norm in highly efficient production systems across the world.

The turning point in process control occurred in Japan, during the re-construction period after the World War II. Japanese companies needed to expand their output and quality of production without having the resources to increase production capacity or hire more employees. Individual workers began to take responsibility for more machines. In this environment, the interruptions and cost caused by errors admitted in the SPC approach were unacceptable (*loss function* mentioned in item 3.4.3.1). It was in this period of development that we observe a return of the defenders of "zero defects", and "100 percent inspection", which aimed for the total elimination of defects. However, this movement differs from the early days of quality control because it challenged traditional trade-offs. Controls were now designed to be less time consuming whilst, at the same time, aimed at the elimination of the root cause of problems.

Production systems, mainly in the manufacturing sector, began to build electronic and mechanical instruments into their processes to guarantee 100 per cent inspection. These instruments are called Poka-Yoke or foolproof, mistake-proof, fail-safe devices, or autonomation. The Poka-Yoke term comes from the Japanese words *yokeru* (to avoid) and *poka* (inadverted error). Indeed, the fundamental idea of poka-yoke is to *build in* a mechanism to prevent mass-production of defective work in workstations and production lines. Particularly in automation, machines always incorporate a mechanism to detect abnormalities or defects, and a mechanism to stop the line or machine when occurred abnormalities or defects (NKS, 1987; Monden, 1998).

Poka-yoke takes over repetitive tasks, or actions, that depend on vigilance or memory and, hence, can free the worker's time and mind to pursue more creative and value adding activities. NKS (1987) identifies three basic functions of poka-yoke devices: shutdown (*stop the process*), control (*correct*) and warning (*alert the operator*). Micro-switches and limit switches are the most frequently used detection devices in poka-yoke. A limit switch is used to ensure that a process does not begin until the component is in the correct position, or to stop the process if a component has the wrong shape. It is also becoming common to use photoelectric switches that detect the presence of objects, people or machines.

3.6.4 DISCUSSION

The literature review showed that there is a growing volume of research in construction dedicated to development of tools and techniques used to analyse the root cause of problems in the construction sector. However, the usual approach of researchers working in the construction field is simply to copy methods used in the manufacturing sector or to adapt them to the construction environment. Although the abstract principles and concepts may be transferable, the characteristic of mobile dynamic flow of operations and processes in construction demand new approaches for monitoring production activities. The author believes that specially designed process measurement techniques should be incorporated into the construction processes. Besides, process measurements should require the least time possible from the workforce. The application of this idea in practice implies the development and implementation of innovations in construction sites, mainly in terms of electronic and mechanical devices.

The literature also gives greater emphasis to the development of written standards. However, it is worth emphasising that the development of written standards is only the means to ensure the expected end result that is process stabilisation through the application of homogeneous practices. Therefore, to develop and implement a process for standardisation is as important as the standard procedures themselves. The learning process that leads to the formalisation of standards is the crucial factor that sustains the effective use and continuous improvement of standards in practice.

Variability is generally seen as contradictory to process efficiency. Whilst this is true for the majority of production systems, there are situations where variability is clearly

beneficial to enhance process performance. When production systems achieve low levels of process variability it may be advisable to introduce some "artificial" variations in order to drive further improvements in processes. These planned and carefully introduced variations in stable processes can instigates operatives and managers to search for new limits of process performance. For instance, Ohno (1988) reports that at Toyota the variation in production schedules is one of the forces that pushed continuous improvement efforts towards new limits.

3.7 INCREASE OF TRANSPARENCY

3.7.1 DEFINITION OF THE PRINCIPLE

Increase of transparency means to increase the ability of a production activity to communicate with people. This is one of the core principles behind a number of managerial methodologies and techniques such as Visual Management, Kanban, 5S programs, Andon, Poka-yoke, and so on.

The way in which information is organised for accessibility is the distinguishing feature of transparency as portrayed in modern theories. In conventional communication, information is transmitted in a "push" mode and the user has little or no control over the amount and type of information that is transmitted or received. In contrast, in the new paradigm nothing is transmitted: an information field is created which can be "pulled" by any person at any time (Greif, 1989). This is a fundamental move from the usual *silent* production process to a more *communicative* one, more self-explanatory, self-ordering, self-regulating, and self-improving (Galsworth, 1997).

Production systems operating in competitive environments should no longer lead to loss of time with people searching for information. According to Galsworth (1997), information should be part of the process, as physically close as possible, pre-set at the point-of-use, fresh and available at a glance, without the need of people to ask questions or spend time processing it. In short, the process itself should be able to inform its state.

A transparent (or visual[11]) workplace/process is characterised by a certain dualism, existing simultaneously, communication directed toward a group's internal need and messages to people outside the workplace (Greif, 1989:27; NKS, 1991:4). In an ideal situation, even a lay visitor should be able to understand what is happening in any production process and, consequently, be able to identify problems. This definition goes against traditional ways of thinking, such as the one exemplified in the phrase of Edwards & Peppard (1994:252): *"Customers do not recognise much of what goes on within an organisation, nor should they"*.

3.7.2 IMPACT ON PRODUCTION SYSTEMS

Transparency can be used as an instrument to increase the motivation of workers for improvement, reduce the propensity of errors and, most certainly, increase the visibility of errors (Koskela, 1992). The manufacturing literature shows a list of other advantages relating to the implementation of transparency, such as (Greif, 1989; AKS, 1991):

- Simplification and greater coherence in decision making;
- Stimulation of informal contacts throughout different hierarchical levels;
- Contribution to introduction of decentralisation policies;
- Helps to broaden employees participation and autonomy in management;
- More effective distribution of responsibilities;
- Increase in employee morale;
- More effectiveness of production scheduling;
- Simplification of production control systems;
- Rapid comprehension and response to problems.

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[11]The term "visual information" includes messages communicated through any of the senses: tasting, touching, hearing, seeing or smelling.

3.7.3 IMPLEMENTATION APPROACHES

This section describes the principal approaches to implement transparency in production processes. It is not the intention of the author to discuss approaches used at the organisational level, such as the increase of informal contacts outside of the hierarchy, the overlap of responsibilities or the frequent visit of top managers to the shop floor level.

3.7.3.1 Reducing the Interdependence between Workstations

When two or more different professionals have to work in the same area the immediate consequence is usually an increase in the degree of disruption and cluttering. This often makes it more difficult to understand and control such environments. One of the approaches used to minimise the occurrence of these situations is to reduce the interdependence between production units.

Reduction of interdependencies may be achieved through improvements and innovations in design, production methods or simply by carrying out changes in schedule (*see* item 3.5.3.5 Changing the Order of the Process). In the manufacturing industry, for instance, this often leads to the arrangement of production in "focused factories", or manufacturing cells, has contributed in reducing the net effects of interdependencies within complex production systems.

There are two types of interdependencies: sequential and reciprocal. Interdependence is sequential when the workstation is dependent for its input on one or more preceding workstations. When the interdependence happens in a two-way fashion (upstream and downstream), it is called reciprocal dependence. In this category, stoppage of work at any workstation will result in shutting down the other workstations, irrespective of whether they are upstream or downstream (Arogyaswamy & Simmons, 1991).

The usual responses of production managers to the uncertainty arising from interdependencies has been to try and reduce their effects by de-coupling the relevant production activities from each other through the use of inventory or time buffers (Arogyaswamy & Simmons, 1991). However, like the explanation given to batch sizes (item 3.4.2.3.1), the greater the time buffers the greater the difficulty of understanding process problems.

3.7.3.2 Use of Visual Controls Enabling Immediate Recognition of Process Status

Visual controls can give an important contribution to enhance efficiency of production systems. The easy and fast identification of waste, or any other process problems, helps enabling and promoting continuous improvement activities. For instance, appropriate visual controls should be able to help people to identify whether or not boxes of a certain item are where they should be, or if they have exceeded the maximum limit of a required quantity. In an ideal situation, anyone should be able to detect or avoid errors like this and, thus, contributing to improve the process performance.

In the manufacturing industry, the pressure for achieving increasingly high levels of process performance has driven the development of a great variety of visual controls. The most mentioned visual controls in the literature are:

- Kanban: this is intensively used in "pull production systems" as a major instrument for communicating orders from downstream to upstream workstations. Kanban is usually associated with cards but, it actually has many different formats such as coloured containers or even limited areas painted on the floor (Steudel & Desruelle, 1992);

- Call Light: this is used when an operator regularly needs to call for a supervisor, maintenance worker or a general worker. Usually there are several different colours of lights and each one is used to summon a different type of assistance (Monden, 1998);

- Andon: this means "lantern" in Japanese. Andon is a nickname for the indicator board that shows when and where a worker has stopped the line (Monden, 1998);

- Digital Display Panels: this shows the pace of production, with information such as the day's production goal and the unit's production so far (Monden, 1998);

- Visual Controls in Poka-yoke Devices: (*see* item 3.6.3.3 - PokaYoke) usually consists of a detecting instrument, a restricting tool and/or a signalling device. The signalling device alerts the operator when it detects an abnormality or defect (Monden, 1998).

Another important visual control often mentioned in the literature is called "bordering". Bordering is used to indicate the space for the designated location of a production process, making it clear when an item is not at its appropriate location. In world-class companies, factory after factory has shown that a simple floor border offers a positive contribution to increase production efficiency, even in situations where the layout is constantly changing. Such companies use borders in many different ways and for many different purposes, for example (Galsworth, 1997):

- differentiation between walk-ways from work-ways;
- as a trigger for improvement, through the identification of as many forms of movement as possible;
- identification of minimum/maximum supply levels;
- home addressing for equipment (e.g. profile or silhouette painted on the place for storing tools or equipment).

Allied to bordering is the practice of giving address names or numbers for locations and identification labels to materials, tools or equipment. Working together, "borders", "home addresses", and "identification labels" ensure *item recoil*. Galsworth defines "*item recoil*" as the capacity of an object to find its way back to its designated location (home), solely on the basis of location information built into it. In practice, this means that every item that leaves its designated location is more likely to come back to its original position. These are also crucial requirements for better health and safety conditions in any production system. When there is a need to find a fire extinguisher, for instance, there can be no waste of time (Galsworth, 1997).

Colour is an important consideration for bordering and for transparency in general. Standard specifications such as OSHA and ANSI give guidelines for the adequate use of each particular colour. For example: red is used when meaning stop, to mark emergency stop bars and stop buttons on hazardous machines; green is used when meaning safety and to mark the location of first aid and safety equipment (Galsworth, 1997)[12].

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[12] According to (Galsworth, 1997) the most readable combination is black letters on a yellow background.

3.7.3.3 Making the Process Directly Observable

According to the definition of transparency, even people not familiar with the production environment should easily understand how the process works just by looking at it. One of the approaches for obtaining this is by making the process directly observable through appropriate layout planning, illumination or appropriate planning of the workstation flow. The layout and flow of process and operations has to be planned to allow observation for as many perspectives as possible.

With this practice in place, operators should be able to understand why the parts of the preceding workstation are getting late or why the next workstation has stopped the work. In cellular manufacturing, for instance, the start of a process is located as close as possible to the end of that process, making it easier to follow the flow materials (Galsworth, 1997). Steudell & Desruelle (1992:302) argue that cellular manufacturing makes tracking work-in-progress simple and almost unnecessary.

The application of this approach can be problematic in production systems where workstations and materials constantly change in terms of volume, type and position. Notwithstanding this, even in such dynamic production systems as construction this approach is useful since new workers need to understand quickly the state of the process they are working on (Greif, 1989:39). In companies facing such situations, the use of visual controls such as standing signs and ropes can help to reduce the difficulties of frequent changes (*see* item 3.7.3.2 - Use of Visual Controls Enabling Immediate Recognition of Process Status).

3.7.3.4 Incorporating Information into the Process

The move from an environment of silent disorder to an environment of informative visual order starts by asking questions such as *"What do I need to know?"* and *"What do I need to share?"* In that sense, the incorporation of useful information throughout the production system is a necessary step to reaching a self-explanatory and self-regulating environment. This is the most passive form of transparency, since it gives helpful information without necessarily demanding obligatory adherence (Galsworth, 1997).

The content of information displays can range from specific recommendations about products or processes to general information about the company plans (e.g. next contracts). Obviously, information needs to be helpful and meaningful to workers. Defects display boards, defective storage part areas, general statistics about the process or even illustrative videos from suppliers are examples of this informative role of visual communication (Greif, 1989). In standardisation programs, information displays can play an important role in promoting the ownership of documents (adherence), improving the visibility of results (observation) or helping the follow-up of improvement ideas (modification).

Appropriate information can also help customers "get smart" about the production processes. For example, some manufacturing companies post the name of each machine and the operators who run the machine, and even a photograph, along with the number of years that this person has worked for the company. This brings a sense of commitment to the workforce and can also have a considerable positive effect on the image of the company. Another example of a device to help the customer "get smart" about production is the *"Where-I-am Maps"* that inform the customer of his/her position in relation to other locations within the system (Galsworth, 1997).

Incorporation of information into the process can play an important role on the workforce perception of effectiveness. Its implementation should be based on intention, motivation and voluntary adherence; it will only work when one wants to become a recipient of that information. Setting up a computer network, developing a system for routing inter-departmental memoranda, or creating an in-house newspaper is possible in any company but it is a waste of money if staff are not self-motivated to use the system or interpret the information. Managers are often tempted to display indicators in work areas but there is no value in doing so if the work-team involved has no concern about its performance (Greif, 1989:174).

Steudel & Desruelle (1992) argue that people have a bias to remain silent when anything goes wrong, and this tendency is even more pronounced when the person who signals a problem might be blamed for it. In this respect, Neave (1997) reminds us that the majority of problems in the production systems are the responsibility of management rather than the workers at whom the posters and slogans are normally aimed. Posters and slogans can create adversarial relationships if there is no genuine

purpose to help, advise or inform the workforce when there is a problem within the organisation (Deming, 1988).

3.7.3.5 Maintaining a Clean and Orderly Workplace

When a workplace is clean, safe, and orderly, the worker can relax and do his/her work more efficiently. The most famous and successful method of keeping a clean and orderly workplace is known as *"5S"*. The term 5S is a familiar term among "world-class companies" and refers to the five traditional housekeeping practices that are part of the daily routine of every Japanese household. From the mid-1950s, these practices became corporate imperatives in Japanese companies. The letters in 5S mean, in Japanese (Galsworth, 1997; Monden, 1998):

- Seiri: *proper arrangement, organisation.* In this phase, materials are separated into necessary and unnecessary stacks. Seiri is made daily or even only once or twice a year depending on the level of waste. One of the techniques to operate the seiri is to use the "3 tag technique": red tags are posted on items that people want to be removed from their area; yellow tags when an item is necessary but not at the present moment or when people are not sure whether to get rid of or keep such an item; and green tags are applied when the item is necessary for the production process;

- Seiton: *orderliness, selecting locations.* This step determines the location for each item. The usual practice is to define the most frequently used items and place them around the corresponding workstations. Some of the general empirical rules for seiton are the use of *"First-in First-out"* storage, development of easier handling in set-up operations and to regard stock space as part of production space. Clearing out the clutter in seiri automatically eliminates many basic safety hazards and makes the environment more tidy;

- Seiso: *cleanliness.* After the application of seiri and seiton, only the essential items should remain in the workplace. At this stage, workers should carry out a "scrub" that brings every item to a standard level of cleanliness. This should be done continuously to maintain tidiness within the production system;

- Seiketsu: *cleaned up, neatness*. Seketsu is about standardising 5S activities so that the actions are specific and easy to perform;

- Shitsuke: *discipline, good conduct*. This is the method used to motivate workers to continually perform and participate in seiso and seiketsu activities. Some companies use photographs as a technique to obtain that motivation. By taking pictures of the workplace from the same position and with the same direction and camera, before and after the application of 5S, people can perceive clearly the progress of their actions.

3.7.3.6 Rendering Invisible Attributes Visible Through Measurements

In the strict theoretical sense, transparency means the separation of the network of information present in the production system from the physical production system itself (Greif, 1989). The network of information is always implicitly there and can be externalised through measurements. So, for instance, attributes such as quality of production workmanship, waste or productivity are invisible unless they are measured and transformed into performance indicators (*see* more on item 3.6.3.1 – Measuring, Finding and Eliminating the Root Cause of Problems).

3.7.4 DISCUSSION

Transparency depends on the creativity of managers and workers and it is difficult to identify some strict rules and guidelines for its implementation in practice. Therefore, the correct application of the approaches presented in this section relies on the adequate judgement of any person facing a practical problem. They have to be continuously reflected and tried in practice in order to be effectively ingrained in peoples' minds and in order to help them refine their own judgement.

Cultural differences will certainly affect the way this principle is transformed into action in different contexts. The attitude about the types of information that can be disclosed within a company milieu are not the same from Japan to France or the United States (Greif, 1989:179). Thus, although abstract definition may remain the same, people have to read and present case material bearing in mind the social/cultural context in which the information has been produced.

Increase of transparency is a support principle that enables the full potential of other principles. Some of the heuristic 'implementation approaches' presented here may even offer a contrary effect if not integrated with other principles. For example, one of the risks of increasing interdependencies is to reduce the interaction between people and, consequently, reduce the generation of new ideas for improvement that this interaction could produce. In pull production systems, this problem is contemplated through the creation of "virtual" interdependencies. These "virtual" interdependencies are achieved, for instance, by implementing kanbans. The workstation can only start the execution of the next operation if the previous workstation has performed its task properly, in the right time and right specifications. Communication across different teams is then driven by the need of solving process problems that interrupt the flow of kanbans.

3.8 BUILDING CONTINUOUS IMPROVEMENT

3.8.1 DEFINITION OF THE PRINCIPLE

Building continuous improvement consists of implementing practices that result in ongoing incremental actions aimed at improving production efficiency and efficacy. Continuous improvement is at the core of all theories related to quality management. According to Werner (1994), one of the basic premises of this principle is not to accept established knowledge as the ultimate truth. This premise implies that nothing is static - it is always subject to review so it can always be improved, whether it is a machine, a process, a system or a human activity (Imai, 1986; Shingo, 1988). Even if an activity is being carried out well, questions should always be asked about the possibilities for improving it.

This principle is commonly associated with the Plan-Do-Check-Act cycle, also referred to as the *Deming Wheel* or *Shewhart Cycle*. When continuous improvement is in place, the PDCA[13] cycle is repeated over and over again, as illustrated in Figure 3.10 . Each phase of this cycle has an important role to sustain ongoing improvement in production, as explained below (Vonderembse & White, 1996):

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13 When the PDCA involves the maintenance of a standard it may be called SDCA (Standard-Do-Check-Act cycle)

- Plan: to identify problems or opportunities for improving and developing a plan to make changes;
- Do: to implement the plan, documenting any changes made;
- Check: to analyse the revised process to see if goals have been achieved;
- Act: to standardise, document and disseminate the results. In case of not achieving the goals determine why not and proceed accordingly.

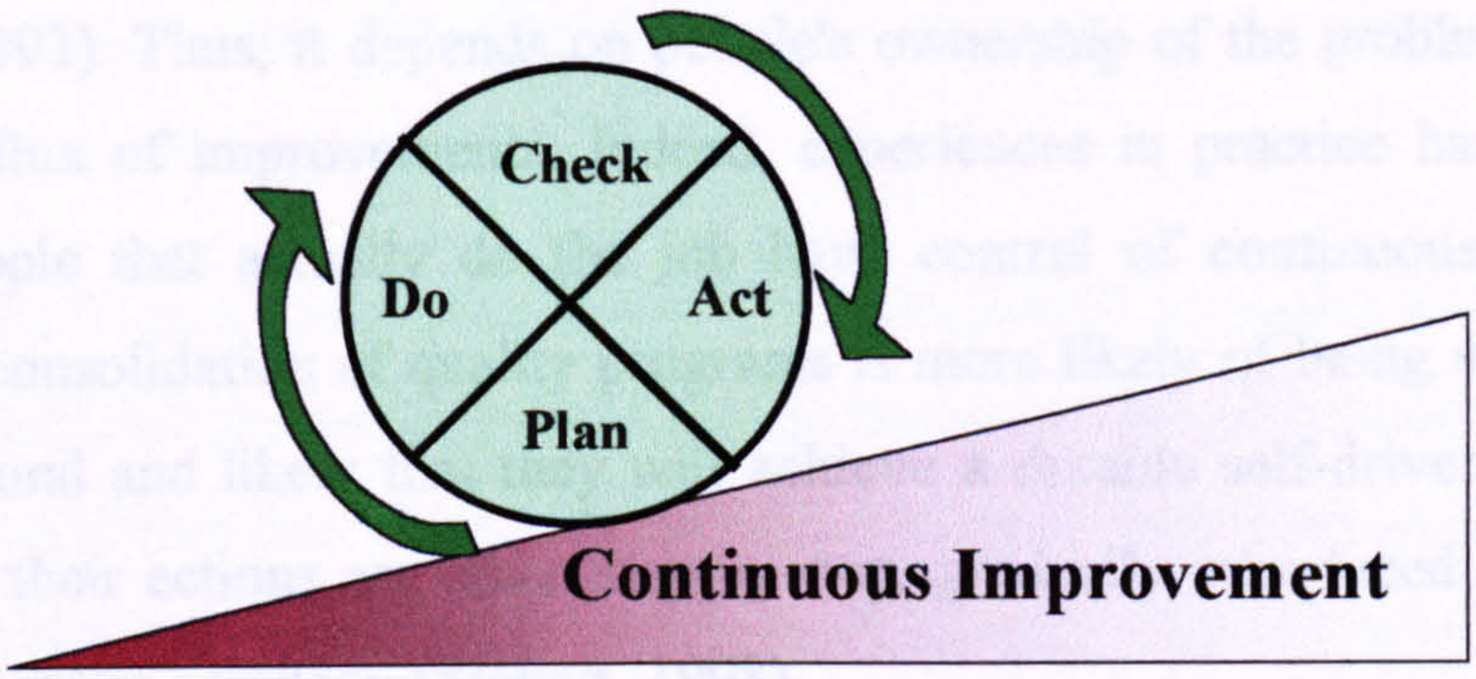


Figure 3.10 - Illustration of the PDCA Cycle

Most of what is discussed today about continuous improvement comes from interpretations of the Japanese practice called *kaizen* (Vonderembse & White, 1996). It is claimed that their practices were heavily influenced at the beginning by the American statisticians W. Edwards Deming and Joseph M. Juran. Their teachings about rigorous statistical control, right after World War II, matched very well with the Japanese unique holistic, democratic and collaborative behaviour[14] and the urgent need for improving quality in their products (Deming, 1986; Juran, 1989).

One important lesson from the best Japanese practices in the application of the continuous improvement principle is their relentless attitude towards solution of problems in production. According to Imai (1986), Japanese managers have found that

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[14] This behaviour is attributed to the legacy from the community behaviour in the small villages of the past. There they have to fight together to survive earthquakes and typhoons, make joint efforts to re-build houses and help each other to build irrigation channels in a difficult landscape. Associated with this was the influence of Confucius, Shintoism, and Buddhism with their holistic view of the world. This cultural heritage effectively became incorporated into the village social code, and affects many aspects of today's Japanese life (Hannan, 1993).

seeking improvement for improvement's sake is the surest way to strengthen a company's overall competitiveness in the medium and long term. Monden (1998) reinforces this argument by saying that many highly competitive companies world-wide are realising the importance of constantly searching to cut organisational slack and waste, whether in prosperous or adverse times. Unfortunately, it is common to find companies trying to reduce organisational slack and waste only when the economy is in recession or when there is a struggle to survive.

Continuous improvement is driven by knowledge and problem solving activities (Schoreder, 1993). Thus, it depends on people's ownership of the problems in order to maintain the flux of improvements. Indeed, experiences in practice have shown that when the people that actually do the job have control of continuous improvement activities the consolidation of quality programs is more likely of being successful. It is also more natural and likely that they will achieve a durable self-driven improvement process when their actions are taken step-by-step, gradually introduced as a collective system for the entire company (Sjoholt, 1998).

The challenge of building continuous improvements into production systems is to devise ways of establishing win-win relationships throughout the entire organisation and with external stakeholders. In this sense, it requires sharing the benefits of eventual reductions in waste and increases in value with everyone involved (Starkey & McKinlay, 1993; Imai, 1986).

3.8.2 IMPACTS ON PRODUCTION SYSTEMS

Since continuous improvement attacks the sources of waste, such as scrap and rework, it is also capable of actually reducing costs. Furthermore, this principle can contribute to an increase in the installed capacity of production systems by recovering the wasted capacity used to produce rejected products. TQM calls this late waste and the activities involved in its reduction as "cost of quality", and divides it into two groups of components (Crosby, 1996):

- Control costs: related to activities which remove defects from the production stream:

- *Appraisal costs*: the costs incurred in measuring quality, assessing customer satisfaction, inspecting and testing products (e.g. customer satisfaction survey);
- *Prevention costs*: activities to prevent defects from occurring (e.g. training quality control procedures);
- Failure costs: when a product or component of a product fails to meet requirements;
  - *Internal failure costs*: during the production process (e.g. scrap, rework);
  - *External failure costs*: after the product is delivered to the client (e.g. returned goods, guaranteed charges).

The advocates of "Zero Defects" use the "cost of quality" to justify investment in the continuous search for processes free of errors. Searching for zero defects goes against the common belief that it is acceptable to make errors, or that it is too expensive to do the job "right the first time" (Crosby, 1996; Schroeder, 1993; Tagushi & Clausing, 1990). A particular production practice that strongly uses this idea is the use of a "stop button" mechanism. This is a mechanism that gives people the ability of stopping the entire process from moving forward whenever an error is detected. In this case the responsibility for correcting errors is collective since deviations have to be corrected in order to move the processes forward (Shingo, zero defects).

While reducing waste, continuous improvement can also be oriented to increasing value to the end customer. In this sense, it can be directed to contribute to any of the various dimensions of quality. According to Garvin (1987) these dimensions include performance (e.g. hardness), features (e.g. extra bolt), reliability, conformance, durability, serviceability (e.g. easy to repair), aesthetics and perceived quality. However, this thesis does not explore the application of continuous improvement to increase value since the present focus is on the "flow" and not on "value".

Next sections present the implementation approaches to implement continuous improvement into the production process.

3.8.3 IMPLEMENTATION APPROACHES

3.8.3.1 Setting Stretch Target

An effective way to promote a continuous flow of ideas for improvement is to challenge the participants of the production process with "stretch targets". This should generate a creative tension between a desired situation and the present situation. Drucker pioneered this idea in the 50's in what has become known as *"management by objectives"* (Cheetham, 1996). Nowadays even ISO-9004-4 encourages the setting up of targets for promoting quality improvement (Sjoholt, 1998).

Management by objectives recommends the establishment of procedures to formalise the continuous process of stating, and critically reviewing, an organisation's strategic and tactical plans. Such objectives are obtained after agreeing with each manager the key results areas of his/her job and the performance standards he/she should achieve in accordance with company objectives (Cheetham, 1996). Obviously, the establishment of objectives and targets need to be followed by adequate logistical and managerial support, and enough resources.

Many new organisational activities automatically bring challenges in themselves, such as the act of applying for ISO certification. In certain countries it is difficult for a company to remain on tender lists, to obtain work, and even remain in business without ISO certification. Thus, the certification process can become a challenge for the whole organisation and a driver to adopt better approaches (Sjoholt, 1998).

The establishment of "stretch targets" is a fundamental issue when working in teams. Scott & Townsend (1994:65) found that teams with higher goal levels are more likely to have higher group cohesion and team commitment. Additionally the same authors found that goal commitment and performance expectation positively associates with team productivity, group cohesion and team commitment. When an employee improves his/her self-efficacy perceptions, and the confidence in his/her own ability to perform, there is a positive effect on team productivity, group cohesion and team commitment (Scott & Townsend, 1994).

Cross-functional processes are another important area for establishing "stretch targets" (and objectives). According to Imai (1986) without cross-functional targets, the

departments with the loudest voices tend to win inter-departmental negotiations, regardless of the impact on company-wide goals. Consequently, this may lead to important strategic production decisions being unheard in the organisational debate.

Finally, an extremely important factor concerning the attitudes of managers and workers towards continuous improvements (or innovation) is the horizon they use to evaluate cost and benefits. Large gaps between the present situation and future actions, can make targets appear unrealistic or fanciful, thus, discouraging people to get involved (Senge, 1990:150). Therefore, the "learning horizon" - *a breadth of vision in time and space within which people can assess their effectiveness* - has to be carefully established when establishing targets (Senge, 1990:23). Differences in culture certainly affect the establishment of this learning horizon. Japanese companies, for example, generally favour the gradual approach, which usually takes more time to show results. In contrast, most Western companies emphasise the great-leap approach, looking for short-term results, according to Imai (1986).

3.8.3.2 Giving Responsibility for Improvement to All Employees

In nearly all the best companies world-wide there are initiatives to give more responsibility to employees. Sharing responsibility for improvement is in tune with the *learning organisation* theory. A learning organisation is premised on egalitarianism and fairness[15]. The assumption of such organisation is that all individuals have potential to contribute to the joint enterprise (Leonard-Barton, 1992). In fact, the need for constructive co-operation between management and workers one of the fundamental principles of Frederick Taylor, back in 1911 (Taylor, 1911; Barnes, 1980).

There is some disagreement in the literature about what constitutes the leadership of the process of continuous improvement within the organisation and where it should start. Imai (1986) argues that the introduction and direction of continuous improvement should be top-down, while suggestions for improvement should flow from bottom-up. In contrast, Starkey & McKinlay (1993) argue that the Japanese approach is middle-up-down, with middle managers assuming the role of translation of strategic objectives into

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[15] In the Japanese system, fairness means equal participation while in the American system fairness means equal opportunity (Baba, 1990).

operational targets. Despite this divergence of opinions, the consensus within the literature is that there should be an increase in the share of responsibility by employees and suppliers with respect to improvements (Imai, 1986, Monden, 1998).

In CWQC[16] - *Company Wide Quality Control* (or TQM) applications, for example, the control of quality is the responsibility of workers at every level and in every department of the organisation. Traditional management believes that workers are not willing to participate in improvement activities and have to suffer some sort of pressure to do so (*Theory X*). However, within the new paradigms managers have found that it is possible to move towards a more friendly and respectful relationship with workers. They do encourage and give scope to worker's creativity, assuming that they can be self-starters and can have initiative (*Theory Y*) (Hannan, 1993).

A key aspect of sharing the responsibility for improvement with employees is teamwork. Employees are increasingly demanding more opportunity to influence decision-making and involvement in meaningful work (Scott & Townsend, 1994:62). "Quality Control Circles" (QCC) is the most common type of team-working aimed at continuous improvement. QCC usually consists of a small group that voluntarily performs quality control activities on the shop floor (Imai, 1986). Many successful companies use these teams as the fundamental infrastructure that co-ordinates the participation of people in continuous improvement efforts. The importance of building such teams has been recognised in the *ISO-9004-4 (Quality Improvement)* which encourages the establishment of improvement groups (Sjoholt, 1998).

According to Karlsson & Ahlstrom (1996), one of the most salient features of the work organisation of lean production systems is the extensive use of team-working, particularly cross-functional teams. Cross-functional teams help to focus the organisational functions into common strategic objectives and, hence, into coherent actions around the main value process. Moreover, according to Lessen (1993), the proportion and quality of insights increases naturally with the use of cross-functional teams.

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[16] The term CWQC is used to distinguish from Feigenbaum's TQC (Total Quality Control) where the control of quality goes to specialists.

For improvement activities to be effective within the team, everyone in the organisation should have a strong consciousness of the need to eliminate waste and abnormalities from the production system (Monden, 1998). This consciousness can only be achieved if people perceive a "win-win" situation and clearly understand their role in the organisational network in order to achieve such a objective (Jones, 1992). When the improvements involve a supplier, this "win-win" relationship can be achieved through the establishments of partnerships. In a partnership, the team has to abandon power-based bargains and adopt an agreed rational structure of work for joint improvements, analysing costs, determining prices, and sharing profits (Womack, Jones & Roos, 1990).

3.8.3.3 Using Standards as Hypothesis of Best Practice

When knowledge is explicit in standards it acts like a mirror to the worker, reflecting what is already known, but in a much more precise and detailed form (see *item 3.6.3.2 Standardisation*). Because of this characteristic, standards are a powerful tool in challenging the workforce to develop better practices. When people participate in such an activity, the standard becomes the means to engage them in the kind of learning process that can transform data into meaningful information and, finally, into further insights for improvement.

The paradox of reducing variability through standardisation and, at the same time, constantly looking for improvements is often misunderstood in production management. In reality, standardisation and continuous improvement are inter-connected since there can be no improvement where there are no standards (Imai, 1986).

According to Imai (1997), "following the standards" means *maintenance* and "upgrading standards" means *improvement*. Hence, in order to promote continuous improvement it is necessary to establish basic standards and then introduce the discipline of continuous revision by continuously challenging their content. The maintenance and improvement of standards must be a manager's responsibility. In fact, in Imai's (1997) opinion, maintenance of standards should constitute a majority of a production manager's daily activities.

3.8.3.4 Measuring and Monitoring Improvements

Already, in the beginning of the century Taylor advocated data collection (time analysis) as the first step to maintaining and improving standards of production processes (*see* item 2.2.2 - Scientific Management School). The maintenance and advancement of improvements carried out in production systems strongly depends on the systematic measurement and monitoring of improvements and subsequent correction of eventual deviations as specified in the "check" step of the PDCA cycle (*see* item 3.6.3.1 Measuring, finding and eliminating the root cause of problems). After all, once an improvement has been analysed, developed and implemented it is normal for unforeseen problems to occur.

Production systems are naturally variable and to consider all sources of variability during process analysis is not always practical. Normally, the best way to perfect an improvement is to implement, measure and monitor it within real conditions. Systematic monitoring and measurement helps to point out the problems that need to be resolved in order to enable the improvement to operate as expected.

Additionally, the positive effect that an appropriate monitoring of process improvements can have on motivation towards enhancement of the improvement itself has already being identified by the Hawthorne studies back in the 1930's (*see* item 2.2.3 - Human Relations School). If the monitoring process is open to public scrutiny it may increase even further the commitment of the people involved with the success of the improvement. Nevertheless, this approach can produce even contrary effects on continuous improvements if the appropriate organisational support, knowledge and resources are not in place when errors occur and adjustments are required.

3.8.3.5 Linking Improvement to Priorities set by the Control

Instead of promoting continuous improvement indiscriminately throughout all areas of a production system, resources should be focused on selected problems. In this respect, the identification of the most significant causes of production problems is paramount for efficient use of the – usually scarce – resources available for continuous improvement. Fortunately, according to the Pareto principle, the majority of production problems usually lie in a small group of causes (Imai, 1997).

Hence, information gathered in production control should help the establishment of improvement priorities (refer to *item 3.6.3.1 Measuring, Finding and Eliminating Root Causes* and *item 3.8.3.4 Measuring and Monitoring Improvements*). Once visible progress has been made in those causes, improvement efforts need to be extended to other causes. This dynamic shift of focus in the improvement efforts helps reduce the risk of apathy in continuous improvement activities.

3.8.3.6 Pull Instead of Push Production Orders

In "pull production"[17] workers/managers must regard downstream workstations as their clients and make every effort to pass to them only good materials or sub-products, in the exact quantity and time required (Imai, 1986). In "pull production" there is stronger pressure on the upstream workstations to achieve higher speed and flexibility, but with fewer defects and inventory (Shadur, Rodwell & Bamber, 1995). The combination of these factors, and the direct interaction between downstream and upstream operations, contributes to drive continuous improvement in the production system.

According to Monden's (1998) definition, "pull production" happens when people of a certain process "*go to the preceding process to withdraw the necessary units, in the necessary quantities, at the necessary time*". Most importantly, the preceding process should produce only enough units to replace those that have been withdrawn, rather than relying on buffer stocks (Monden, 1998). In contrast, in production systems using a "push" mode, this client-supplier relationship often tends to be weak since there is a lack of direct contact between workers. This situation often results in poor quality, a high level of inventory and, consequently, a waste of precious resources (see *item 3.7.3.1 Reducing the Batch Size*).

Following the above definition, one of the first priorities of "pull production" is to achieve reliability of processes and, concomitantly, smooth and synchronised flows. It is fundamental that each process is able to produce each batch unit in a predictable amount of time. Therefore, standardisation of operations and adequate training of workers and managers is fundamental in implementing such an approach. Set-up operations will

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[17] Note that this approach was not among Koskela's (1992) original list of heuristic approches to implement continuous improvement.

need improvements in order to allow rapid response since there will be small or no buffer stocks. "Pull production" will also require a more intensive use of visual controls in order to enable rapid understanding of positions, and addresses. In short, the adoption of "pull production" demands a wide range of complementary heuristic approaches. Thus, the implementation of "pull production" drives improvements in various aspects of production.

3.8.4 DISCUSSION

Leadership and trust are important factors that are constantly mentioned in the continuous improvement literature. However, less is discussed about the handling of external factors that sometimes stop an individual company to persevere in continuous improvement activities. For instance, we need to improve our understanding of how to implement continuous improvement in industries where there is a low level of education among the workforce or intensive use of subcontractors.

It became clear throughout the literature that the principle of continuous improvement is the most central principle to the implementation of the flow principles. All other principles cannot be fully implemented in a production system without an adequate degree of continuous improvement. At the same time, 'continuous improvement' is totally dependent on other principles when it comes to identifying and developing solutions for production problems. Therefore, a reasonable understanding of the other principles and approaches is required in order to obtain full effectiveness of continuous improvement.

Following the flow concept, improvement activities should aim first at the process (flow of material/information) and then at the operations (flow of human/machines). However, the literature review showed a reduced number of authors mentioning this analytical criterion. Obviously, it is a social and ethical issue to invest effort in the improvement of human flows. It is also an economical and environmental issue to avoid substitution of existing machinery by improving and making better use of the existing production capacity. Nevertheless, reducing, or eliminating, process stages offers the potential benefit of moving people to more creative jobs, therefore, reducing the amount of machines involved in the process. Only when there is no other feasible process

improvement should one decide, for instance, on the introduction of new machines that generate less pollution or on the development of a training package for new workers.

3.9 CONCLUDING REMARKS

Throughout the literature review, it has been possible to verify that there are many disagreements concerning the structure and the meanings of the foundations of production management. 'Simplification', for instance, is one "approach" to reduce cycle time to Carter et al. (1995), while Koskela (1992) understands simplification as a principle *per se* and has identified a set of specific approaches to implement it. Even some of the heuristic approaches presented by Koskela (1992) himself are clearly multi-purpose and affect various principles at once. The implementation approach '*measuring, finding and eliminating the root causes of problems'*, for instance, is quite similar to '*rendering invisible attributes visible through measurements*' or '*measuring and monitoring improvements'*.

Nevertheless, Koskela (1992) has shown a higher level of abstraction and coherence than in other theoretical frameworks proposed by other authors. His abstract concepts, principles and heuristic implementation approaches, were paramount to the interpretation and categorisation of the literature reviewed in this research (Koskela, 1992; Koskela, 1999). Because of this, it is the researcher's belief that his framework is also useful as a starting point to enable communication between construction and other industries and the interpretation of practices across different countries.

Yet, some of the heuristic implementation approaches that have been proposed by Koskela (1992) still allow ambiguity and misinterpretation. The '*isolation of value adding activities from support activities*' depends on the definition of what exactly contributes to add value to the external customer. This cause-effect relationship may not always be clear when analysing production systems. What is not valued in one process may help a distant downstream process to add further value or reducing costs to the external client. '*Solving the control problems and constraints to a speedy flow'* may also not be easy to operate when it comes to analysing production systems. After all, a 'constraint' could be interpreted as anything in the production system, ranging from excessive batch size to a rigid interdependence between processes. The researcher has

limited the definition of 'constraints' to the physical characteristics of equipment, products or materials. This allows a clearer differentiation of this particular approach from other approaches.

Finally, it became clear that there are other heuristic approaches applicable at the wider organisational and supply chain level that can have direct effect on the four principles in study. The 'increase of transparency', for instance, can also be achieved by informal contacts outside of the hierarchy, the overlap of responsibilities or frequent visit of top managers to the shop floor level. In general, these heuristic approaches crossed the boundaries established for this research, i.e. approaches under the production personnel's range of decision making. Future investigation should be carried out to transform these and other approaches into more abstract definitions and, then, include these ideas in the portfolio of heuristic approaches available for production managers.

3.10 SUMMARY

In order to enable paradigm shifts it is important to understand the concepts underlying the theory and practice of production management. The literature shows that there are three core concepts underlying current theories: conversion, flow and value. The conversion concept sees production as a transformation of inputs into outputs. The flow concept, on the other hand, sees production as a set of waiting, transporting, inspecting and processing activities. The value model sees production as the transformation of the information on the customer's wishes and requirements into the final product. Each of these three models has different implications on production practices. Hence, they should be integrated in practice in order to offer the most comprehensive results.

Currently, the conversion model is dominant over production managers in construction; this is pointed in the literature as one of the fundamental reasons for the high levels of waste and sub-optimal performance of production systems in the sector. In this context, there is a need for implementing the "flow" and "value" concepts in the thinking and practice of construction. Since a doctoral study has to limit its scope, this thesis focuses on the flow model and, in particular, on the principles that aim to 'reduce the share of non-value adding activities'. These principles are: reducing cycle time, reducing variability, increasing transparency and building continuous improvement into the

process. This chapter revises each of these principles and correspondent heuristic implementation approaches and establishes the benchmark of practice that will be used to analyse construction practices.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter **4**

RESEARCH METHOD

Logic is the art of going wrong with confidence.
Joseph Wood Krutch

4.1 OVERVIEW

Chapter 3 presented the foundations of production management that will be used in this thesis as the benchmark of best practice when analysing construction practice. Firstly, it discussed, in general terms, the main features of the abstract levels of theoretical framework. Then, the chapter described the concept of conversion, flow and value along with the heuristic flow principles and correspondent implementation approaches that will be investigated against empirical evidence collected in construction.

This chapter, in turn, presents the research method and the data collection techniques adopted in this research. Initially it presents an overall view of the research design and the philosophical approach. The reasons for choosing the case study approach is then presented together with a review of its critical aspects. It proceeds with a description of the protocol adopted in the data collection and a general presentation of the six case studies developed in this research. Finally, it presents the analytical strategy adopted, including the logic that links the empirical evidence to the theoretical propositions and the criteria for interpreting the findings

4.2 OVERALL RESEARCH DESIGN

The present research uses "case study" as the main research strategy in investigating the application of heuristic principles in construction. Yin (1994) defines "case study" as an empirical investigation into contemporary phenomenon operating in a real-life context. It is particularly valuable when there is not a clear delimitation between the phenomenon and the context itself. Thus, this research strategy is suitable to test the validity of heuristic principles because it incorporates all the normal uncertain conditions faced by practitioners (Robson, 1993; Yin, 1994).

This initial section gives a general view of the research design that shapes the contents of this chapter. In short, it describes the logic used for getting from the initial research

questions to the conclusions. In order to enhance the clarity, the explanation follows through the structure illustrated in Figure 4.1.

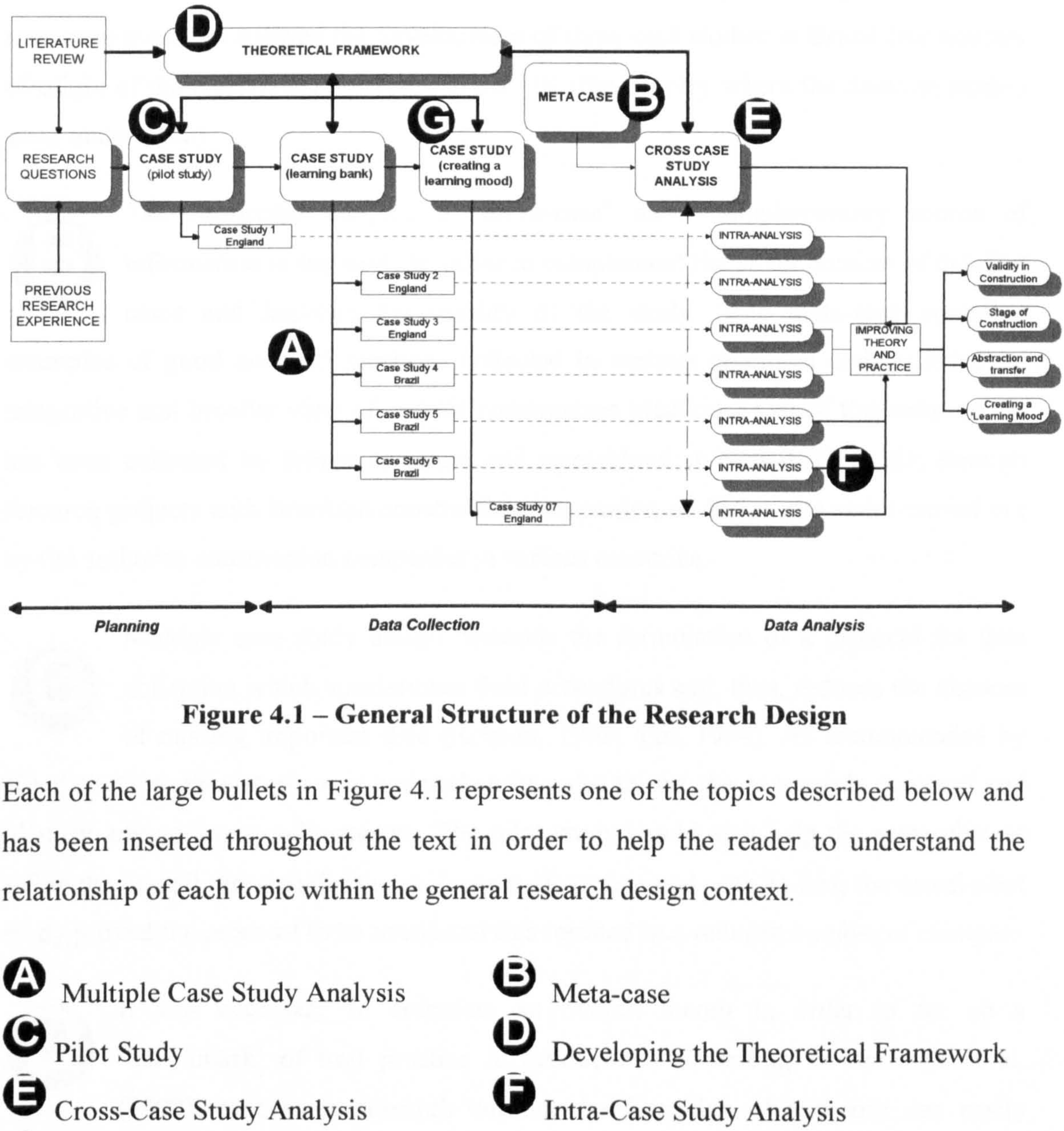


Figure 4.1 – General Structure of the Research Design

Each of the large bullets in Figure 4.1 represents one of the topics described below and has been inserted throughout the text in order to help the reader to understand the relationship of each topic within the general research design context.

- **A** Multiple Case Study Analysis
- **B** Meta-case
- **C** Pilot Study
- **D** Developing the Theoretical Framework
- **E** Cross-Case Study Analysis
- **F** Intra-Case Study Analysis
- **G** Case Study on the Creation of a "Learning Mood"

A There was an opportunity in this research to develop case studies in both Brazil and in the UK. The researcher believed that case studies in both countries could strengthen the weight of findings, particularly with respect to

international generalisation. In this respect, it was felt necessary to carry out, at least, three case studies in each country in order to enable triangulation1 of data and increase the robustness of case study findings. Furthermore, the logistical support, time and resources available allowed the development of three case studies in Brazil (the country of origin of the researcher) and three in the UK (the country where the doctoral studies were undertaken).

B The researcher adopted a "**meta-case**" as a complementary source of information in the study in order to complement the small number of detailed cases and improve the validity of the study. This meta-case compiled examples of good and bad practices collected in various countries and provided an integrative and broader view of current construction practice. Most of this information has been collected by fellow lecturers and researchers at NORIE/UFRGS2, through research projects with Brazilian construction companies, or during site visits carried out by the author to construction companies in various countries.

C Multiple case study design demands the formulation of a protocol for data collection which standardises field procedures and, thus, reduces the chances of missing important data (Robson, 1993; Yin, 1994). As recommended by Yin (1994), a **pilot study** was undertaken in order to test the case study protocol and identify any necessary adjustments. The pilot study would also help the researcher to refine the overall research design on issues such as time and cost. In fact, the actual pilot study proved the protocol to be sound and this resulted in a reduced number of changes.

D It was necessary to articulate an overall theory in order to set up a 'benchmark' of best practice in production. According to Remenyi et al. (1998), case study research without the discipline of a theory can easily degenerate into an anecdotal story. In this context, a detailed **theoretical framework** was initiated from the outset of the empirical work. The literature review supporting this

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1 Multiple-evidence (minimum two) that permit a wider and richer understanding of a particular production management principle in practice. The analysis of two perspectives on the same theoretical proposition can result in a third alternative perspective (triangle).

2 **NORIE** – Nucleo Orientado para a Inovação em Edificações is the research institute that supported this research when developing the Brazilian case studies and it is part of **UFRGS** - Universidade Federal do Rio Grande do Sul, Brazil.

theoretical framework covered the operations management field in general, with a particular focus on the construction and manufacturing management related material. The theoretical framework evolved along side the data collection since the observation of practice drove the researcher to bring it closer to the kind of problems encountered in practice.

The analysis of the six case studies was carried out in two parts: "cross-case study analysis" and "intra-case study analysis". The "cross-case study analysis" used a process called **pattern matching** where the researcher looked for direct replications of the theoretical propositions (Yin, 1994). In this process, the empirical evidence was considered to be a "literal replication" when observed results matched the theoretical predictions (e.g. a visual control that contributes to facilitate measurements). In contrast, when the case study produced contrasting results but for predictable reasons, it was called a "*theoretical replication*" (e.g. excessive measurement associated with a lack of visual controls). Information obtained through quantitative and qualitative techniques was used to substantiate the pattern matching findings. In addition, boundary searching on the typical values of key quantitative indicator contributed to the assessment of the empirical evidence.

The "intra-case study analysis" also used the process called **explanation building** that is similar to "pattern-matching". With this approach, the researcher looked for evidence that matched the theory and built an explanation of the facts. Such a context embedded approach allowed the focus on the predicted interactions among each of the heuristic 'implementation approaches' in study.

Evidence gathered from the case studies, meta-case and the theoretical framework taken together became part of what was called a "learning bank".

This "learning bank" was then used to promote the creation of a "learning mood" in one construction company. This exploratory case study used both "pull" and "push" learning strategies in a *participant observation* approach. In the "**push learning**" strategy the researcher simply applied the case study protocol and then presented a report to the company using his own perception of their needs. In contrast, the "**pull learning**" strategy allowed the company to be in charge of the learning process. As a result, data collection techniques had to be adapted to time constraints and requirements

of managers. Therefore, the researcher gave advised only on those problems that they perceived as important.

4.3 PHILOSOPHICAL BACKGROUND

This section discusses some of the main philosophical issues considered when preparing and undertaking the present research. Like every human action, research is grounded on philosophical perspectives, implicitly or explicitly. To ignore the philosophical issue, while not necessarily fatal, can seriously affect the quality of research in management science. According to Easterby-Smith et al. (1991), understanding the philosophical positioning of research is particularly useful in helping researchers clarify alternative designs and methods for a particular piece of research, and identifying which one is more likely to work in practice.

4.3.1 POSITIVIST APPROACH vs. INTERPRETATIVE APPROACH

Two distinct philosophical approaches for developing research have been the subject of a long-standing debate in science: the positivist and the interpretative (or phenomenological) approach. The **positivist approach**, often designated as quantitative research, believes that the subject under analysis should be measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition. Among the major implications of this approach is the need for independence of the observer from the subject being observed, and the need to formulate an hypothesis for subsequent verification. Positivism searches for causal explanations and fundamental laws, and generally reduces the whole into the simplest possible elements in order to facilitate analysis (Easterby-Smith et al., 1991; Remenyi, 1998).

On the other hand, the **interpretative approach**, also known as phenomenological or qualitative approach, understands reality as holistic, and socially constructed, rather than objectively determined. The interpretative approach arose largely in reaction to the application of positivism to the social sciences, in the last half of the twentieth century. According to this philosophy, the researcher should not gather facts or simply measure how often certain patterns occur, but rather appreciate the different constructions and meanings people place upon their own experiences and the reasons for these

differences. The interpretative approach tries to understand and explain a phenomenon, rather than search for external causes or fundamental laws (Easterby-Smith et al., 1991; Remenyi, 1998). Table 4.1 summarises the main features of both philosophies:

Table 4.1 - Key Features of Positivist and Interpretative Paradigm

	Positivist Paradigm	**Interpretative Paradigm**
Basic beliefs:	The world is external and objective Observer is independent	The world is socially constructed and subjective Observer is part of what is observed Science is driven by human interests
Researcher should:	Focus on facts Look for causality and fundamental laws Reduce phenomena to simplest elements Formulate hypotheses and then test them	Focus on meanings Try to understand what is happening Look at the totality of each situation Develop ideas through induction from data
Preferred methods include:	Operationalising concepts so that they can be measured Taking large samples	Using multiple methods to establish different views of phenomena Small samples investigated in depth or over time

Source: Easterby-Smith et al. (1991)

Remenyi (1998) argues that both positivism and interpretative approaches are not totally different in terms of their impact on research, and in the generalisation of findings. Both need to be replicated before any generalisation can be made. Also, both approaches need a convincing argument that the findings are valid before these finding are accepted as a valuable addition to the body of knowledge. Ultimately, it is more useful to see these two approaches as complementary to each other rather than as two opposite extremes (Remenyi, 1998).

4.3.2 THE BALANCED APPROACH ADOPTED IN THIS THESIS

Philips & Pugs (1994) advocate that the actual psychological behaviour that makes research work holistic, involving reworking, corrections, blind alleys and, above all, inspiration. Thus, the boundaries of a chosen scientific research method cannot be assumed as the exact boundary for all sources of new ideas and inspirations. Previous experiences, for example, represent a very important and complex collection of ideas that strongly affect the process and results of research in practical settings. Moreover,

according to Easterby-Smith et al. (1991), the major scientific advances are not only produced by a logical and rational application of a scientific method but from creative thinking which goes outside the boundaries of existing ideas.

In this context, the dominant philosophical approach underlying this thesis is a balance between the positivist and the interpretative approach. The implications of that may be seen in the way the author decided to study the research questions. Initially, he hypothesised that empirical evidence would be found to validate the heuristic principles. Consequently, he formulated objectives aimed at the identification of empirical evidence that matched the theoretical definitions. This led him to be able to confirm, or refute, the truth of a number of hypotheses.

However, this hypothetical-deductive method over-simplifies reality and usually strips out complicating factors that could be important to construction practitioners (Remenyi et. al., 1998). After all, following the conclusion of Remenyi et al. (1998), the world is essentially non-deterministic in any absolute sense and even repeated positivist research will always produce different results. Therefore, a pure positivist approach could not be adopted in this thesis.

On the other hand, because the researcher intended to understand the holistic content of construction site practice, an interpretative approach would help to provide the means to interpret practice. Using a pure interpretative approach the researcher could study, for instance, the various different meanings that construction managers gave to the content of the theoretical framework. The researcher could, then, arrange to talk with a large number of construction managers about their practices and about the aspects they found more, or less, important, and so on.

A purely interpretative approach was not adopted because there was an expectation at the beginning of this research that, to a certain level, other researchers should be able to apply the same research method and obtain similar results. This assumption was incompatible to the basic fundaments of the "pure" interpretative approach where establishing "different views" is one of the preferred research methods (*see* Table 4.1).

Therefore, a balanced approach seemed to be the best description of the philosophical emphasis adopted in this research. It is true that in its "pure" interpretation, the positivist

approach is epistemologically different and quite incompatible with the interpretative approach. However, as Easterby-Smith et al. (1991) states, *this apparent incompatibility is blurred and the differences are by no means so clear and distinct when it comes to actual research.*

4.3.3 DISCUSSION

It became clear throughout the literature review that production management research is still strongly affected by its Industrial Engineering origins, where the positivist "scientific research method" was first applied. Researchers in the field usually try to follow a hypothetical-deductive method, proceeding in a logical step-by-step fashion. However, the need to consider human aspects in production management research demands the inclusion of the interpretative ideas in order to obtain meaningful results that reflect the holistic reality of production systems. Furthermore, rather than contradict, the interpretative approach usually reinforces the findings of positivist methods, and vice-versa.

The adoption of a balanced philosophical approach follows the course of ideas set by the Neo-Classical School of thought, presented in Chapter 2. Indeed, the deterministic ideas of the Scientific Management School underlie many of the data collection techniques and the fundamental thinking guiding some aspects of this research. At the same time, many of the Human Relations School ideas also underlie the choice of other non-deterministic data collection techniques and the strong emphasis on the holistic interpretation of production practices.

4.4 ACTUAL RESEARCH STRATEGY ADOPTED

Research studies in production management have been criticised by their anecdotal research approach when interpreting real world phenomena. In this sense, Minor, Hensley & Wood (1994:19) argued that the clear definition of a research strategy is a fundamental and necessary requirement for a sound empirical study in such a field.

4.4.1 CASE STUDY RESEARCH STRATEGY

Production management has reached a stage of theoretical maturity that demands the validation of its heuristic principles within different "real world" situations in order to refine and integrate them. "Real world" conditions imply little or no control over the events surrounding observed practices. In particular, the principles under study needed to be assessed in the construction site environment where there are still many disagreements regarding heir applicability. There was a strong need to understand how the heuristic approaches support each other in order to enable the achievement of optimum results. In this context, Table 4.2 shows that "**case study**" is the research strategy that matches better with these characteristics.

Table 4.2 - Research Methods vs. Research Characteristics

METHOD	RESEARCH QUESTION	CONTROL OVER EVENTS?	FOCUS ON CURRENT EVENTS?
Experiment	How? Why?	Yes	Yes
Survey	Who? How many? What? How much? Where?	No	Yes
Case study	How? Why?	No	Yes
History	How? Why?	No	No
Archival analysis	Who? How many? What How much? Where?	No	Yes/no

Source: Cosmos corporation apud Yin (1994)

Most of what has been written about case study comes from other fields of knowledge rather than from the study of production management or construction management. Thus, definitions in the literature very often reflect only the types of topics to which case studies have been applied in these fields. Psychologists think of individuals in treatment, anthropologist of events in societies and political scientists of policies (Platt, 1998). In the management field, Remenyi et al. (1998) defines case study as a detailed investigation of the context and processes that affect a phenomenon within organisations.

The most widely accepted definition is given by Yin (1994:13) who defines case study as *"an empirical inquiry that investigates a contemporary phenomenon within its real-life context and where the boundaries between phenomenon and context are not clearly evident*". This definition is highly pertinent since the present research is a "testing-out" research. In this type of research data collection has to be carried out in "real world" conditions where the kind of control present in a laboratory is not feasible and not even ethically justifiable (Phillips & Pugh, 1994; Yin, 1994; Remenyi et al., 1998)

4.4.2 DEFINING THE NUMBER OF CASES

It was anticipated that a single case study would not supply enough evidence to validate all principles and correspondent heuristic 'implementation approaches' under study. In this context, a **multiple case study** design appeared to be the most appropriate configuration for this research because it increased the degree of certainty and judgmental accuracy about replications. According to Remenyi et al. (1998) evidence from multiple-case studies is more compelling and the results are, thus, more robust.

There was an opportunity to carry out case studies in Brazil and in the UK. It was believed that it would be helpful in understanding the degree of international generalisation of findings. In Brazil there was the logistical support of NORIE and a large number of companies willing to expose their construction site for analysis. The University of Salford also already had many links with the construction industry through its research projects and postgraduate programs. It was felt that three case studies were necessary in each country in order to enable the triangulation of data and increase the robustness of findings. In this context, the researcher was indeed able to carry three case studies in Brazil (Porto Alegre and Sao Paulo) and three in the UK (Bradford, Wigan and Salford).

The researcher still expected to find difficulties in identifying enough evidence to validate all heuristic principles in the study, even by using empirical evidence from six construction case studies. Thus, a **meta-case** compiles complementary sources of information in order to fill the possible gaps of the data collection. This meta-case constitutes of non-structured portfolio of examples concerning good and bad practice found in other construction companies during visits to sites around the world.

Researchers and students at NORIE/UFRGS also found many of these examples during research projects with Brazilian companies.

A further case study (Case Study 7) focused on the learning aspects of the theory. In part of this case study the researcher himself had a certain level of active participation in the development of solutions ("*participant observation*"). It was also an unusual opportunity for the researcher to gain insight into this area since the researcher would not be merely a passive observer. The rationale of this learning case study was to obtain insights with respect to strategies for introducing the heuristics back into practice.

4.4.3 CRITICAL ASPECTS OF CASE STUDY RESEARCH

Traditionally, case study has been viewed by some as a less desirable form of empirical research strategy, due to the possibility of bias on the part of the observer. Indeed, without careful protocols it is easy to see how different interpretations can fit the empirical evidence collected in a case study. Quite often this bias reflects in the use of equivocal evidence or, in other words, evidence that could have a contrary interpretation by another person (Yin, 1994; Remenyi, 1998; Platt, 1998).

However, as Remenyi et al. (1998) and Yin (1994) argue, bias can similarly affect the conduct of any research strategy. Furthermore, Yin (1994) asserts that the perspective of reality from the viewpoint of someone "inside" a case study is invaluable in producing an accurate portrayal of a real phenomenon. Thus, the practical validity of a case study resides in the fact that it operates within a "real world" context that gives findings a higher sense of openness to public scrutiny.

Nevertheless, the case study research strategy is still seen as "soft" research by many researchers and generally considered as time-consuming, too expensive and likely to generate excessive documentation. These arguments do not consider the fact that a case study has more flexibility in relation to other research strategies when studying "real world" events. In experimental designs, for instance, any failure to carry out the pre-specified research design has serious implications and, often, is fatal in terms of interpretations. In the same way, a survey calls for considerable and detailed pre-planning before one starts data collection which, in turn, may face unexpected

impediments when applied in "real world" conditions (Robson, 1993; Remenyi et al., 1998).

In the context of this research, perhaps the most critical aspect of a case study approach is the fact that it provides a limited basis for the traditional "scientific generalisation" (Yin, 1994; Remenyi et al., 1998). Notwithstanding, like all experimental observations, case studies results can be generalised to theoretical propositions (analytical generalisation) but not to populations or universes (statistical generalisation). Thus, the aim of case studies cannot be to infer global findings from a sample to a population, but rather to understand and articulate patterns and linkages of theoretical importance (Remenyi et al., 1998). Statistical validity in the chosen topic of research is particularly interesting for those researchers searching for hard and definitive evidence for the correlation between the heuristic principles and process performance.

Additionally, it is important to emphasise that case studies deal with unique situations and, because of that, it is not possible to elaborate detailed and direct comparisons of data. However, results and conclusions are comparable in a general sense. Comparison of case studies can also lead to the formulation of theoretical conjectures or, in some circumstances, the confirmation of working hypotheses or to suggest empirical generalisations (Remenyi et al., 1998). Such comparisons may also more accurately suggest new areas of investigation for quantitative research (Platt, 1998).

A very important advantage of the case material lies in the richness of its detailed understanding of reality. This means it can work as an effective mnemonic device. Indeed, good case study material can be compelling in the way the narrative feels real to the reader and, thus, gives aesthetic appeal that attracts "human interest". The real-life story contained in a case study seems to be a more humanistic mode of presentation than other traditional research strategies. In particular, the peculiar rhetorical style of case study material is useful when exposing research findings to audiences without scientific background. This rhetorical strength also makes it important that such material be used carefully in ways which support, rather than override, the logical grounds for the conclusions reached (Platt, 1998)

4.4.4 DISCUSSION

An interesting method, which was originally thought to be suitable for this research, was the "*heuristic research method*". According to Moustakas (1990:38), whilst in the traditional empirical investigation there is a search for cause-effect relationships, in the heuristic research the scientist seeks to discover the nature and the meaning of the phenomenon itself. In this method the researcher would need to use depiction from real situations, events, conversations, records, papers and so on, to derive, develop and consolidate further the heuristic principles in study. Eventually, this approach was not embraced because of its excessive emphasis on the interpretative philosophical approach.

Another approach explored, but not adopted in this research, due to its excessive emphasis on interpretative philosophical approach is "*history analysis*". According to Yin (1994) "*history analysis*" as a research method is used in situations where there is no access or control over events, and where the research deals with the historical past. History analysis can bring insights into the evolution of heuristic principles throughout time where they have failed or succeeded in practice.

Finally, reflections have been made at the beginning of this research regarding the value of checking the validity of heuristic principles in construction practice. After all, current concepts and heuristic principles have mostly been generated from observation of actual practice in production systems all over the world. However, not all of the heuristic principles have been produced or validated within the construction environment. Therefore, the contribution of the present research to knowledge will come from the validation and interpretation of many of these heuristics principles for the construction context (Phillips & Pugh, 1994:49/50).

4.5 PROTOCOL FOR DATA COLLECTION

4.5.1 OVERVIEW

Multiple case study design demands the formulation of a protocol for data collection that reduces the chances of missing important data and, thus, facilitates subsequent

analysis (Robson, 1993; Yin, 1994). In the present research, the developed protocol followed the structure illustrated in Figure 4.2.

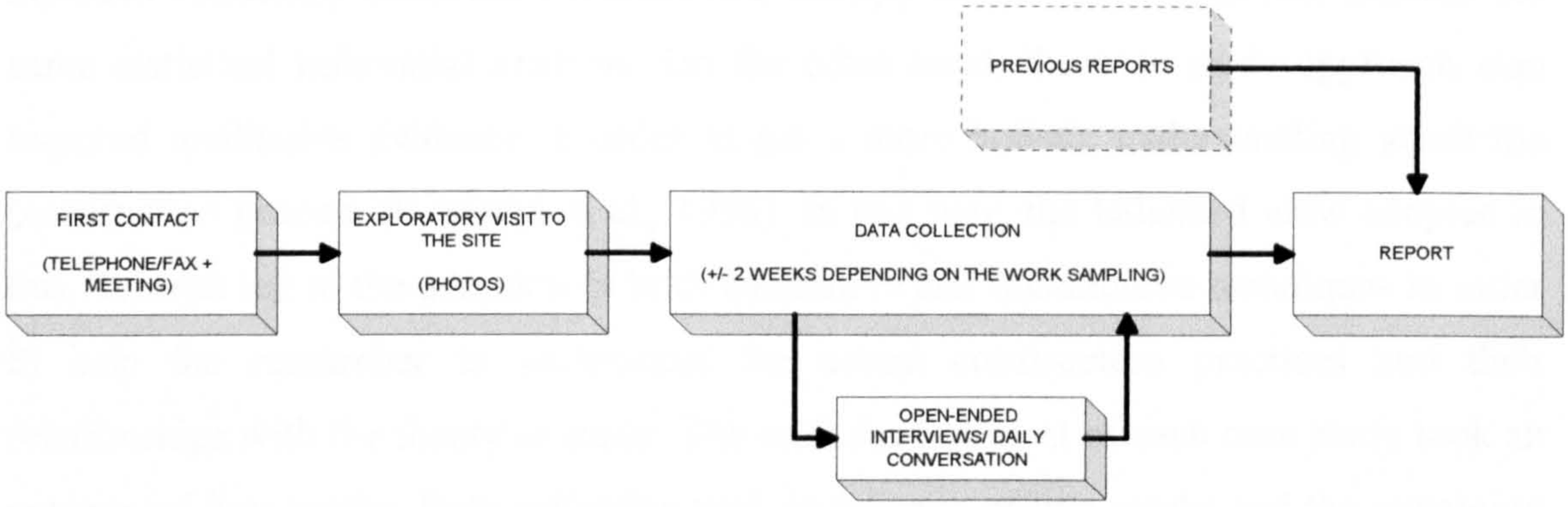


Figure 4.2 - Protocol for Data Collection

The first stage of the protocol was the establishment of first contact with a company interested in getting involved with production system analysis. The second step consisted of an exploratory visit where the researcher would investigate the conditions of the site and sketch a plan for data collection. The third step was the data collection itself and involved the use of a standard "tool-box" with various techniques for a brief analysis of a production process. Open-ended interviews were carried out throughout the project and formal meetings at the end of the data collection exposed the researcher's findings to debate and practitioner's validation. Reports were then compiled to group the main empirical evidence and the main findings at the end of each case study. These reports incorporated comparisons with the findings from other case studies.

This standard protocol restricted data collection to the physical limits of the construction process itself (bricklaying) and to those actions that were under the direct responsibility of people on site. Many different data collection techniques were adapted in case study research to ensure robustness of observation and analysis. Indeed, Remenyi et al. (1998) considers the use of multiple sources of evidence one of the principles of good practice in this type of research. Multiple sources of evidence can substantially help to improve validity and reliability in this type of research because it enables the assessment of the same phenomenon from different perspectives. Moreover, the evidence can then be triangulated to give an even greater degree of validity and reliability (Remenyi et al., 1998).

As mentioned earlier, the detailed observational approach was to be balanced between the positivism and interpretative philosophical approach. The positivist approach included collecting numerical evidence and the application techniques that allowed the same statistical inferential analysis. On the other hand, the case study approach also required qualitative evidence in order to get a more holistic understanding about the construction process (Remenyi et al., 1998). In this way, the balanced view adopted in this research led to the adoption of both qualitative and quantitative techniques in order to help the researcher to understand the actual construction practices and their relationships with the theory in study. The total development of each case study took an average of four weeks. Data collection took an average of two weeks and the remaining time was dedicated to establishing contacts, meetings or writing up the case study report. The next sections describe in detail each of these stages.

4.5.2 FIRST CONTACT

Other academic researchers acted as intermediaries for the majority of 'first contacts' with the host companies. Only on one occasion did the researcher make a direct contact with a company that had no involvement with academic research. Fax or telephone was the media usually applied adopted for the first contact. The researcher presented an overview of the research project at this opportunity. All case studies participants received a folder containing information on the researcher's background, the research description and objectives, schedule and expected outcomes for academia and industry (see Appendix 1).

The emphasis of this first contact was on the short and medium-term benefits for the company. The researcher also emphasised the cost-free character of the research and the international dimension of the analysis. Once the company showed interest in the research then the researcher explained the protocol for data collection.

4.5.3 DATA COLLECTION

4.5.3.1 MAIN QUESTIONS DURING DATA COLLECTION

One of the first aims of the data collection was to understand the dynamics of the actual practice on site. In order to understand this, the researcher had to get familiar with the

daily routine of the site, the bricklayers and labourers, the bricklaying technology and the process flow. This familiarisation occurred, in general, during a two-week period with the application of the data collection techniques described in the next section. The purpose was to get a realistic and accurate picture of the current bricklaying practice in the construction site regarding the four heuristic principles investigated in this research.

The observations tried to identify all bricklaying practices that matched the four heuristic principles to be investigated in this thesis. It is worth reminding that these principles were based on the flow concept and their primary aim is to "reduce the proportion of non-value adding activities". In other words, these principles searched for reduction or elimination of all activities related to transport, waiting or inspection of the bricklaying process. In this context, one of the researcher's first concerns when initiating the data collection on a construction site was a clear identification of the main-value adding activities.

⇨ **QUESTION 1:** *Is this practice a value-adding activity?*

In the case of bricklaying, the main value adding activities included all those directly connected with the building of a brickwall. Thus, activities such as putting mortar on the course, putting brick on the course, fixing a window frame on a brickwall were classified as value adding activities. In this way, any other practice not directly connected with the rising of the wall was classified as a non-value adding activity. Excessive transportation, for instance, was among the most common non-value adding activities.

The questions then turned to the link between the observed practices and the four heuristic principles described in Chapter 3. In this context, the great difficulty was not in confirming the match between practice and theory but identifying areas where the theory should have been applied and was not. Thus, for each question focusing on the match between practice and theory, there was another counter-question on the existence of any negative effects relating to the lack of the theory in practice. When the observed practice was directly or indirectly related to one of the heuristic principles, the next task was to classify it according to one of the heuristic implementation approaches. The following question is related to the principle "reduction of cycle time":

⇨ **QUESTION 2:** *Is this practice reducing the period for a particular piece of material to reach the main value adding activity?*

⇨ **Counter Question:** *Is this practice contributing to increase the period for a particular piece of material to reach the main value adding activity?*

The two questions above were repeated for every single practice detected during the entire observational period in each case study. The approaches described in the theoretical framework acted as the main categories when classifying empirical evidence which related, or not, to a reduction of cycle time. Next is the question related to "reduction of variability":

⇨ **QUESTION 3:** *Is this practice contributing to the identification and elimination of the root causes of process deviation from target value and tolerance limits?*

⇨ **Counter Question:** *Are there any unattended source of variability related to this practice?*

The presence of practices aimed at reducing variability in practice was usually visible in the first two or three days of observation. Like the previous principle, the categories used to classify practices relating to a reduction of variability have been extracted from the theoretical framework (standardisation; poka-yoke; systematic measurement, identification and elimination of the sources of variations). Next is the question related to the principle "increase of transparency":

⇨ **QUESTION 4:** *Is this practice communicating useful information to anyone that requests or needs it?*

⇨ **Counter Question:** *Can I know all the information I want to know about this process stage without having to ask somebody else? Is there anything that the process should tell me but is not?*

Most of the diagnosis on transparency occurred in the first two days of observations. Here again, every practice relating to the principle of transparency was categorised accordingly to the approaches described in the theoretical framework. Next question relates to continuous improvement:

⇨ **QUESTION 5:** *Is this practice resulting on ongoing incremental actions aimed at reduce waste?*

⇨ **Counter Question:** *Is the sources of waste in this process stage the focus of any systematic activity within the site organisation?*

The answer for the questions above depended on daily observation in order to build an accurate understanding of the actions taking place within the construction site. Naturally, all observations were simultaneously compared with the practices observed in other sites for the same process stage. This comparison was important, in particular, to alert the researcher to the range of alternatives available when applying the principles in the construction practice. In this respect, another key question was:

⇨ **QUESTION 6:** *How this practice compares with benchmark practices found in other sites and other industries regarding the heuristic principles in study?*

Finally, in order to certify the correctness of the researcher's conclusions it was necessary to understand what the workers felt and knew about the observed practices. Thus, the same questions presented above were put to the workers through daily conversations and open-ended interviews. Obviously, these questions had to be communicated through different routes of questioning since the workers often used different terms to explain the same principles. The researcher made intensive use of photographs and videos from other sites in order to explain the practical implications of some of these questions. Next section describes the techniques that guided the observations through the site.

4.5.3.2 A TYPICAL DATA COLLECTION PROCEDURE

The data collection always started with a 'first visit' or 'exploratory visit' that usually lasted about four hours. It also always started with a meeting with the site manager in order to supply more details of the research schedule and objectives as well as gather information on the construction plans and flows. There was invariably some more casual conversation about the construction site problems and strength. Getting the site manager's support for the research was vital for securing free access to all information available and in order to establish a data collection plan which was coherent with the construction flow. Soon after this meeting the researcher would start the data collection.

On his 'first visit' to a construction site, the researcher applied four observational techniques in order to enable a more detailed planning of the subsequent daily data collection, as illustrated in Figure 4.3. It is worth emphasising that in order to avoid interruptions in the normal workflow in the host company, the researcher chose a combination of low-obtrusive techniques for the entire data collection.

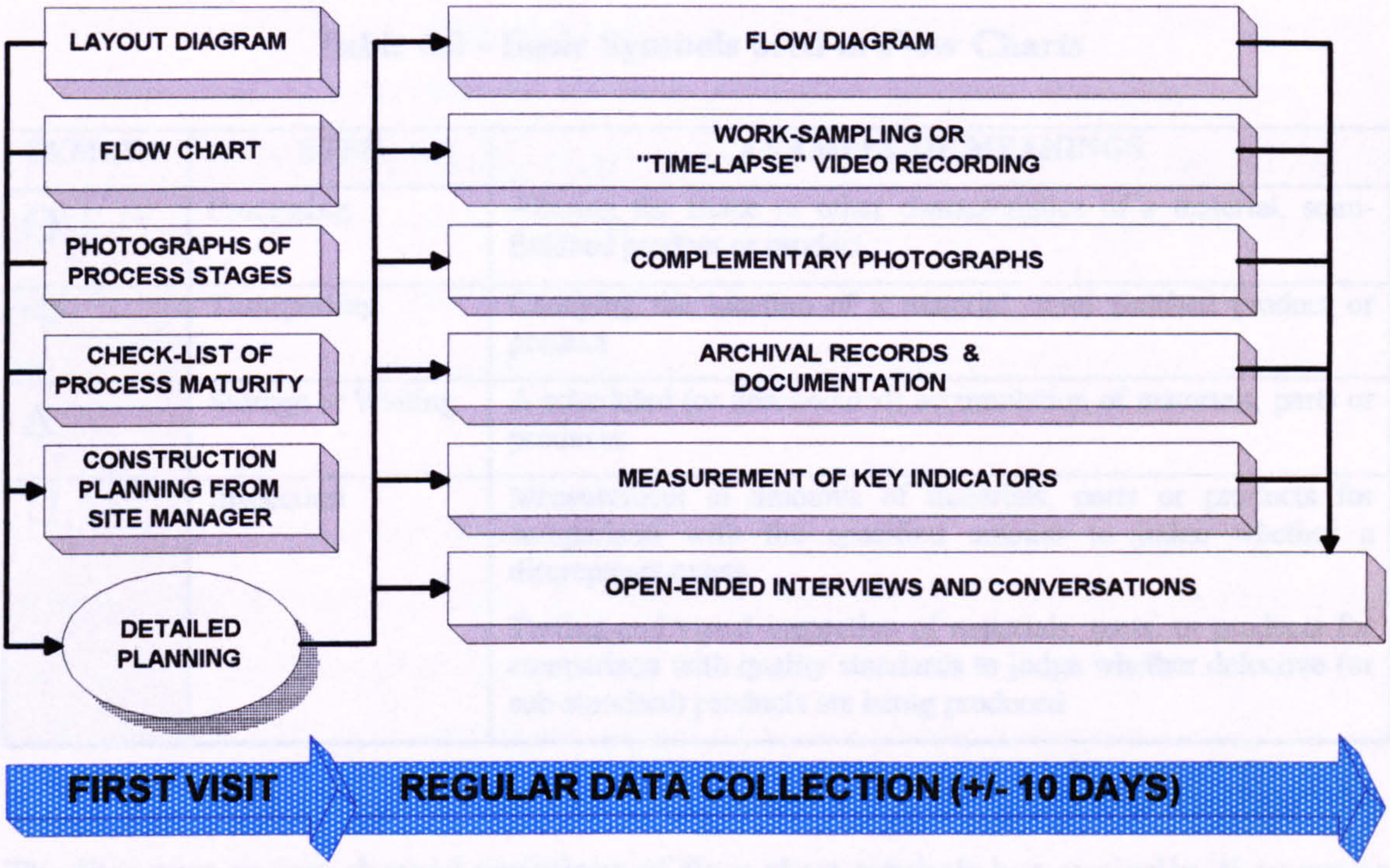


Figure 4.3 – General View of the Data Collection Procedure

The first data collection technique that was applied in every case study was the **flow chart** in order to determine the process profile (see Appendix 2) Flow charts are the analytical tool most commonly used in Industrial Engineering. In general, the aim of flow charts is to discover where waste, inconsistency and irrationality exist in production systems (Ishiwata, 1984). More specifically, the purpose of the flow chart is to check for problems such as delays, and unnecessary transportation trips and distances (Ishiwata, 1984). This technique was extremely helpful in the present research to aid understanding and analyse systematically the flow of *processes* (materials and information) and *operations* (workers and machines). Often, the researcher sketched flow charts while walking through the site in order to plan the application of other data collection techniques.

The flow charts adopted used standardised symbols to describe the various steps of process and operations. The objective of using standard symbols is to make easier communication with production personnel and with other researchers (Barnes, 1980). The symbols used in this research correspond to the basic flow components, as Table 4.3 explains.

Table 4.3 - Basic Symbols used in Flow Charts

SYMBOL	STEP	EXAMPLE OF MEANINGS
O	Processing	Altering the shape or other characteristics of a material, semi-finished product or product
⇨	Transporting	Changing the location of a material, semi finished product or product
Δ	Storage or Waiting	A scheduled (or unscheduled) accumulation of materials, parts or products;
□	Inspection	Measurement of amounts of materials, parts or products for comparison with the specified amount to judge whether a discrepancy exists Testing and visual inspection of materials, parts, or products for comparison with quality standards to judge whether defective (or sub-standard) products are being produced

The literature review showed variations of flow chart symbols but, typically, they are an interpretation of the four symbols presented above. The final drawing of a flow chart usually included information on distances, time and corresponding descriptions for each single component. The same symbols were also used to draw up **layout diagrams**. These diagrams represented, in two dimensions, the position of storage in relation to the whole building as well as the pathways of man and machines as they moved throughout the site. Sometimes the researcher would draw lines over these diagrams representing the various flows in order to assess the efficiency of the layout. These "flow lines" were also useful in identifying the actual workstation flow and, in this way, enable clarification on the root causes for excessive work-in-progress.

Photographs and **video recording** were the instruments used to collect the images of practice during the entire data collection period. Both techniques offered speed and flexibility during data collection and, later, proved to be exceptionally useful in communicating findings to industry and academia. Video recording took the place of several observers because it captured all concurrent activities, confirming the

descriptions found in the literature. In order to be effective, video recording demanded careful preparation of all workers and managers before collecting data. This preparation aimed to make it clear that the film would be used only to develop general principles and would not be used against the workers. The objective was to get the workers to behave normally (Barnes, 1980; Elding, 1990).

In order to determine the stage of the site regarding normal practices in the sector, the researcher used a **checklist of process maturity** obtained in co-operation with researchers at NORIE/UFRGS, Brazil. This check-list contains the current 'good practices' of typical Brazilian building sites regarding safety, transport and facilities (see Appendix 3). The researcher assessed the Brazilian and English case studies using the percentage of pertinent items of this check list that were present on the construction site.

With the initial photographs, video, flow chart, layout diagram and information regarding the construction flow, the researcher was able to establish a more detailed plan to apply the other techniques devised to understand the actual construction flow on each site. The first item on the list of priorities for planning was the worksheet for applying the **work sampling** technique (see Appendix 4). The reason for adopting work sampling was that it offered many advantages to other techniques of time measurement, mainly with respect to cost and flexibility. This advantage lies in the fact that this technique is based upon the laws of probability. The logic is that a sample taken at random from a large group tends to have the same pattern of distribution, as a larger group or universe (Barnes, 1980). Therefore, by using sample logic it became cheaper and easier to carry out time studies and understand how bricklayers distributed their activities throughout the day.

The assumption underlying work sampling is that the distribution of the activities during the period of the study will follow a Normal Distribution Curve. Because of that, the observation needs to be carried out only on typical working days, i.e. avoiding special periods such as bank holidays. The number of work-sampling observations necessary was determined using the formula below. This formula is valid for a 68% confidence level and corresponds to one standard deviation (σ) (Barnes, 1980):

$$Sp = \sqrt{p * (1-p)/N} \qquad (x)$$

Where:

S = relative error
N = number of observations required
p = percentage of the activity under analysis (e.g. manual transport)

The balance between the need for rigour and the constraints of time available for data collection led to the definition of 68% as the statistical confidence level. Higher levels of statistical confidence would demand a different work sampling formula and, most certainly, a excessive number observations for the purposes of this research. However, statistical generalisations are not part of the objectives of this research.

The protocol also admitted a maximum relative error (S) of 10%. Entering these values in the formula 'x' above, where "p" is the percentage of unproductive time, it was possible to estimate the number of random observations necessary (N) to complete the data collection (Barnes, 1980). After the exploratory visit the researcher was able to estimate the first value of "p" and from that point on "N" was calculated regularly in order to avoid excessive data collection {For example: p= 0,30 (30%), S=0,05 (5%), entering these values in the formula result in N= 933 observations}.

Time-lapse video recording was used as an alternative technique for those situations where it was not possible to apply the work-sampling technique. Using this special type of video-recording the researcher was able to increase the lapse of time between each frame (most modern video-recorders already have 'built in' an electronic device that enables the use of 'time-lapse'). Thus, when the 'time-lapse' videotape was projected in real time the researcher was able to see an entire day of work in just fifteen minutes. Time lapse has been used only on two sites due the high level of repetition of design details and to the high concentration of bricklayers in a small area, respectively. On both sites, the actual process followed the same pattern of flows during the entire observational period.

The protocol established the need for key **measures of performance** of the bricklaying process. The measurements adopted were restricted to the productivity of bricklayers alone, their waste of materials and turnover of storage. The measurement of these

indicators was carried out in every single visit to the site in order to understand the pattern of variability. Such measurements depended heavily on the co-operation of site managers and foremen in order to obtain accurate information, such as the presence of workers in previous days and turnover of material.

In order to increase the accuracy of the pattern-matching process, the researcher defined a number of **key indicators** to enable the translation of some key qualitative aspects of the process observed into quantitative measures. Chapter 5 gives further details regarding the description of each indicator, the reasons for their choice and the procedure for obtaining them. Searching for the typical behaviour and limits of these indicators helped to benchmark the position of each case study in relation to the theory itself and in relation to the universe of empirical evidence available from other case studies.

Archival records helped to corroborate the indicators and were often used to substantiate other observations of practice. The most common archival records investigated in this research were the frequency of personnel, orders of material and delivery receipts. Yin (1994) alerts that one of the difficulties of working with such evidence is the need to obtain a satisfactory certainty about its accuracy. Indeed, it was necessary to make constant double checks in order to confirm the exactness of these data.

The search for additional **documentation** was another important source of evidence. One of the most important uses of documents was to corroborate, verify and even produce inference from other sources of evidence (Yin, 1994; Remenyi et al., 1998). The most useful document for understanding the (intended) construction process was the written standards. Other documents of relevance included, for instance, letters, memoranda, manuals, proposals and supplier's description of technology.

When it was necessary to know more about the facts, opinions about the practices of those observed on site, feedback on initial findings, and personal insights, the researcher used **open-ended interviews** as a complementary source of information (Robson, 1993; Yin, 1994; Remenyi et al., 1998). In general, these interviews assumed a conversational manner. They were not recorded in order to avoid any discomfort to workers due to the presence of the tape-recorder, as recommended by Yin (1994). The question framework

used in these open-ended interviews is the same as the one presented in the previous section.

A typical procedure of data collection is exemplified below for the case of "reduction of work-in-progress":

> *In order to identify if there was a consistent attempt to reduce the amount of 'work-in-progress' on site the researcher needed, firstly, to draw a "flow chart" in order to understand the amount of operations involved in each production unit. A "layout diagram" then identified the position of all bricklaying workstations and all workplaces where bricklaying activities have been initiated. The researcher then took "photographs" of all workplaces and workstations and video-recorded some of the most regular movements of material, equipment and personnel across the process. In order to help to improve the understanding regarding the root causes of delays between process stages, the researcher then applied the "work-sampling technique" or, in some cases, the "time-lapse video-recording". In order to enable a comparison of the practice observed in one site with the observations in other sites two key indicators were defined: "number of visits to complete all operations" and "average time between visits". Finally, an "open-ended interview" would confirm or refute the researcher's perception of the practice observed on the site. In this open-ended interview the researcher would also investigate how much the workers knew about what they were doing and what they felt about it.*

4.5.4 REPORTING

Each company received a report containing the main findings of the site observations and a summary of data collected on site. The findings presented in this report included the results of daily discussions and conversations with the workforce, foremen and site managers. Their contribution was acknowledged although specific names were avoided throughout the text, following an agreement regarding the maintenance of anonymity. These case study reports also summarised and compared data of other case studies since all involved the analysis of the same construction process (bricklaying).

Most of the companies presented a verbal feedback in which they normally expressed their impressions about the practical validity of the researcher's findings. This 'checking-back' with those under observation was a critical substantiation of the case data set. Their feedback was always incorporated into the final case reports to ensure authenticity and helped to focus and guide the literature review and re-direct the analysis. The accumulation of case material focusing on the same construction process progressively strengthened the quality and depth of the reports

4.5.5 DISCUSSION

The conflict between the pure positivist and interpretative philosophical approach was constantly present during the development and application of the adopted research protocol. The pure "positivist" view demanded the development of a protocol that could lead to the exact same results if applied by another person in another place. On the other hand, the interpretative approach accepted that exact replications of a protocol were almost impossible when exploring "real world" conditions and there will always be some room for personal interpretations of data.

The protocol adopted in this thesis was, therefore, a balance between these two approaches since it was set to be as structured as possible but still relied heavily on the researcher's correct interpretation of practice and theory. Thus, there is no absolute guarantee that another researcher will end up with the same findings. However, precautions have been adopted to reduce these variations, such as the establishment of quantitative indicators and the use of real examples throughout the text in order to calibrate the analysis of practice.

It is worth stressing that the exclusion of the external context in the data collection is motive for controversy in the literature. Critics argue that context excluded research may override the importance of external variables when describing a phenomenon and that it may affect the validity and transfer of findings to other settings (Barrett, 1997). Wider issues regarding the full implementation of the heuristic principles in practice would certainly involve a more complex study of the social and cultural issues that affect the entire production system as well as its surrounding environment. However, the exclusion of strictly external context is coherent with the emphasis of this research

on the validation of heuristic principles at the very operational level where the correlation with macro issues is less visible.

4.6 SELECTING CRITERIA FOR THE CASE STUDIES

The criteria to select the cases was a matter of discretion and judgement, convenience, access and geographic proximity (Yin, 1994). For the purposes of this thesis, an important criterion was the **presence of the bricklaying activity** on the construction site. The emphasis on abstract principles made it unnecessary to consider in the selection criteria organisational characteristics such as the company size or type of client.

Because the research was to be based in England it was natural to chose companies from this country as key case studies. Additionally, since the researcher had easy access to Brazilian companies, this was seen as an opportunity to increase the scope of analysis for comparison on an international scale. The globalisation and the resulting pressures to understand how to enable international learning presented in Chapter 1, are the main justifications for developing case studies in these two different countries. Voss (1995) reinforced this idea by saying that there is an urgent need to increase the scope of field studies, not confining them to one single country or region.

It is important to acknowledge that some of the case studies were obtained through a network of previous and evolving contacts within the industry and academia in both countries, as advocated by many authors (Easterby-Smith, 1991; Miles, 1994). It is also worth noting that among the common criticisms of most cross-national studies is the use of convenient samples in the choice of nations Cheng (1994). It is true that logistical limitations contributed to the choice of Brazil and England. However, the social, cultural, technical and economical differences between these two countries offered an excellent background in gaining insights into international generalisation and international transfer of know-how.

The **level of practice** on site was another important criteria for choosing the host companies. The researcher intended to compare the "best practices" of the "best companies" to ensure fair comparisons. Information in magazines, quality awards and,

above all, the opinion of practitioners and academics working in industry were the main criteria in substantiating this choice. Additionally, in order to get a real picture of what is really practised in industry it was also necessary to select companies with lower profile in production practices. Table 4.4 shows the result of this selection using these criteria:

Table 4.4 – Distribution of Case Studies According to the Expected Level of Production Practices

EXPECTED LEVEL OF PRACTICE	ENGLAND	BRAZIL
Good Reputation in Production	Case Study 01	Case Study 06
	Case Study 02	Case Study 04
Typical Production Practice	Case Study 03	Case Study 05

Following the same criteria of the six case studies presented above, the company for developing the learning exercise (Case Study 7) had to have the bricklaying activity on one of its construction sites. The idea was to be able to use the "learning bank" of good and bad bricklaying practices compiled in the previous six case studies as a change instrument. The actual host company for this learning exercise had various construction sites throughout England with the bricklaying activity under operation in most sites. Foremost, this company was participating in an Action Learning project with Salford University that made it easier to use a *participant observation* approach. It must be said that their willingness to get involved in action was also among the main criteria for adopting this case study.

4.7 PRESENTATION OF CASE STUDIES

4.7.1 GENERAL VIEW

Three case studies have been conducted in Brazil and three in England, as illustrated in Figure 4.4. Along with the reasons presented in the previous sections, the conduction of equal number of case studies in both countries contributed to reducing the bias during

the analytical process. Following the selection criteria, the company size and the typology of the buildings varied as did the technology and the number of professionals used on site.

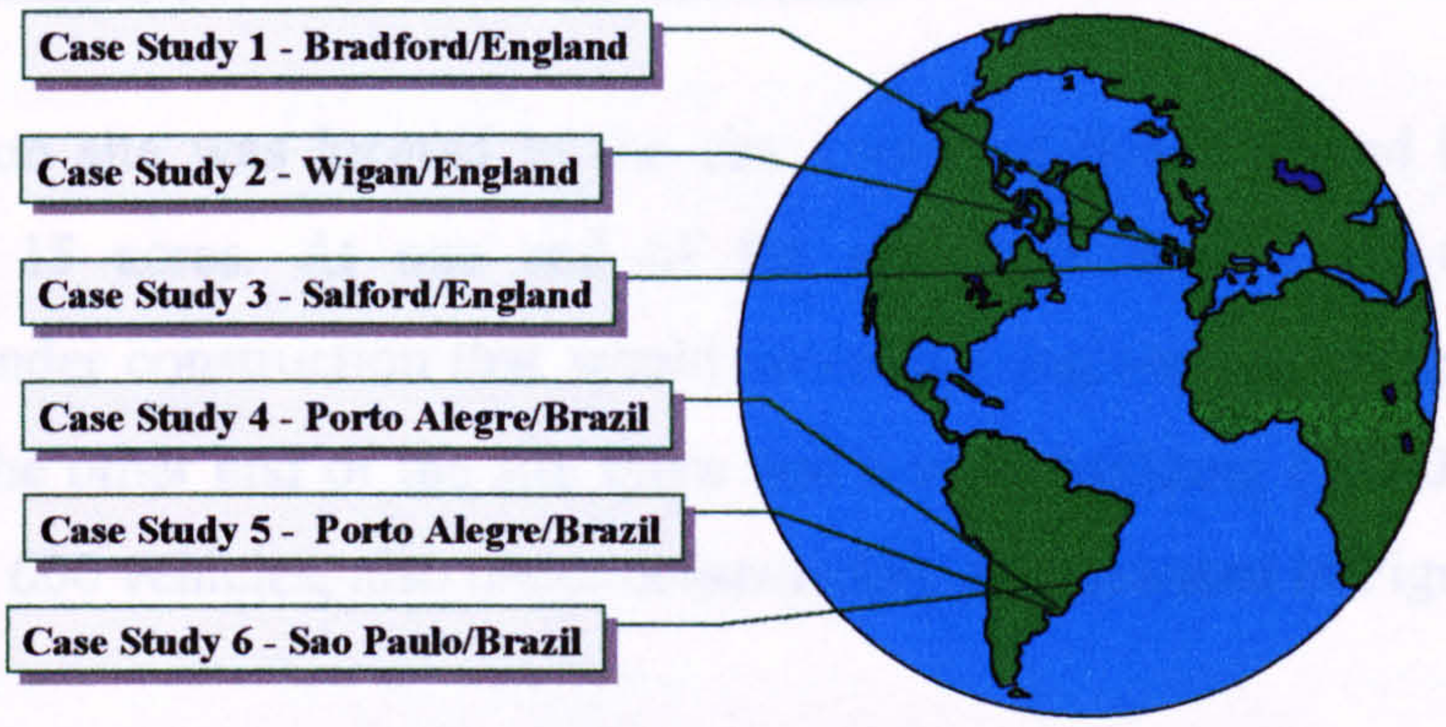


Figure 4.4 – Location of the Case Studies

The researcher had assured the host companies that total anonymity would be maintained. This assurance fostered free expression of managers and easier access to their construction sites. Obviously, the firms involved can easily identify themselves through the photos and descriptions placed in the next chapters. However, it will be difficult for others to do the same. The following sections describe the main features of the six case studies. Chapters 5 and 6 describe and analyse in detail their practices. Chapter 7 presents the case study on the creation of a "learning mood" (Case Study 7).

4.7.2 CASE STUDY 1 (PILOT STUDY) - Bradford, England

This case study was carried out between May and June 1996. The author's former supervisor made the first contact with the host company through one of his final year students who was working in the company at that time. In the first meeting with the project manager, the researcher explained the research objectives, the potential benefits for the company and the corresponding research schedule. This case study was originally planned to be a pilot study for testing and refining the data collection protocol. However, because only a few changes have been necessary to the data protocol, this pilot study was later considered as being one of the standard case studies.

The host construction company was large (> 500 employees) and had offices all over England. The company won the contract for the site under observation after winning a

bid based on the lowest price for construction. Communication with client, design management, subcontractors and supply management was the responsibility of a project manager. However, an experienced construction manager was also responsible for the actual daily management of all construction works.

The construction site was located in the city centre of Bradford and had an area of approximately 15 acres. At one end of the site there was a 103.000-sq.ft-office development under construction that would serve as a regional office for another large company. At the other end of the site there was a retail building (105.000-sq.ft) and a car parking for 600 vehicles, also under construction, as illustrated in Figure 4.5:



Figure 4.5 – View of Case Study 1

The data collection on this site concentrated on the bricklaying operating in the retail building. At the start of the data collection most of the steel structure was practically completed and painting had just been commenced. The roof fixation was around one quarter of the total roof area. External walls, DPC and the slab had just started construction. Externally, there were many simultaneous activities being carried out such as drainage, roads and the foundations for the car park.

4.7.3 CASE STUDY 2: Wigan, England

This case study was carried out between October and November 1996. One of the lecturers at the University of Salford arranged the first contact with the host company. The first meeting with the company's representatives, at one of their own training centres, defined the construction site most suitable for this research.

As in Case Study 1, this company was large (> 500 employees) and had offices all over England. This company was a direct competitor of the company observed in Case Study 1 and also had an excellent reputation. Surprisingly, during the study, part of the business owned by the company of Case Study 02 was sold to the company of Case Study 01. In this way, all personnel, offices and equipment would soon be absorbed by the new parent company. Nevertheless, this situation did not affect the present study since the organisational structure and practices observed remained the same until the end of the data collection.

The construction site analysed consisted of an extension to an existing hospital complex. The data collection concentrated on the construction of a corridor that would connect the new building with the existing one, as illustrated in Figure 4.6:



Figure 4.6 – View of Case Study 2

The operation of the construction site benefited from other hospital facilities, such as a large car park and cafeteria. However, the hospital administration had imposed restrictions in terms of noise and dust due to the negative health effects they could have on the patients. These restrictions also involved limitations in transport times and the space available for storage. The floor of the corridor linking the old and the new building were both ready for construction at the beginning of the research. Bricklayers started to lay down the first brickwall courses at the start of the observations.

Simultaneously, the bricklaying supervisor began to fix the steel columns that would help to sustain the corridor's ceiling.

The contract for this construction was awarded through a bid where price was the main criteria of assessment. Price was also the main criteria to select bricklaying subcontractors but the good quality of their work in previous jobs was an important component in the decision to appoint them. In total, there were five hierarchical levels on this site but at the management level there was considerable overlapping of responsibilities. A site manager and a sub-contractor manager were directly responsible for the daily management of the bricklaying process.

4.7.4 CASE STUDY 3: Salford, England

This case study was carried out between October and November of 1996. The researcher made the first contact directly with the project manager of the site through an informal meeting. The criteria "reputation of the company" was relaxed for this case study as explained in item 4.6 (Selection Criteria of Case Studies). The construction site represents a typical situation in the region in terms of technology and workforce skills. It offered excellent insights into the reality of the average construction company.

The company was small (20<employees<100) and was involved in construction projects around the Great Manchester region. The bricklaying subcontractor's bid had been evaluated solely on the basis of price. The organisation on site was very flat and the subcontractors had almost total autonomy of managing their daily operations. The site manager controlled only the deadlines of the project, the budget and the delivery of materials. The project was a speculative development comprising 119 homes. The proprietors already occupied some of these houses. The data collection focused only on eight homes, which was correspondent to two buildings, as illustrated on Figure 4.7.



Figure 4.7 – View of Case Study 3

In these buildings the flooring had already been finished and the drainage work was in the final stage when the research started. The road works were only accomplished at the end of the study and that affected the speed of transportation in the bricklaying activity. The data collection started simultaneously with the construction of the walls of one of the houses. During this period the weather was rainy and very cold, directly affecting the quality of pathways on the site and the continuity of bricklaying.

4.7.5 CASE STUDY 4: Porto Alegre, Brazil

This case study was carried out between April and May 1997. The host company was among the most competitive companies in Rio Grande do Sul, the most southern state of Brazil. In previous years they had received awards from the regional union of contractors due to the quality of their production and commercial innovations. This company could be classified as a medium sized company (100<employees<500) and employed most of its workforce. Its buildings were usually sold before or during the construction, through a system of a hundred payments.

One of the senior lecturers of the Federal University of Rio Grande made the first contact. The acceptance of the research project took place during a meeting with the production manager at the company headquarters. During this meeting the production manager also explained, in detail, the new partnerships in development and the current activities in their quality program that gave the researcher a better understanding of the context of the production system. It is important to note that, despite their excellent reputation, this company had never opened its sites before to academic research.

The chosen site consisted of a large development of multi-storey housing (*see* Figure 4.8). The building analysed had twelve storeys with four apartments on each level. The managerial staff on site constituted a foreman, a construction manager and a secretary. The site was located in an area of the city where there were many other new developments that had started after the construction of a large new shopping centre.



Figure 4.8 – View of Case Study 4

The masonry technology used in this scheme was relatively novel in the region and had been used for the first time by this company two years before the researcher's visit. The company had constructed exactly the same type of building many times. Thus, the researcher expected that this company should have had a learning curve effect regarding their new technology. When the research started the concrete structure was ready and the bricklaying activity had reached the half way stage. Water proofing, window fittings and piping were in their initial stage.

4.7.6 CASE STUDY 5: Porto Alegre, Brazil

This case study was carried out during May 1997. The host company was small (20<employees<100) and had their headquarters in the same city as Case Study 04. It was regularly involved in academic and industrial research programs. Indeed, it was through a joint research project with the local university (NORIE/UFRGS) that this company launched one of the first "quality programs" in the region. Additionally, during the present research, a national project investigating the root causes of construction waste used one of this company's construction sites as a source of data.

This history of partnerships with academia made it easier to get access to the production system and co-operation from their staff.

The company's director allowed the researcher to choose any of his construction sites for data collection. The chosen site had been designed for the middle class market and presented typical technological and organisational characteristics of construction sites in this region (*see* Figure 4.9). This site matched the selection criteria that had been set at the beginning of this research. The concrete structure was at the last stage of its construction and the bricklayers were working just two floors below the formwork. Plumbers and electricians were preparing some of the walls in the floors below in order to facilitate their operations.

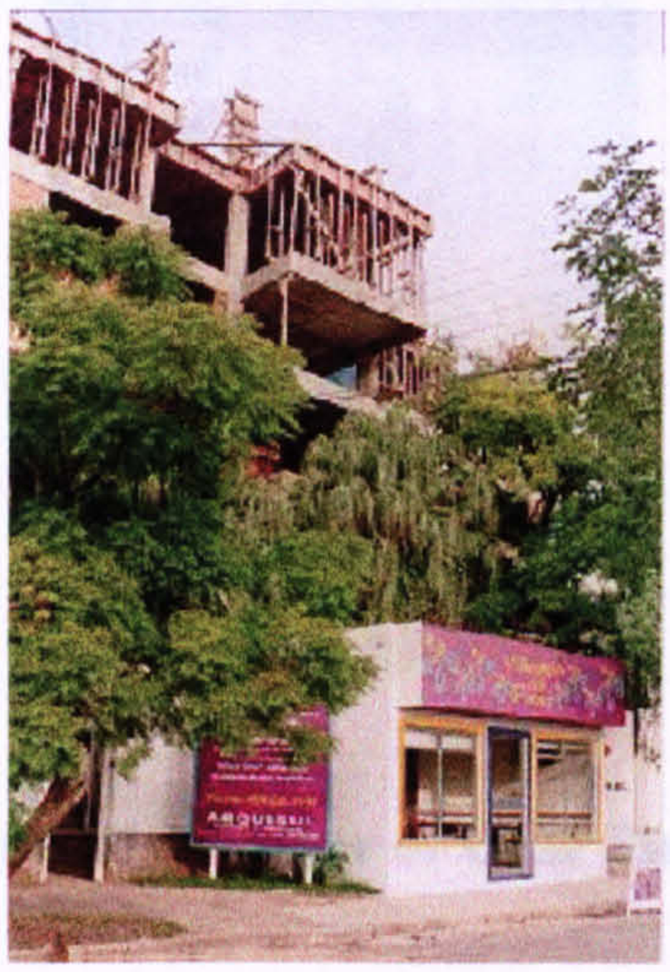


Figure 4.9 – View of Case Study 5

The company was selling apartments at a fixed price and, during the research, the last units were still on sale. All bricklayers were employees receiving a fixed salary and a bonus related pay attributed to their performance. The managerial staff consisted of a site manager and a foreman. However, on this site the foreman retained a more direct role in the daily management of the bricklaying activity.

4.7.7 CASE STUDY 6: São Paulo, Brazil

This case study was carried out during July 1997. The first contact was established through the director of a consultant company. The host company was medium sized (100<employees<500) and, according to the information received, they were developing

a number of technological and organisational improvements that could offer valuable insights for this research.

The construction site that was suggested to the researcher consisted of a multi-storey building, as illustrated in Figure 4.10. This site was located at the centre of São Paulo and had both commercial and housing purposes. The construction company was working under commission from a developer representing the client. Most of the workforce was subcontracted and paid on the basis of a fixed salary plus a bonus related to their performance.



Figure 4.10 – View of Case Study 6

This case study unveiled a number of technological improvements such as plumbing shafts, a new plastering material and a new masonry system that were relatively new in the region. The new masonry system was similar in many aspects to the technology identified in Case Study 4. However, it was the first time the company had worked with this system. This factor affected the quality of practice recorded during data collection. When the data collection started the bricklaying activity was on the last floor of the scheme and it was closely followed by the electrical and plumbing operations.

4.8 ANALYTICAL STRATEGY

4.8.1 UNIT OF ANALYSIS

The definition of what is the "unit of analysis" is of paramount importance to any analytical strategy. Dubin (1978:91) stresses that only when these units are put together, with their correspondent interactions, do they enable the generation of "laws" as the term law is usually employed in science.

Different types of units can be considered, from individuals, to organisations, small groups, roles, events, etc. The definition of the analytical boundary determines the limits of data collection and analysis. This boundary, in turn, can be defined by the propositions set up in the theoretical framework (Yin, 1994), or simply by what will or will not be studied (Miles, 1994).

The present thesis has generated a critical reflection on the basis of international and inter-industry generalisation of the heuristic "**implementation approaches**" presented in the theoretical framework. These heuristic "implementation approaches" are the smallest abstract units of the theory in study. Their boundaries were established in the theoretical framework, allowing conclusions representing logical and true deduction about their propositions.

Dubin (1978:44) suggests that "units of a theory" may be represented either by attributes or variables. An attribute is a property of element of practice (material, method, equipment, human management practice) distinguished by the quality of being present. In this research, a variable is a property of a practice that may be present to a certain degree. According to this definition the present research interprets the "unit of analysis" as a variable, since a heuristic "implementation approach", even when it is present in practice, may vary its degree of application.

4.8.2 *ANALYTICAL STRATEGY ADOPTED*

The analysis of the multiple case studies carried out comparisons between the empirical evidence with the theoretical propositions developed in Chapter 3. It has been divided into two main streams: cross-case study analysis and intra case study analysis. The

cross-case study analysis focused on isolated theoretical propositions, and the intra-case study analysis focused on inter-relationships among the theoretical propositions.

The cross case study analysis used the process that Yin (1994) calls replication logic, or **pattern-matching**, similar to that used in multiple experiments. In this process, when similar results happen and for predictable reasons, the evidence produced is seen to involve the same phenomena described in the theory, and is called *"literal replication"*. In contrast, when the case study produces contrasting results, but also for predictable reasons, it is called *"theoretical replication"*. For each "literal replication" there must be an equally plausible rival example showing a "theoretical replication" (Yin, 1994). Just as with experimental science, if some of the empirical cases do not work as predicted, modification must be made in the theory.

The holistic character of the intra-case study analysis demanded a different approach for analysis. There is an agreed definition in the literature that a case study is a "bounded system" where all facts and measurements are inter-connected with each other. Therefore, each individual case study consisted of a "whole" study that had to be able to stand alone in its own right (Yin, 1994; Platt, 1998). So, in the intra-case study analysis an **explanation building** approach was adopted complementary to the pattern-matching approach. This approach is similar to the pattern matching, but the aim is to analyse the data by building an explanation about the case.

The analysis of the Case Study 7 ("Exploratory Study on the Creation of a Learning Mood") is fundamentally different and concentrated on findings obtained from the "participant observation", where the researcher acted as a "process consultant". In this way, the analysis of this case study is based on the description of situations, observations, facts and experiences as perceived by the observer (Robson, 1993).

4.8.3 CRITICAL ASPECTS OF THE ANALYTICAL STRATEGY

There is some criticism in the literature concerning the lack of precision of the pattern matching approach. Yin (1994) alerts that there is a risk of some interpretative discretion on the part of researchers. They may be overly restrictive in claiming a pattern to have been violated or overly lenient in deciding that a pattern has been matched. Since there is no precise way of setting the criteria for interpreting these types

of findings the present research searched for sufficiently contrasting examples of empirical observations as a criteria for accepting, or not accepting, a replication of the theory.

The overall quality of the pattern-matching was improved in this thesis by using quantitative indicators (described in Chapter 5 and summarised in Appendix 5), supported by the qualitative techniques described earlier in this chapter. Additionally, non-structured discussions with practitioners and academics, visits to research institutes and the researcher's own network of contacts helped to refine further the interpretations of theory and practice. The corrections made through this continuous learning enhanced the accuracy of the interpretations, hence increasing the construct validity of the study, as recommended by Yin (1994).

4.8.4 BOUNDARY SEARCHING

Searching for the typical behaviour and practical boundaries of quantitative indicators was the key strategy for increasing the accuracy of the "pattern-matching" and "explanation building" analysis. Jones (1970) defines the aim of "boundary searching" as *"to find limits within which acceptable solutions lie"*. In practice, boundary searching may be useful for diagnostic and other management purposes. It minimises production management compromises by creating a reference point of limiting dimensions. Furthermore, boundary searching can generate information that is usable for future repetitions of production practices. This approach tries to identify acceptable and extreme values and the expected progression that characterises these quantitative indicators.

One of the consequences of searching for limits of variables, rather than uniquely acceptable benchmark values, is that the results may be just as useful for a particular case study as they are for the entire range of case studies. Moreover, each of the six case studies offered opportunity for incremental refinement of the definition of limits and typical curve for each of the chosen indicators. Critical analysis of the literature and open-ended interviews in the case studies supplied fundamental clues with respect to the possible range of values for the indicators in question.

4.8.5 LINKING EMPIRICAL EVIDENCE AND THEORY

A number of methods used to establish a link between abstract managerial concepts/principles and objective reality have been examined. The Malcolm Bardridge National Quality Award, the NASA Quality Award and European Quality Award, as well as auditing processes for ISO 9000 series are examples of such methods (Zairi, 1996). Clearly, other operations management researchers in the field have already faced similar challenges to those faced by this researcher when trying to establish the link between practice and theory. The usual approaches identified go from hard statistical analysis to purely subjective judgement. Karlsson and Ahlstrom (1996), for instance, suggested the identification of continuous improvement through the verification of the existence of formal suggestion schemes, multifunctional teams, quality circles and spontaneous problem solving activities.

The researcher resorted to both quantitative and qualitative information to validate the analysis linking practice to theory as much as possible. The confirmation, or otherwise, of a literal replication was obtained from a holistic assessment of information from various sources and types. Appendix 5 summarises the connection between the data collection techniques, indicators and the theoretical "implementation approaches" under investigation.

Some of the "pattern-matching" findings depended upon the correct account of each situation in detail from the point of view of those under observation. Documents and archival records, for instance, helped to confirm the existence of a process of "standardisation" and determined the 'number of revisions per year in the written standards' (*see* Appendix 5). After all, the frequency of revisions should reflect the commitment of the company towards standardisation. Nevertheless, it was from open-ended interviews that the researcher could most effectively assess the effective use of this approach. One of the direct indications in this respect was the "percentage of workers that actually knew the content of standards" of their own processes.

Some of the "implementation approaches" in study were quite straightforward to identify in practice and could be confirmed using information from various sources. The practice of "minimisation of distances", for instance, had a direct effect on the use of time. Time, on the other hand, could be assessed using the "work sampling" technique;

"video-recording" showed the effect of short or long distances in real time; "flow charts" looked across the entire process and clarified long pathways that could not be observed simultaneously. Likewise, a "layout diagram" can be a powerful tool for understanding the root causes and the implications of long distances across the horizontal plan. "Documents and archival records" also revealed, for instance, how often a layout was revised. The indicator "number of bricklayers per labourer" was very useful since it reflected how well a workflow or the layout on site was planned. An open ended interview usually brought further insights into the information collected on site and led to additional evidence that substantiate the researcher's own findings (*see* Appendix 5).

In all situations, analysis of practice relied heavily on the correct understanding of each of the heuristic principles. "*Changing Push Orders to Pull Orders*", for instance, could only be confirmed because the researcher followed the dynamics of production on a daily basis. The number of variables coming into mind when trying to confirm the presence of this approach in practice was large and complex. Thus, the researcher focused on those facts that represented the main expected outcome of a "pull" production system such as continuous improvement and leaner and faster flows. The researcher also used some key indicators to help identify this approach. However, without an adequate understanding of each heuristic principle it would be difficult to integrate the great variety of information into a coherent conclusion.

4.8.6 DISCUSSION

After revising the literature and exploring various instruments used to detect and quantify abstract principles in practice, the researcher began to question the practical usefulness of searching for precise assessments of literal and theoretical replications. Cause-effect relationships are almost impossible to establish among the intricate set of practices observed in construction processes. Thus, the evolution of theoretical assessments from small process elements towards more aggregate assessments of entire production systems is likely to be always dependent, to a large degree, on qualitative interpretation. In this respect, the use of a protocol for data collection focused on only one type of production process, the definition of some instrumental indicators and the option for multiple-case studies are an attempt to bring more robustness to the analysis.

Quite often empirical evidence matched in a partial way with a theoretical proposition. In those cases, it was highly subjective to establish how much had been achieved of the theoretical proposition. In this way, the existence of a large quantity of empirical evidence in this thesis was the key to enable comparisons and obtain more sound judgements. Availability of large quantities of evidence was also fundamental to a proper definition and refinement of the boundaries of the indicators that substantiated and strengthened the robustness of the analysis.

4.9 CONCLUDING REMARKS

The literature shows little examples of research methods for assessing the match between practice and theory. Techniques that support the transformation of "real world" observations into abstract observations are still scarce and deserve further investigation. Likewise, there is an urgent need for methods that represent complex theoretical findings in a simple graphical manner so that academics and practitioners can easily understand the whole situation of a production process or production system in construction.

It is worth emphasising that the various external sources of information that surrounded the development of the case studies (e.g. seminars, visit to research centres, etc.) did play an important role in helping the researcher improve his own understanding of the theory and practice under investigation. This natural learning process must be acknowledged since it influenced the research method and the entire writing up of this thesis. The spontaneous way in which this learning occurred does not diminish its contribution. In fact, it reinforces the connection between the research findings, latest thinking and best practices.

4.10 SUMMARY

This research adopted a balanced philosophical approach in the definition of the research method and data collection techniques. Hence, it resembles both the "positivist" and "interpretative" philosophical approach. The "positivist" approach, often designated as quantitative research, believes that the subject under analysis should

be measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition. On the other hand, the "interpretative" approach, also known as phenomenological or qualitative approach, understands reality as holistic, and socially constructed, rather than objectively determined.

"Case study" was the research method chosen for investigate the research questions described in Chapter 1. According to Yin (1994:13), case study is *"an empirical inquiry that investigates a contemporary phenomenon within its real-life context and where the boundaries between phenomenon and context are not clearly evident*". The data collection focused on the bricklaying process since it is one of the first processes to receive systematic analysis the production management field. There was an opportunity in this research for developing case studies in Brazil and in the UK. The researcher believed that case studies in both countries could strengthen the weight of findings, particularly with respect international generalisation. In this respect, it was felt necessary to carry out, at least, three case studies in each country in order to enable triangulation of data and increase the robustness of case study findings. An additional case study explored the creation of "learning mood", using a *participant observation* approach.

The analysis of the six initial case studies was carried out in two parts: "cross-case study analysis" and "intra-case study analysis". The "cross-case study analysis" used a process called "pattern-matching" where the researcher looked for direct replications of the theoretical propositions (Yin, 1994). In this process, the empirical evidence was a "literal replication" when observed results matched the theoretical predictions. In contrast, when the case study produced contrasting results but for predictable reasons, it was called a "*theoretical replication*". Information obtained through quantitative and qualitative techniques was used to substantiate the pattern matching findings.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter 5

CROSS CASE STUDY ANALYSIS

No progress towards perfection is possible
if the current state can't be described.

James Womack

5.1 OVERVIEW

Chapter 4 has described various methodological issues of this research such as the philosophical approach and the reasons for choosing case study as the research strategy. It also included a description of the research project design, the observational protocol and the criteria for selecting the case studies. The chapter also introduced each case study and presented the analytical strategy. The present chapter focuses on the analysis of each heuristic implementation approach, as described in the Theoretical Framework (Chapter 3). The analysis uses the pattern matching approach described in Chapter 4 and is further illuminated using indicators and key illustrative examples from any of the case studies. The chapter ends with a discussion concerning the current construction practices in production management. Hence, this chapter explores the first research question stated on Chapter 1: *Are there construction practices matching the production flow principles?*

5.2 GENERAL ANALYTICAL STRUCTURE

This chapter brings together empirical evidence from all the case studies in order to analyse each specific heuristic approach. It assembles information from different types, such as quantitative indicators and photographs, with the aim of obtaining a rich and accurate description of practice and substantiating the arguments. The same information will be used in Chapter 6 when developing the analysis of the inter-relationships among the heuristic implementation approaches. It is no intention of the author for readers to go through this long Chapter from start to finish. Rather, the twenty-two vignetes exploring each of the heuristics under investigation should be read to answer key learning questions posed by interested parties in the true sense of "pull learning". The discussion is kept complete in order to show the richness and differences at the level of necessary detail.

Case Study reports produced throughout the development of this research already began the analysis of empirical evidence. In addition, specific reports relating to each individual heuristic approach followed these reports and these have been written and discussed in relevant conferences (e.g. Santos, Powell & Formoso, 1998; Santos & Powell, 1999; Santos, Powell & Formoso, 1999). These papers had a significant role as a communication channel with industry and academia and, therefore, were fundamental to strengthen the analysis presented in this chapter.

In order to facilitate understanding, the analysis of each heuristics follows a standard structure, as described below:

a) *Working definition*: a short definition of each heuristics is firstly given. This was necessary to guide the researcher throughout his analysis of observed practice and to communicate early results with practitioners. Note that this working definition always refers to the bricklaying process since this was the main source of empirical evidence;

b) *Observational focus*: it then describes the researcher's focus of attention when trying to distinguish "literal replications" in construction practice. It presents the data collection techniques and indicators used in the process of observation, as well as the reasons for their choice;

c) *Key Indicator*: it then presents the principal indicators used to analyse the heuristic approaches and the reasons for that choice. This presentation is summarised in those cases where the indicator had already been described;

d) *Expected Behaviour and Practical Boundaries*: following Jones' (1970) suggestion, the researcher tried to specify an expected behaviour for each indicator in relation to process performance. The literature and discussions with the people in the case studies supplied the insights for establishing 'practical boundaries' within which construction should have been operating;

e) *Summary of Results*: this item presents in summary form the general aspects observed across the case studies regarding a heuristic approach. These results range from direct interpretation of the indicators to the most frequent answers obtained from open-ended interviews;

f) *Discussion*: this section always begins by drawing the main lessons from the analysis of the empirical case evidence. It then discusses the current application of each heuristic approach in the bricklaying process and the key issues for its implementation in the construction sector. This discussion also includes suggestions for improvements of the theory, or proposals for refinement of current definitions;

g) *Conclusion*: it presents the strict findings relating to the research questions and some other major conclusions unveiled from the empirical evidence.

It is worth emphasising that the observations of practice also showed so many "theoretical replications", i.e. where the failure in adopting the theory resulted in predicted problems. This thesis presents only a few of these in order to make a point since they were too numerous to report in full. With respect to the "literal replications", although the observations were extremely comprehensive (*see* Chapter 4), there were few exemplary practices for the majority of indicators measured. Because of this, the researcher was able to count the number of "literal replications" in each case study for all heuristic implementation approaches.

5.3 REDUCTION OF CYCLE TIME

5.3.1 REDUCTION OF BATCH SIZE

5.3.1.1 WORKING DEFINITION

Reduction of batch size simply means to reduce the size of production or transportation volumes within bricklaying in order to speed up the delivery of products to the internal or external client[1].

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[1] Key definitions:

Transfer batch: it represents a fraction of the lot and constitutes those construction sub-products that are ready to receive next operations;

Production batch or Lot: sum of all similar transfer batches necessary to finish a particular phase of the construction project;

Delivery batch: volume of material or components delivered on site.

5.3.1.2 OBSERVATIONAL FOCUS

The central focus of observation of this heuristic was on the amount of material arriving in each delivery to bricklaying, the amount of work-in-progress, the bricks/blocks storage volumes and the relationship of these variables with production rates. Observations started in the exploratory visit with photographs and video recording of the process status in terms of workflow, layout and storage volumes. Hence, during the next two weeks (average time of data collection) the researcher documented the position of workstations and measured productivity and storage turnover. The relationship between the productivity and the storage turnover helped in understanding how lean and synchronous the flow of bricklaying was. Analysis of documents and archival records directly concerning bricklaying helped to check if the frequency and volume of deliveries were consistent throughout time. The work-sampling technique (or time-lapse video recording) showed the effect of large batches on the generation of non-value adding activities.

5.3.1.3 KEY INDICATORS

The literature had shown that a good observational criterion to use in this context was the amount of inventory available on site. The researcher decided to use a relative measure by linking the average storage of blocks/bricks to the rate of productivity. Ideally, the rate of deliveries of bricks/blocks should be closely linked to the production rate of bricklaying and, in this way, there should be no intermediary storage. The procedure to obtain these indicators was, as follows:

a) *Productivity*: bricklaying production was measured once in each visit to the site. When a bricklayer produced more than one brickwall or brickwalls with different brick/blocks sizes in the same day, the researcher had to ask the bricklayer the exact moment of change in order to estimate the productivity. In the end, the productivity measure adopted for each case study corresponded to that most widely applied brick or block work production. The measurements were all translated into m^3/hour/bricklayer in order to link this indicator with the average volume of storage on site, as described next;

b) *Average Storage:* this indicator was obtained by simply counting, or measuring, the storage once in each visit to the site and dividing it by the number of bricklayer working

in that day. Ideally, this indicator should be measured using the average between the storage in the first and last working hour. Logistical constraints of this research and the fact that the storage usually decreased at a relatively slow and constant rate led to the determination of this value only once a day. The measurements included all material present on the site relating to bricklaying and included the material present in the workstation. However, this thesis used only the values referring bricks/blocks;

c) *Flow Efficiency:* this indicator was obtained by dividing the values of 'productivity' by the 'average storage'. Since both indicators use the same dimensional unit - m^3/hour/bricklayer - the indicator of 'flow efficiency' is a relative measure and has no dimensional unit.

5.3.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The investigation into the behaviour and practical boundaries of indicators focused solely on the indicator of 'flow efficiency' since it links both 'productivity' and 'average storage indicators' in one single measure. The literature does provide evidence and arguments that the ideal situation should be to produce and receive materials to a single batch unit at a time (Shingo, 1988). In this situation, the downstream operations should order one batch unit at time. However, none of the construction sites had defined what such a batch unit was, and there appear to be no direct orders from downstream construction processes.

If the delivery rate had fell below the production rate, it would have had negative effects on process performance. On the other hand, excessive delivery batches would also affect the production efficiency for the reasons explained in Chapter 3. In this context, based on discussions with practitioners, the researcher established a minimum value of 0.5 for the 'flow efficiency' indicator. At the same time, based on discussions with the site managers, a value of 0.9 has been established as a challenge for construction since it has been found no benchmarks for such an indicator.

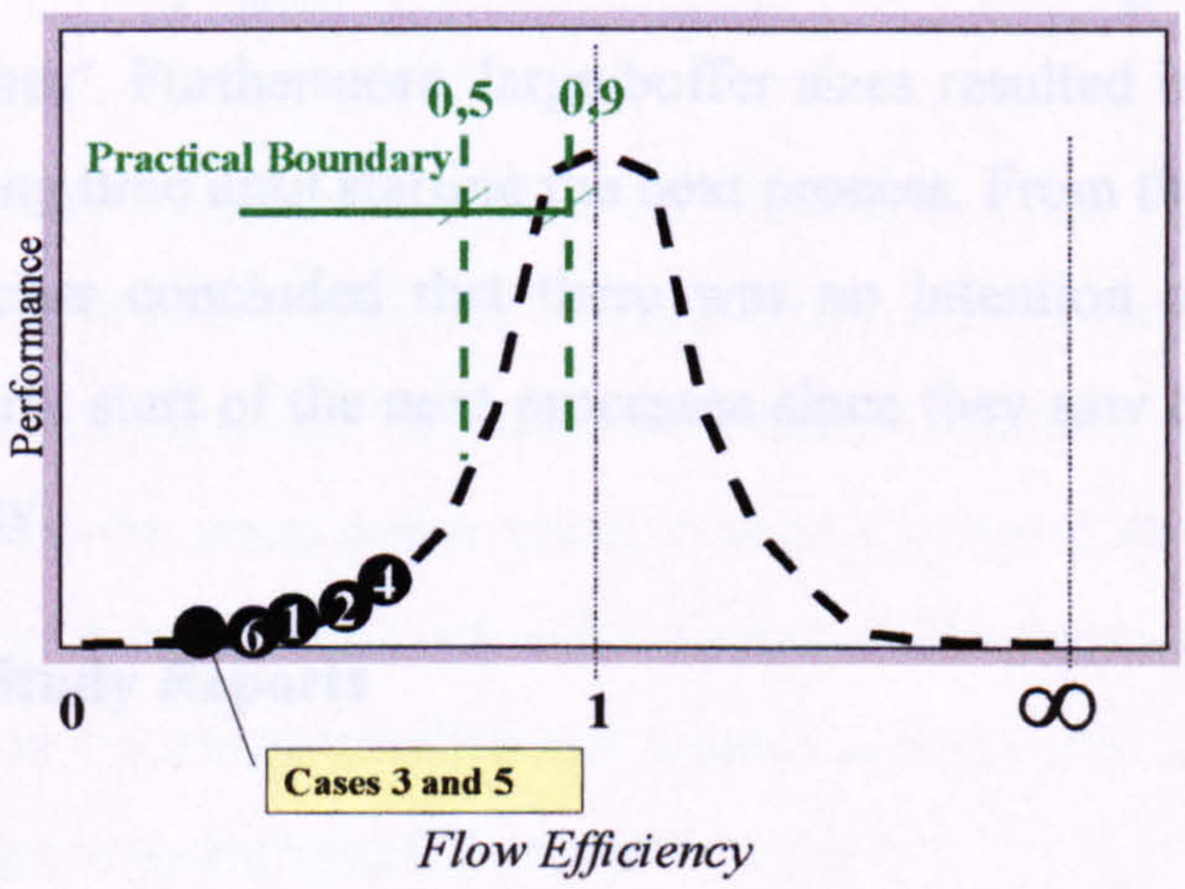
5.3.1.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

The observations of the case studies have shown the widespread use of large batch sizes in the bricklaying activity. Most 'delivery batches' were not consistent with the consumption rate. Indeed, Table 5.1 shows the severe discrepancy between the 'average storage' on site and the 'productivity rates'. Case Studies 2 and 4 presented the best performance among all six case studies in this respect. Even so, the 'flow efficiency' values presented in Table 5.1 shows that they were holding, on average, more than fourteen times the hourly consumption of bricks/blocks.

Table 5.1 - Performance of Case Studies Regarding *Reduction of Batch Sizes*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Bricklayers	6	6	2	4	3	8
Productivity (A) (m^3/hour/bricklayer)	0.33	0.21	0.18	0.19	0.29	0.23
Maximum Storage of Bricks/Blocks (m^3/hour/brickl)	10.10	4.00	6.80	6.20	11.36	8.25
Minimum Storage of Bricks/Blocks (m^3/hour/brickl)	5.00	1.00	5.00	1.00	8.10	6.12
Average Storage of Bricks/Blocks (B) (m^3/hour/brickl)	6.12	3.54	5.30	2.62	10.38	6.34
Flow Efficiency (A/B)	0.05	0.06	0.03	0.07	0.03	0.04
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications	**0**	**3**	**0**	**1**	**0**	**0**



As Table 5.1 shows, there were considerable variations in the delivery and production volumes across all construction sites. The researcher witnessed, on various occasions,

the delivery of various truckloads in a short amount of time and then, longer periods without a delivery. These variations created difficulties in the pathways on site and reduced the transparency for stock control. The lack of a detailed workflow plan, clearly defining the expected consumption of material and the actual direction of flows, was a major factor increasing still further the impact of large delivery batches.

In general, the observations revealed that equipment, packing methods and containers used in the construction sites had not being developed with the purpose of enabling effective small batches. Indeed, most of the equipment observed had been developed using the paradigm of mass production of large batches. Discussions with managers revealed it was they understood that the delivery of large batches, and maintenance of large storage, was necessary in order to tackle the high level of variability on site. These managers also believed a reduction in 'delivery batches' would increase the costs of transportation. When asked about the possibility of developing alternative transporting and packing systems to enable the reduction of 'delivery batches' they expressed their frustration for lacking the power and means to influence the supply chain in this way.

The open-ended interview revealed that managers and sub-contractors had no clear understanding of the implications of reducing the size of 'transfer batches'. Their normal policy was to put as many bricklayers, and as much equipment and material on site, in order to carry out constructing as many brick/blockwalls as possible. The financial constraints of the project seemed to be the main driving force in defining the size of 'transfer batches'. Furthermore, large buffer sizes resulted in finished brickwalls often waiting for a long time until starting the next process. From the conversations with managers the researcher concluded that there was no intention of reducing 'transfer batches' to enable early start of the next processes since they saw this as an increase in production complexity.

b) Individual Case Study Reports

b.1) Case Study 1

Case Study 1 presented around five cubic meters of variation of storage per bricklayer in the two weeks of investigation (*see* Table 5.1). The practice of large 'delivery batches' was worsened by the manager's decision to concentrate the blocks in a single storage area. The construction was large and the use of this single storage area meant

the need for long transportation distances. Furthermore, the large amount of blocks on site reduced transparency regarding the control of volumes and the position of machines.

The site manager revealed during interviews a great lack of concern with the excessive transportation activities caused by the large amount of material flowing across the site. In his words, "*...the complexity and size of this project does not allow me to concentrate on the detailed flow of each subcontractor*". Clearly, ordering all blocks at once reduced the complexity of managing production flows, since there were fewer orders to keep track of. However, the reason he was not concerned with the waste generated by this decision was his misconception that the subcontractor was the only one losing with inefficiencies in production.

b.2) Case Study 2

Case Study 2 was the most consistent in terms of batch size reduction, although not reaching the highest mark of *flow efficiency*. This site also presented a satisfactory integration of this practice with other complementary practices such as 'visual controls' and 'sharing responsibility with employees'. Table 5.1 shows that this site presented three days where there was a clear "literal replication" of the practice of small batch sizes. Furthermore, open-ended interviews with managers and analysis of their archival records showed that the maintenance of low levels of storage was a normal practice in this company.

This construction site also revealed the practice of small batches for sand, bricks/blocks and cement. This result in lower need for storage space and less material handling. This practice was economically feasible because the truck transported other materials in the same load. In fact, even the same pallet could contain different materials, as Figure 5.1 illustrates, for the case of cement and pre-mixed mortar. The supplier benefited from the reduction of batch size by using smaller and faster trucks, confirming Hall & Jackson (1992) arguments regarding the benefits of small batch.



Figure 5.1 - Literal Replication of *Reduction of Batch Size* (Case Study 2)

b.3) Case Study 3

This case study was among the worst performers in terms of the amount of bricks/blocks delivered to the site and the actual need of the workstations, as demonstrated in Table 5.1. The outcome of practising large batches corresponded exactly with all the negative predictions of the theory (*theoretical replication*). Among the most evident consequences of this were the difficulties in identifying process problems and an increase in transportation distances.

The practice of large batches on this site extended also to the use of large production batches. Figure 5.2 below shows the construction of two houses initiated almost at the same time by a group of four bricklayers and two labourers. The dispersion of workstation resulted in an increase in the transportation distances, work-in-progress and amount of equipment required (e.g. more scaffolding). Furthermore, discussions with bricklayers and direct observation showed that this practice resulted in a poor level of communication and co-ordination among personnel.



Figure 5.2 - Theoretical Replication of *Reduction of Batch Size* (Case Study 3)

b.4) Case Study 4

The supply of bricks and blocks on this site was much closer to the actual needs of the workstation than any other site analysed in this thesis. 'Flow efficiency' was 0.07 whilst in the worst case studies it was 0.03 (*see* Table 5.1). Nevertheless, analysis of the archival records showed that the practice of this case was not consistent throughout time. Indeed, during the ten-day's observation period the researcher observed a large variation between the maximum and minimum volumes of storage (from *1.00 to 6.20 m^3/bricklayers/hour*).

Paradoxically, managers and workers shared the opinion that the reason for this variation of storage on site was the high level of trust on the reliability of the block's supplier. This trust allowed them to order loads of blocks at the last possible minute. Usually, only when stock levels reached the equivalent of the needs of two days of work, would they communicate their orders to the supplier. Each supplied truckload contained enough material enough for one week of work. However, the large volume of blocks in each truck demanded the relocation of bricklaying labourers to support the unloading activity. Therefore, this practice directly affected the main value adding activity of bricklaying.

b.5) Case Study 5

This site was one of the worst performers in terms of storage levels and the 0.03 value measured for flow *efficiency* reflects this situation (*see* Table 5.1). This indicator means that the pace of the workstations demanded only 3% of the amount of storage on site. However, the storage measured on this site was small (minimum = 8.10 m^3/ maximum = 11.36 m^3) comparatively with the average storage (10.38 m^3). Conversations with the

manager revealed that there was a policy of maintaining large 'safety' storage in order to avoid uncertainties and guarantee the completion of the construction on time. Therefore, although there was regular deliveries of small quantities of bricks, this site did not benefit from this practice because of the policy adopted regarding minimum storage levels.

Like the previous Case Studies 1 and 3, the negative effects of large storage on this site corresponded exactly with what is described in the literature (Monden, 1998). Among the most clearly identified negative effects was the lower visibility of quantities, the increase in transportation distances and the increase of waste due to excessive handling of bricks. Moreover, the large amount of storage had compromised safety on site since workers had to climb the brick piles in order to take bricks from the top and reduce their height.

b.6) Case Study 6

The analysis of archival records and interviews with managers on this site confirmed that the values obtained for 'flow efficiency' reflected the normal practice on this site. Considering that this site had almost the same technology as Case Study 4 (best performer) it became clear that 0.04 of 'flow efficiency' represents the clear indication of sub-optimal use of the resources available on the site. On average, each bricklayer had 6.12 m^3 of blocks moving through the site, although what was necessary in a typical day was just 1.5 m^3. This excess of material moving through the site meant, for instance, more labourers involved in transportation, thus, not supporting bricklayers in main value-adding activities.

When questioned about this practice, both managers and workers expressed their clear understanding of the benefit of having small batches of materials being delivered directly to the workstation at the same speed as the bricklaying activity. However, both also noted that they had always worked with large batches and did not expect that suppliers would change their practices in the short term. The site manager also expressed his concerns with the difficulties in applying this practice due to the uncertainties in the national economy. In his view, buying and storing material on site was a safe measure to avoid any unexpected turmoil in the Brazilian economy.

5.3.1.6 DISCUSSION

There were three main lessons from the analysis of the case studies on the issue of batch size reduction, as follows:

i. It became clear from the case studies that partnership with suppliers is a critical point to reduce batch size in the construction industry.

ii. Construction need to adapt or re-dimension its transport equipment and packing system in order to enable the full application of this approach in practice;

iii. The paradigm of mass production is heavily present among construction managers and needs to be changed prior to the implementation of this approach.

Small batches demand dynamic and continuous communication between all parties on because adjustments in schedules are almost inevitable and, to a certain extent, expected. The practice of small batch sizes in Case Studies 2 and 4 was only feasible due to a partnership atmosphere between the contractor and suppliers. The commitment of the project manager to partnerships translated into a formal commitment to maintain the same supplier throughout the entire project.

The packing system, containers and transporting equipment throughout the supply chain is another critical aspect for those who wish full implementation of this approach in construction. In this research, the best examples of transportation equipment and containers enabling the reduction of batch size came from the 'meta-case'. Figure 5.3 shows an example of this: a set of plastic containers developed during an ergonomic study of a Brazilian construction company. These containers are small and light and allow direct transportation of the right quantities to the workplace or, at least, at a reduced number of intermediary stops. Such small batches demand better synchronisation between the mixer and the bricklayer's workstation. Any variation in the bricklayer's production rate has to be followed by rapid changes in the mixer's production rate



Figure 5.3 - Literal Replication of *Reduction of Batch Size* (Meta Case)

The paradigm of mass production among construction managers was seen as a major barrier for implementing small batches in construction. The volumes of 'transfer batches' were large in all construction sites investigated in this thesis. Since the bricklayers started bricklaying operations in more workplaces than they could operate, the end result was large amounts of work-in-progress throughout the sites. Construction managers did not seem to agree that the use of resources in their full capacity, producing more sub-products than necessary, is a waste of resources. In fact, for some managers, waste due to overproduction does not appear to exist in a construction since the parts of a project have to be produced anyway.

Indeed, the demand for sub-products is guaranteed during a construction project and one could be tempted to initiate the production of large batches. Similarly, the benefits of immediate identification and correction of errors due to the practice of large batches was not acknowledged by most construction managers interviewed. This situation suggests that considerable efforts still has to be directed towards education and training of construction managers on the modern approaches of production management.

In an attempt to analyse production and the transfer of batches in the case studies, the researcher identified a critical theoretical issue that is the definition of what constitutes a batch unit in construction. The observations of practice suggest that a single batch unit in construction could be defined as the production volume corresponding to one set-up at one workstation. In the case of bricklaying, it could correspond to segments of brickwalls identified in the design, as illustrated in Figure 5.4.

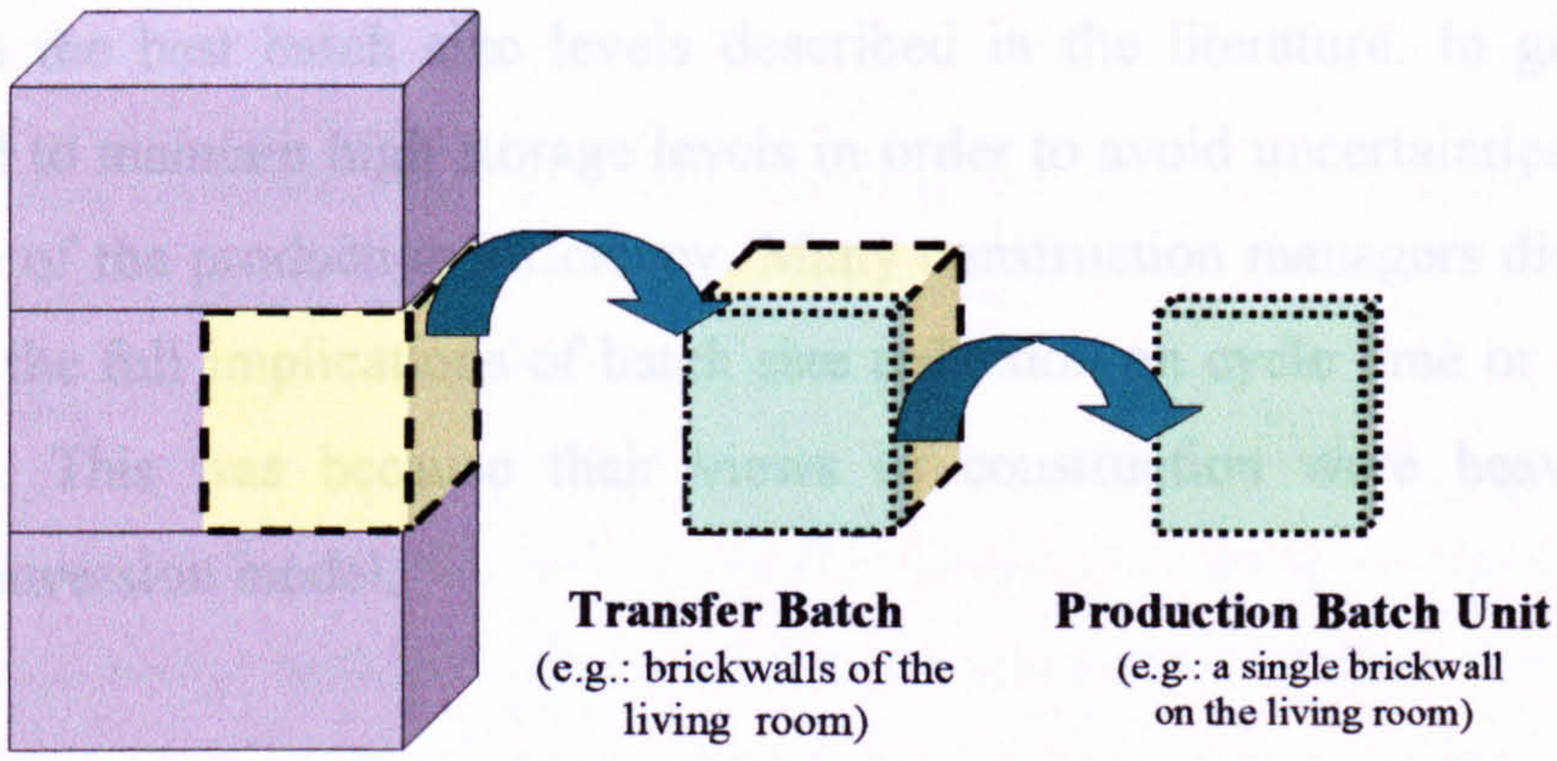


Figure 5.4 – Illustration of Production Batch, Transfer Batch and Production Batch Unit

The use of physical or virtual delimitation of construction workflow (e.g. painting the floor with spray) could be a helpful instrument in making the batch unit visible and workable in the construction sector. This single batch unit may differ from manufacturing in the sense that in construction one set-up usually corresponds to only one production unit (e.g. one door installation). Indeed, in mass production manufacturing one set-up often corresponds to various or, sometimes, millions of production units (e.g. headache pills in pharmacy industry).

The important lesson for construction is the idea that this approach can drive improvements and innovations in design and production in the sector. Solutions should be developed in order to enable the production and transfer to the next process of one single batch unit at a time, even if it is not required in the present demand levels. For instance, interdependencies between batch units need to be reduced at the design stage in order to allow the unrestricted work of downstream processes. However, none of the sites analysed has tried to bring on the next process as soon as any bricklaying batch unit was ready. Large buffers in schedules, process variability, design constraints and the lack of adequate workflow planning were generally major barriers to implementing this practice.

5.3.1.7 CONCLUSION

The observation in the six case studies revealed that some construction practices did use small batches with the most visible benefits being better visibility of process flows and reduction in transportation distances. However, even the best construction companies

were far from the best batch size levels described in the literature. In general, site managers tried to maintain high storage levels in order to avoid uncertainties. This was at the expense of the production efficiency. Many construction managers did not seem to understand the full implications of batch size reduction on cycle time or continuous improvements. This was because their views of construction were heavily biased towards the conversion model.

5.3.2 REDUCTION OF WORK-IN-PROGRESS

5.3.2.1 WORKING DEFINITION

'Reduction of work-in-progress' refers to that reduction in the number of units in a transfer batch waiting for completion of the bricklaying process.

5.3.2.2 OBSERVATIONAL FOCUS

None of the cases studied had a clearly defined "transfer batch". Thus, the central focus of attention on site was in any brickwall that received, at least, one visit of the bricklaying workstation. A "literal replication" thus occurred when there was only one visit of the workstation to the workplace to accomplish all bricklaying operations. The observations of each brickwall stopped when there was reasonable guarantee that there would be no more visits from the bricklayer to complete the operations. Observations were made of all bricklaying operations and the way bricklayers spent their time. Records were also made when they arrived and when they left their workstation in order to establish the average time between each visit. Other supporting evidence was used to certify the accuracy of findings; these were open-ended interviews, flow diagrams, video recording and photographs.

Since the size of a batch unit is generally variable and not clearly defined in most construction sites, the present research considered each 'workplace' as a batch unit. Furthermore, a workplace was considered as the smallest area of work where a complete bricklaying workstation can operate. This was usually a segment of brickwall between steel/concrete columns or between two other brickwalls.

5.3.2.3 KEY INDICATORS

Two observational indicators that had been tested in the pilot study seemed to provide the best and most sensible measurement of performance with respect to bricklaying work-in-progress, namely:

a) *Number of Visits a Bricklayer made to the Workplace in order to Complete the Main Processing Activity*: critical analysis of the literature revealed that the number of visits a bricklayer normally makes to the workplace has a direct correlation with the duration of bricklaying (Heineck, 1983). Indeed, due to the queuing effect, the level of waiting time and process problems is likely to increase with the number of visits to the workplace;

b) *Average time between Visits to the Workplace:* for the same process, the higher the waiting time between visits to the workplace, the more work-in-progress there will be. Moreover, the more time the workplace is inactive, waiting for the end of the process, the more likely are the occurrence of mistakes that, in turn, lead to further increase in cycle time (Heineck, 1983).

5.3.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The researcher therefore defined the expected evolution and practical boundary of the chosen indicators as follows:

a) *Number of Visits to the Workplace to Complete the Main Processing Activity*: critical analysis of the literature indicates that cycle time tend to decrease with the reduction in the amount of visits required to finish all operations in a workplace (Shingo, 1988). Observations in the cases studied suggest that production performance is much better if the number of visits is low. Ideally, each trade should visit the workplace only once in order to finish all their operations;

b) *Average time between Visits to the Workplace*: ideally, there should be no waiting time between bricklaying operations. Yet, discussions with the workforce led to the conclusion that a 24 hour waiting time was a realistic upper limit for this indicator. The lack of evidence, and the scarce literature on this matter, does not allow the researcher to confirm what the effect of this variable on cycle time. Nevertheless, an 'exponential'

curve was adopted to depict the expected relationship because it seemed closer to what is suggested by observations in all case studied.

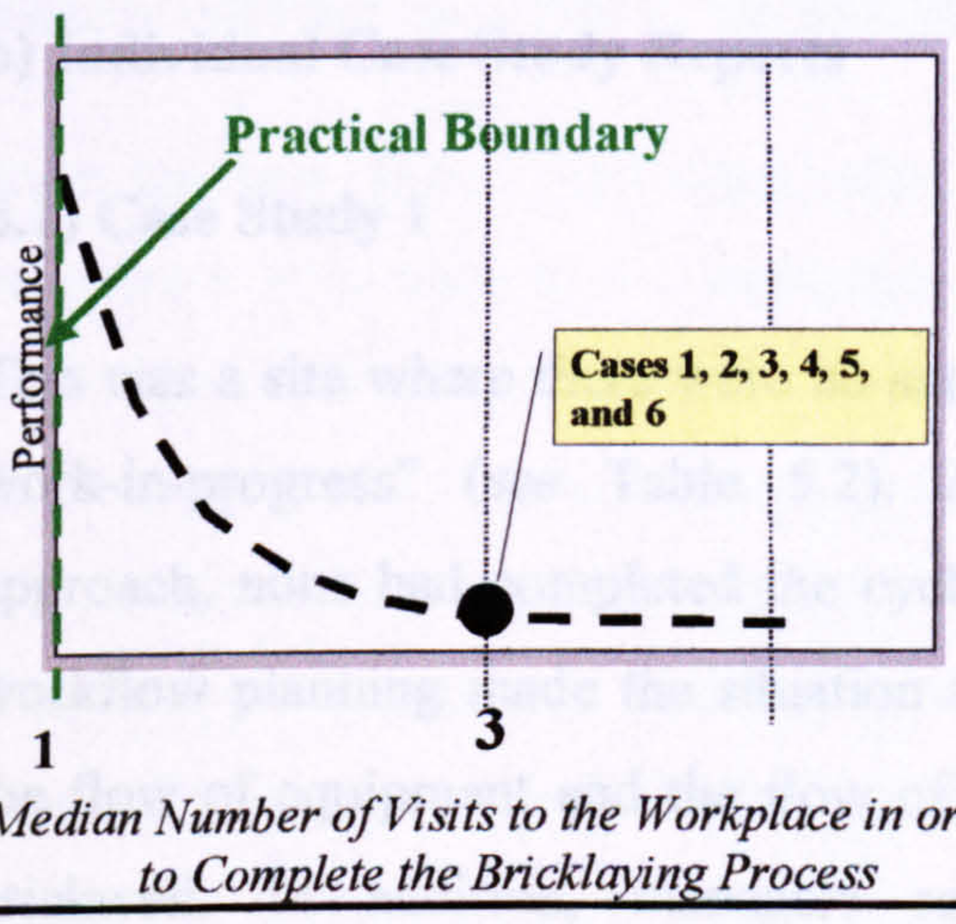
5.3.2.5 SUMMARY OF RESULTS

a) General Pattern across All Cases

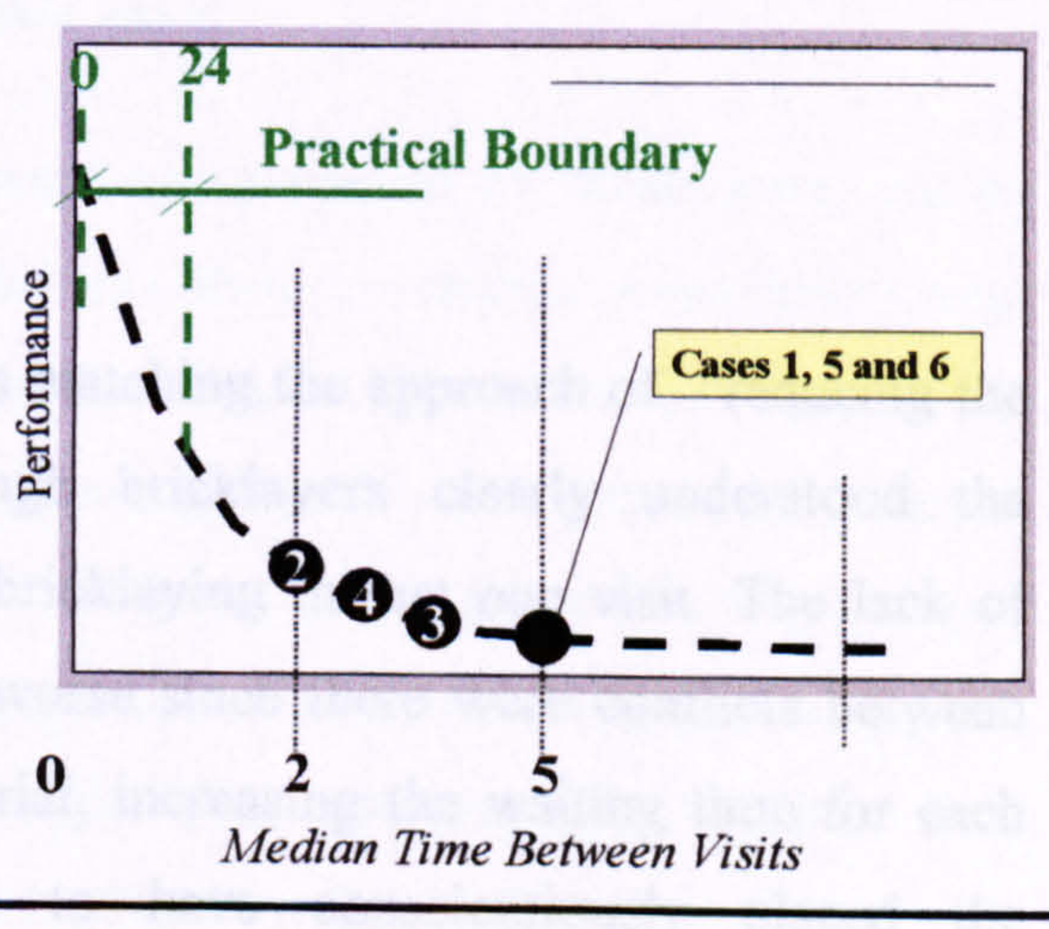
There were high levels of work-in-progress on all construction sites studied in this research. Table 5.2 below shows the large number of multiple visits made by bricklayers to workplaces in order to complete their bricklaying operations. They took an average of three visits to complete all operations in each brickwall. Furthermore, the average time between these visits varied between two to five whole working days.

Table 5.2 - Performance of Case Studies Regarding Work-in-Progress

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Bricklayers	6	6	2	4	3	8
Number of Days Observed	10	10	15	10	10	6
Maximum Number of Visits to the Workplace in order to Complete the Bricklaying Process	4	5	5	4	4	4
Minimum Number of Visits to the Workplace in order to Complete the Bricklaying Process	2	1	1	1	2	1
Average Number of Visits to the Workplace in order to Complete the Bricklaying Process	3	3	3	3	3	3
Median Time Between Visits (days)	5	2	4	3	5	5
Number of Workstations Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications Observed	**0**	**10**	**5**	**22**	**0**	**11**



Median Number of Visits to the Workplace in order to Complete the Bricklaying Process



Median Time Between Visits

This sequential mode of production, and the lack of production input at the design stage, were the main contributors for this situation. In addition, schedules were aimed solely at gains of production using large batches. This practice resulted in even more waiting time since the bricklaying process was, in general, highly variable. The waiting time between finishing one process (e.g. bricklaying) and starting another (e.g. plastering) was often counted in weeks or even months. Discussion with the workers indicated that, in the main, they were unaware of the effect that so many visits had on their efficiency and, therefore, they were not motivated to reduce work-in-progress to a minimum.

In all sites visited there were more examples of bad practice than good practice with respect to work-in-progress. The counter effects of the examples of bad practice replicated the expected results predicted by important writers such as Monden (1998) and Shingo (1988). In particular, the clearest counter-effect was the increase in cycle time and concomitant increase in the reworking due to the lack of continuity of processing activities.

Bricklayers often postponed the construction of difficult parts of their brickwork activity in order to sustain high levels of productivity by concentrating on the large and repetitive parts of the work available. One important cause for this practice was the bonus system that favoured high volumes of production, rather than efficient production. In this respect, most of the bricklayers could see a 'nothing in it for me' situations in terms of their reduction of work-in-progress. Therefore, reduced work-in-progress had not became part of their normal operational procedures. Exceptions for this were a few isolated examples of practices matching the theory.

b) Individual Case Study Reports

b.1) Case Study 1

This was a site where there were no activities matching the approach of "reducing the work-in-progress" (*see* Table 5.2). Although bricklayers clearly understood the approach, none had completed the cycle of bricklaying in just one visit. The lack of workflow planning made the situation even worse since there were conflicts between the flow of equipment and the flow of material, increasing the waiting time for each brickwall. In addition, managers seemed to have conscientiously placed the workstations at extremely long distances from each other. Not surprisingly, the waiting

time to complete a particular wall was invariably longer than the time spent strictly in the processing activities.

b.2) Case Study 2

This case study offered the best overall situation in terms of work-in-progress, both in terms of the waiting time between visits and the number of visits necessary to complete all bricklaying operations (*see* Table 5.2). Discussions with the workforce and managers revealed that the "literal replications" identified happened due to a mix of good design solutions and the active involvement of subcontractors on workflow planning. The reduction of distances enabled labourers to keep a smooth supply of materials and reduced the chance of unnecessary movement among bricklayers. However, the reduction of work-in-progress in the bricklaying activity was not followed by important complementary practices such as "measuring, finding and eliminating the root cause of problems' or the "installation of visual controls". This situation compromised the "reduction of work-in-progress" on this site.

b.3) Case Study 3

This site was generally very poor in terms of bricklayers trying to reduce work-in-progress, with only "five literal replications" among the forty-five workstations analysed. Discussions with the site manager made the reasons for this much clear. He had little understanding of the implications of such an approach. He concentrated his attentions on cash-flows and deadlines without having a clear notion of the cost production inefficiencies. Table 5.2 shows that this site presented one of the longest periods between each visit to the workplace (five days).

Even the best 'literal replication' observed were not produced by bricklayers, but by carpenters who came to the workplace to carry out their operations immediately after bricklayers had reached the level of the wooden slab (*see* illustration on Figure 5.5). Their materials had been delivered on the previous day and the tools required for the job were ready on the carpenter's van. At this point of the operations, bricklayers continued their activities in another building or the same construction site. Four days later, just when the carpenters had finished their job, bricklayers came back to continue their work. There was almost no waiting time between these two processes.



Figure 5.5 - Literal Replication of Work-in-Progress Reduction (Case Study 3)

The production batch was too large in relation to the number of bricklayers and equipment available. This practice resulted in the opening of too many fronts of work at the same time and, consequently, an increase in the volume of work-in-progress and transportation. The more time labourers get involved with unnecessary transportation the less efficient the main value-adding activity was.

b.4) Case Study 4

This site presented a low level of work-in-progress in comparison with the other cases studied. Twenty-two workstations finished all activities in just one visit to the workplace. Moreover, the average time between visits to a workplace on this site was better than most other case studies. The approach was more evident on the interface between bricklaying and electrical installations. Technological innovations in design and materials allowed electricians to install part of their electrical fittings in parallel to the bricklaying activity. These innovations produced some clear benefits to the interface between these two processes such as the reduction of rework, simplification and early correction of mistakes. Foremost, electricians also reduced the amount of visits necessary to complete their operations.

b.5) Case Study 5

This case showed no 'literal replication' and presented a poor performance in all indicators used for assessing work-in-progress. One of the best examples of 'theoretical replication' documented on this site was the excessive waiting time to construct brickwalls around the vertical pipes (see Figure 5.6). These walls were small and complex, and this reduced the bricklayer's productivity. Therefore, the usual practice of

the bricklayers was to leave the construction of these walls until the end of the work. In addition, there was a lack of synchronisation with plumbers. This forced bricklayers to delay the construction of these walls even further.

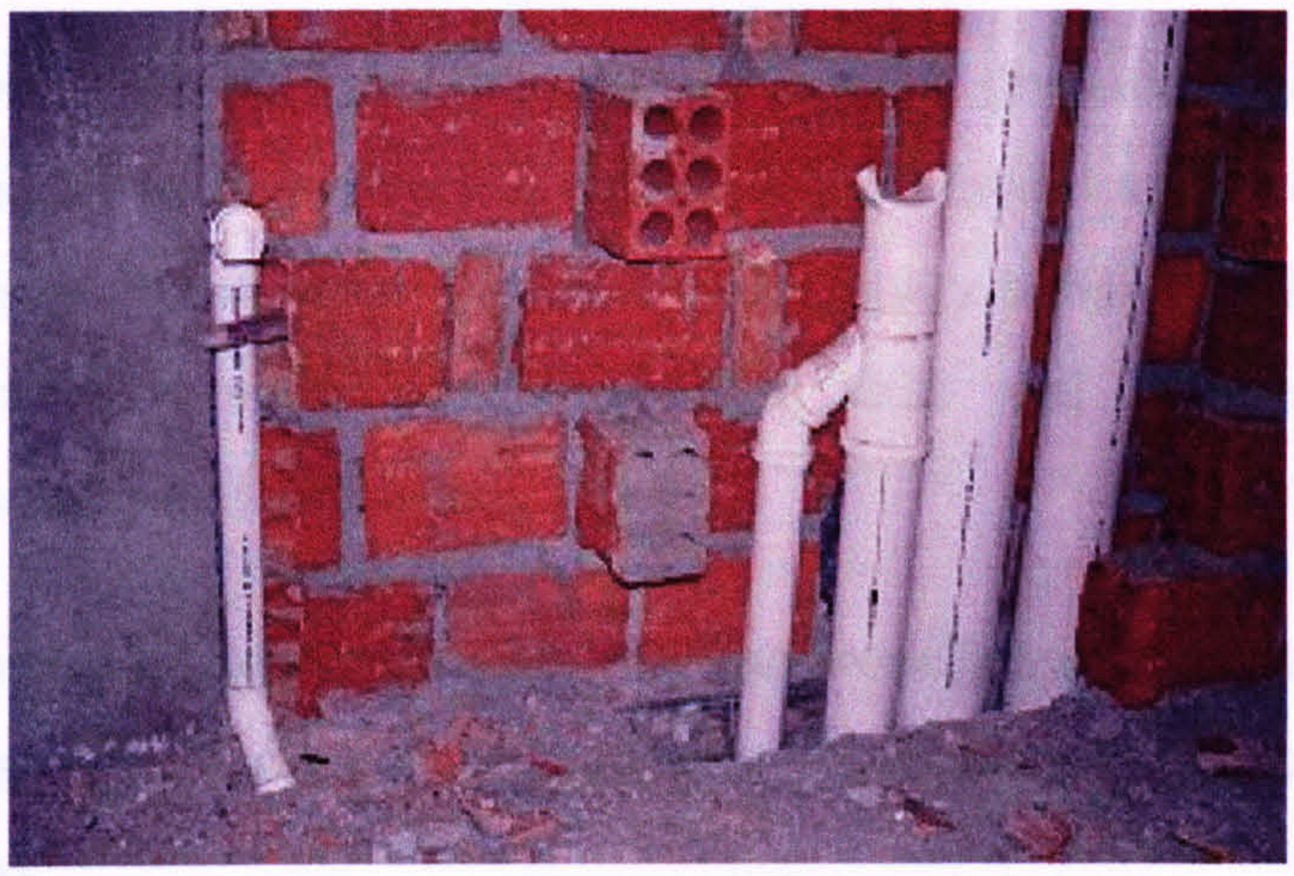


Figure 5.6 - Theoretical Replication of Work-in-Progress Reduction (Case Study 5)

With practices such as the one described above, more time was wasted due to unnecessary movements since the bricklayer had to come back to the workplace many times to do small amounts of work. Adding to this problem, the movements of workstations within an area, where brickwalls have already been built, were extremely difficult. Thus, despite the initial productivity gains on the conversion activity, the total cycle time was far below that possible.

b.6) Case Study 6

Only eleven workstations in this case study concluded all their operations in just one visit to the workplace. Like on Case Study 4, technological innovation was the main factor enabling these "literal replications" to occur on this site. Nevertheless, this construction site had a larger level of waiting time than Case Study 4 due to poor planning, poor communication and lack of teamwork between managers and bricklayers. Furthermore, the pathways were often congested due to the constant movement of workstations back and forth. Managers acknowledged the problem but focused their efforts solely on the design aspects.

5.3.2.6 DISCUSSION

The clear message obtained from the evidence collected within the six case studies was that:

i. Most of the bricklayers and managers failed to give adequate consideration to the need for reducing work-in-progress. Bricklayers preferred to do easier and faster jobs first in order to receive productivity bonuses earlier and managers were usually more concerned with cost and deadlines, rather than effectiveness and efficiency;

ii. Most of the bricklayers neither plan the workflow in order to reduce work-in-progress nor question their managers about excessive volumes of work-in-progress.

Koskela's (1992) criticisms of the traditional conversion model proved to be well founded in this context. Indeed, the problems mentioned above rest upon the concept that production is a process of conversion of inputs into outputs. The actions of production managers in most case studies reflected this since they had disregarded the importance of reducing or even eliminating waiting time in production flows. Furthermore, the typical mass production mentality among construction managers leads to production schedules aimed solely at gains of scale, with little concern for the increase of work-in-progress. All these factors demonstrate that the reduction of work-in-progress, as well as the reduction of batch size demands a radical change in the very deep roots of thinking among managers working in the construction sector. Construction workers and managers need to be better informed of the potential benefits of reducing work-in-progress, despite short-term implications on productivity levels

The case studies also showed a poor level of integration between reduction of work-in-progress and other important complementary implementation approaches. This is at odds with examples of best practice described in the literature. The reduction of work-in-progress in a construction process is not only connected with the reduction of waiting time, but also with batch size reduction. Indeed, according to Shingo (1988), all operations in a batch unit should finished completely before the production of another batch unit starts. Thus, producing one batch unit at time, without waiting time between

operations, is the point where "reduction of work-in-progress" and "reduction of batch size" converge in practice.

The analysis of empirical evidence shows that "reduction of work-in-progress" can easily be misunderstood with the approach "consolidation of steps in the process". The latter usually implies some technological innovation in order to group various operations to eliminate waiting time. For, the more segmented and interconnected a process the more likely it will produce a waiting time which itself increase due to the queuing effect, if the sources of variability are not properly solved. Therefore, technological innovations have an important role in reducing the number of visits to the workplace. However, the interpretation of "reduction of work-in-progress" in this thesis places greater emphasis on those managerial decisions where technology itself does not necessarily need to be changed. So, the focus here is on those typical non value-adding activities present on construction sites, since they often contain great potential for improvement.

Another difficulty in identifying practices matching the reduction of "work-in-progress" is the need for anticipating the future movements of workstations. Most construction sites analysed in this research did not have a workflow plan and, therefore, did not have a clearly defined transfer batch. This difficulty extended to the identification of the exact location and duration of movements of the workstation when the observer is not on site. The present research used conversations with the workforce and open-ended interviews as an instrument to reduce doubts in this respect.

5.3.2.7 CONCLUSION

Although the "literal replications" observed in these case studies suggest that "reduction of work-in-progress" is a valid approach in construction, all construction sites visited during this research presented a poor performance in this respect. One important reason for this situation was the existing bonus system that favoured high volumes of production rather than efficient production. The sequential mode of production and the poor levels of design constructability also contributed to the poor performance of case studies in this respect.

5.3.3 MINIMISATION OF DISTANCES

5.3.3.1 WORKING DEFINITION

This approach has been simply defined in this thesis as the reduction of physical distances within the workstation (micro distances) as well as across the entire bricklaying process (macro distances).

5.3.3.2 OBSERVATIONAL FOCUS

Observations here focused on the duration and quantity of the various transportation activities throughout the process flow. Video recording and photographs documented the position and distances between process stages from the first visit on site. A 'process maturity' checklist was also used to position each construction site against minimum transportation practices. Flow charts were also used to describe the various process stages as well as respective distances. A layout diagram located the position of workstations, storage, facilities and the most regular pathways. Daily observations during two weeks on site enabled the researcher to establish if the status of flows documented in the first visit represented the regular situation. Work-sampling (or time-lapse video recording) was the systematic technique used to follow the interaction between bricklayers and the flow of material. Open-ended interviews contributed to confirm whether the site personnel had a genuine preoccupation with the reduction of distances within the production process. Questions asked usually relating to the frequency of layout revisions and workflow planning. Analysis of documents and archival records produced useful information that helped to check the accuracy of those answers. A "literal replication" was confirmed when the empirical evidence unveiled a clear intention of either managers or workers to reduce distances within the process flow.

5.3.3.3 KEY INDICATORS

Following the adopted working definition, the most obvious indicator of "minimisation of distances" would be the transportation distances themselves. However, transportation distances vary greatly in practice and always depend on the characteristic of each site. In this way, the researcher established two alternative indicators, as follows:

a) *Number of Bricklayers per Labourer:* good workflow planning should enable various bricklayers to use fewer labourers. In this way, this indicator gives a direct measure on the situation of bricklaying distances within a construction site;

b) *Number of Revision in Layout per Month:* in construction sites with low uncertainties, proper layout planning should be able to anticipate all necessary changes in layout throughout the entire project. In such cases, little or no revision in layout planning would be required. Unfortunately, most construction sites contain a high level of uncertainty and variability and this demands constant revision of layout planning. Thus, the commitment of management towards minimisation of distances should reflect on the number of revisions in layout planning. This research obtained confirmation of this through direct observation and open-ended interviews. It then cross-checked the answers with documents and archival records available on site.

5.3.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and practical boundaries for the indicators described above are, as follows:

a) *Number of Professionals per Labourer:* Pigott (1972) argues that there must be an optimal level of bricklayers per labourer in each workstation and that, beyond that level, production performance decays with the increase of bricklayers. According to Pigott's (1972) research, two bricklayers to one labourer (2:1) or three bricklayers to two labourers (3:2) represents an efficient gang composition. However, observations on the case studied showed that it was possible to be highly efficient using three bricklayers to one labourer (3:1). Thus, the researcher adopted 2:1 and 3:1 compositions as the practical boundaries for this indicator;

b) *Number of Revision in Layout per Month:* based on the opinions gathered from open-ended interviews the researcher defined the practical boundaries for this indicator as being between one to four revisions a month. In the opinion of workers and managers, more than one revision a week would have hard negligible effect on performance enhancement since sites did not change at that speed.

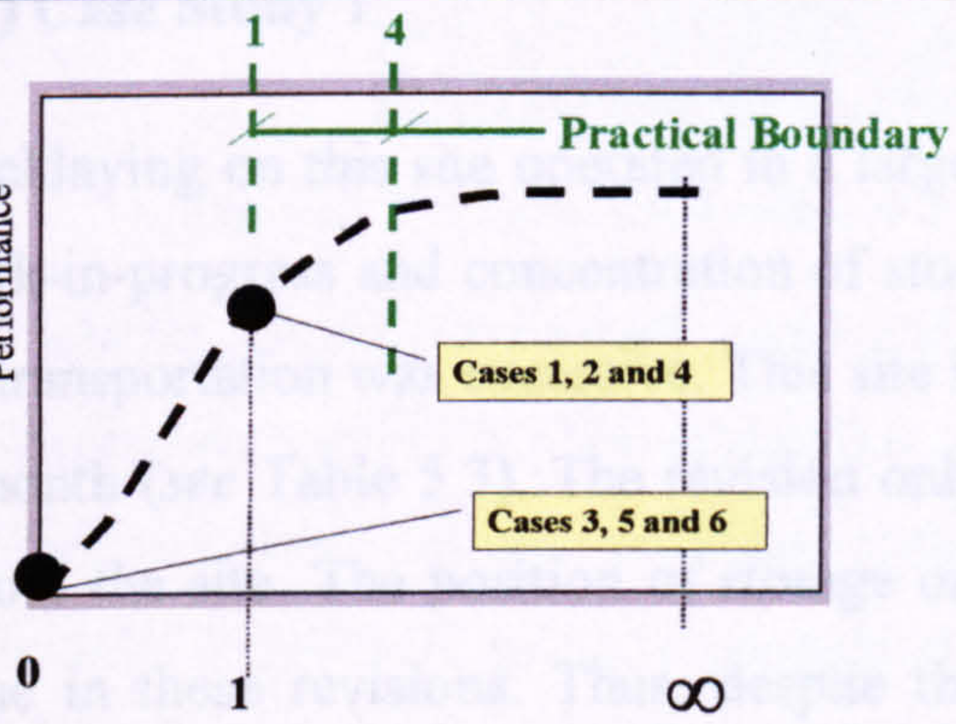
5.3.3.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

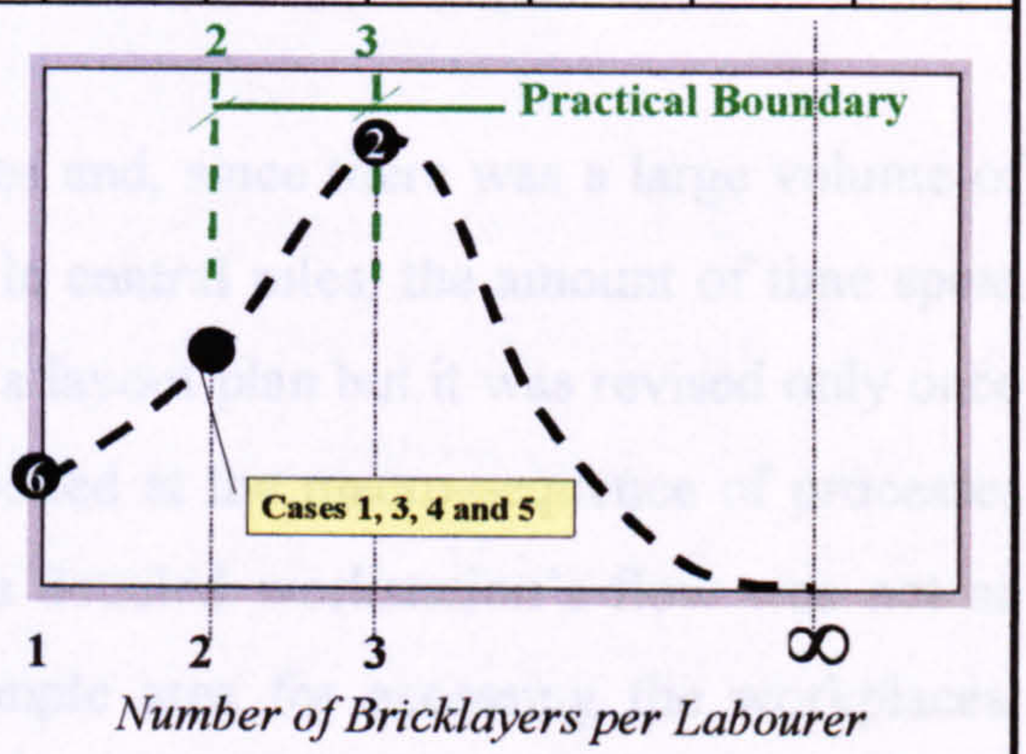
Observations have shown great differences in the practice of distance minimisation across the cases studied. Poor workflow and layout planning and a lack of communication between managers and workforce were the main causes for the excessive distances recorded (see Table 5.3). The sites presenting shorter distances benefited from good communication by reducing the number of labourers on site, reducing the number of process stages and making better use of the production capacity available. This beneficial practice also enabled those sites studied to reduce batch sizes and improve the visibility of process stages.

Table 5.3 – Performance of Case Studies Regarding *Minimisation of Distances*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Bricklayers	6	6	2	4	3	8
Number of Days Observed	10	10	15	10	10	6
Number of Bricklayers per Labourer	2	3	2	2	2	1
Number of Revision in Layout per Month	1	1	0	1	0	0
Check-list of Process Maturity (%)	43	69	28	49	36	43
% of Bricklayer's Time Spent on Transport	-	8	15	10	8	-
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**4**	**8**	**0**	**6**	**4**	**4**



Number of Revision in the Layout Planning/Month



Number of Bricklayers per Labourer

Unfortunately, managers did not share the responsibility for layout planning with their workforce and this had a visible impact on the implementation of such plans. This low level of workforce participation resulted in a reduced number of ideas for improving

positions and pathways. Thus, inconsistencies of layout plans, when implemented in practice were often ignored or put aside, even when there were costly consequences in not doing this terms of long transportation distances and difficult pathways.

On the worst construction sites, the practice of managers and the workforce clearly reflected an intense use of the "conversion model". Bricklayers concentrated their attention exclusively to the main bricklaying activity and gave little attention to the difficulties of labourers with long transportation distances. When asked they appeared to understand regarding this problem, but the daily practices did not reflect the content of their words. Likewise, the managers concentrated their attentions on the speed of the main value adding activities and availability of material on site, and not on the flow of materials. In this situation, all process stakeholders went around a central problem identified on site - the large number of non-value adding activities relating to long distances[2].

There had been no ergonomic studies of bricklaying in the companies analysed and all managers demonstrated a complete lack of understanding about the importance of ergonomics to improve their production performance and the quality of life of their workers. Hence, the workstations were not properly designed to reduce distances and, thus, improvisations were regularly practised among bricklayers.

b) Individual Case Study Reports

b.1) Case Study 1

Bricklaying on this site operated in a large area and, since there was a large volume of work-in-progress and concentration of stocks in central piles, the amount of time spent on transportation was excessive. This site had a layout plan but it was revised only once a month (*see* Table 5.3). The revision only looked at the macro-sequence of processes across the site. The position of storage or the detailed workstation's flow was not an issue in these revisions. Thus, despite the ample area for accessing the workplaces, pallets of blocks and containers of mortar were generally far from the workplaces. The

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[2] James Womack shared the opinion that construction people constantly try to avoid the hard issues to become a leaner environment (seminar attended in Berkeley, CA, 29th July 1999, organised by the Lean Construction Institute)

most clear "literal replication" identified on this site was the workstation for cutting blocks. It had been conscientiously positioned to give rapid access to all bricklaying workstations.

b.2) Case Study 2

Case Study 2 presented an excellent and consistent attention to layout and workflow. Effective layout and workstation flow planning enabled this site to have only one labourer to every three bricklayers. The detailed description of these plans was open to the workers and the implications to subcontractors were even included in the regular safety training given on site. Furthermore, a constant concern of the subcontractor was with the co-ordination of the workstations in order to maintain, at least, two bricklayers next to each other (*see* Figure 5.7). The supply of material was much easier and the labourer could dedicate his time to help more bricklayers in this situation and, consequently, bricklayers could have higher focus on the value adding activities.



Figure 5.7 - Literal Replication of *Minimisation of Distances* (Case Study 2)

This site presented 69% of all 'applicable' practices listed on the 'process maturity' checklist (*see* Table 5.3). The researcher observed that all process stages were planned to maintain the shortest possible transportation distances throughout the entire observational period. The daily co-ordination of workflow and the position and size of the storage compound, in particular, had allowed easy access and transportation of any material.

b.3) Case Study 3

This case study presented the poorest level of practice in terms of 'minimisation of distances'. Only 28% of the 'applicable' items of the 'process maturity checklist' were identified on this site. Poor layout planning resulted in piles of blocks and cement being positioned far from the bricklaying workstation. Truck-drivers used to unload pallets where it was more convenient from their point of view and not from the point of view of the construction flow. Bricklayers rarely interfered in layout planning since they were focused solely on the conversion activity, despite the fact that bricklayers themselves spent 15% of their time in transportation activities (*see* Table 5.3). Conversations with the site manager made it clear that his main concerns were with the schedule and financial control. According to his view, waste with respect to non-value adding activities identified by this research were already included in the original budget and, furthermore, it would be recovered with the commercial gains at the end of the construction works.

Another critical practice that had strong effects on the increase of distances on this site was the size of the production batch, as discussed earlier in this chapter. The construction of two houses simultaneously resulted in an increase of transportation stages, greater transportation distances, difficulties for communication and poor co-ordination of resources. Labourers had to cross from one house to another in search for tools, materials and equipment. In addition, the scaffolding had to move across the houses constantly in order to maintain the workstation flow.

b.4) Case Study 4

Case Study 4 did not have a formal layout plan, but the actions observed on site revealed that the continuous improvement of layout was among the foreman's main responsibilities and concerns. According to the foreman, the site layout was reviewed monthly and the main reason for this was simply the regular presence of clients on site. The efforts to improve transportation practices on this site reflected in the reduced number of process stages and on the identification of 49% 'applicable' items from the 'process maturity check-list' (*see* Table 5.3).

The most clear "literal replication" identified on this site was the definition of the position for a wastage disposal. Since the site did not have a wastage container, the

foreman established for that purpose a specially designated area, very close to an elevator and with easy access from different angles. It is worth emphasising that he made it clear to the researcher that his true desire was to reduce waste and, thus, eliminate the need for a wastage disposal. However, until this happened he defended the need for reducing the time wasted in transporting waste.

b.5) Case Study 5

This case study presented a great number of situations with long transportation distances that resulted in the negative effects anticipated in the theoretical framework. Figure 5.8 shows one example of these *theoretical replications*. The storage of blocks on this site exceeded the height of the labourer's shoulder. This situation made the activity extremely difficult in ergonomic terms and compromised the safety of labourers every time they had to climb the pile. The direct consequence of this improvisation was more time consumed on transportation, with direct effects on the smoothness of flows.



Figure 5.8 - Theoretical Replication of *Minimisation of Distances* (Case Study 5)

The transport system demanded excessive number of process stages. Bricks were loaded into a trolley and then transported to pavements where they had to be unloaded again. The workforce did not have any saying in these problems, and the manager did not express concerns about this since his main attention was on schedule control. During the open-ended interviews, the site manager and the foreman expressed their lack of information regarding the cost of non-value adding activities in relation to the total building costs. This might explain their apathetic reaction to the long transportation distances identified by this research.

b.6) Case Study 6

In this case study, long transportation distances associated with poor workflow plan resulted in the worst gang composition among the case studies: one bricklayer to each labourer. Such composition should have resulted in a higher concentration of bricklayers in the main value adding activities. However, analysis of the time-lapse videotape showed that bricklayers had to move constantly out of the workplace in order to get material, tools and equipment. Here, like in most of the case studies, the site manager only emphasised the control of the macro flow of processes and paid little attention to the detailed flow of workstations.

5.3.3.6 DISCUSSION

The main lessons from the analysis of this approach in construction are, as follows:

i. Layout and workflow planning was not developed and revised systematically in most construction companies analysed in this research. In addition, none of the companies was developing ergonomic studies for improving the workstations. Hence, minimisation of distances was mostly a matter left to bricklayers decide for themselves;

ii. Bishop (1965) and Thomas, Sanvido & Sanders (1989) indicated that transportation is one of the most time-consuming activities in the construction industry. Nevertheless, the case studies have shown that the minimisation of distances is still not considered as sufficiently an important issue by construction managers to do something about it. Interviews with managers suggest that lack of information on the actual cost of transportation and movement activities was the main cause for this apathy;

iii. The most direct impact of long transportation distances was on the inefficient use of labourers and, consequently, this resulted in poor gang compositions.

The application of the approach 'minimisation of distances' in construction can be seen and assessed in relation to three different stages of process maturity. Companies in the first and most basic level should have a formal layout plan of the construction site. These companies should reveal significant attention to factors that affect macro

distances such as the position of the storage area and pathways. Companies reaching the second level should dedicate efforts to detailed workflow planning, trying to avoid situations such as the enclosure of workers in small spaces or the simultaneous presence of different gangs in the same workplace. Finally, in the third level would be those companies developing ergonomic studies aimed at reducing the smallest movements in the workstations, and trying to make them safer. According to this classification, most of the cases studied in this research barely reached the first level of maturity in terms of 'distance minimisation'.

None of the cases studied in this thesis developed ergonomic studies. However, the meta-case offered many examples of construction companies striving for a better environment based on ergonomic parameters. Figure 5.9, for instance, shows the equipment design to support a properly designed box of mortar. Because this support equipment has two wheels, it can easily follow the bricklayer's flow wherever he goes in the workplace without demanding too much effort. In traditional practice, such a box of mortar would be placed on the floor or on fixed scaffolding. Consequently the bricklayer would perform repetitive uncomfortable spinal movements and, with likely consequences that they would be slower than the bricklayer shown below.

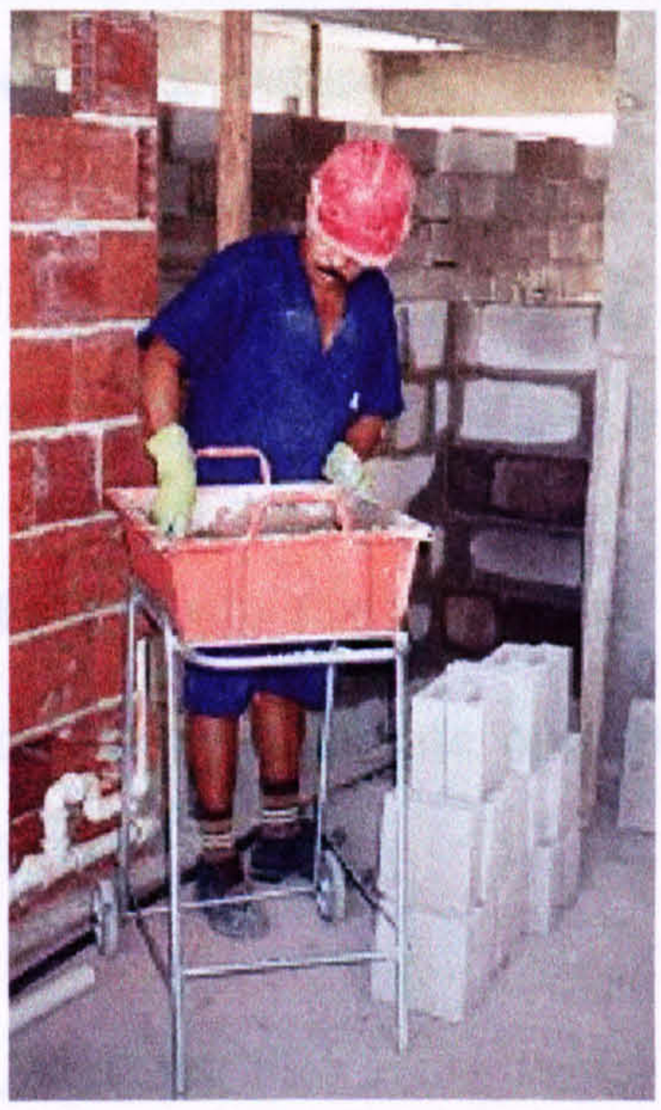


Figure 5.9 - Literal Replication of *Minimisation of Distances* (Meta-Case)

Reflection upon the empirical evidence led to the conclusion that actions aimed to minimise distances in construction are more likely to be successful if they involve both indirect means (e.g. training, planning, visual indications) and direct means (e.g.

physical barriers, limit switches). *Indirect means* should focus on the maintenance of short distances within layout and workstations by increasing the workforce commitment and attention. It would be time consuming and ineffective to maintain managers controlling and improving every single aspect of operations. Optimum arrangements should become a normal practice among the workforce, without the need of managerial control. *Direct means*, on the other hand, focus on the flow of materials alone and include those devices built into workstations designed to avoid excessive distances. In many instances these devices may even operate independently from the worker's own will.

5.3.3.7 CONCLUSION

The empirical evidence showed that construction does use "minimisation of distances" but in a very non-systematic manner. Indeed, most of the case studies did not pay enough attention to layout plan and even less on workflow effectiveness. None of the companies studied was aware of the importance of developing ergonomic studies. Since construction uses mobile workstations, there is a demand for more sophisticated interpretations of this approach, than those often presented in construction textbooks. A major need in construction practice is to find ways to integrate all perspectives within a single coherent set of actions to reduce distances.

5.3.4 ISOLATION OF VALUE ADDING ACTIVITIES FROM SUPPORTING ACTIVITIES

5.3.4.1 WORKING DEFINITION

This approach means to externalise or eliminate operations interfering with the main value adding activity of bricklaying.

5.3.4.2 OBSERVATIONAL FOCUS

The focus of observations in this context was centred on all activities interfering with the continuity of the bricklaying main value adding activity: assembling bricks and mortar on brickcourses. Any activity interrupting the smooth and continuous flow of this activity should be removed or eliminated from the main flow. With this in mind, the

researcher drew flow charts of each process in order to map the path of material, from delivery on site to arrival at the workstation. Photographs and video recording helped to build a detailed description of all bricklayers' main activities during a working day. In addition, the work-sampling techniques imposed a discipline on the daily observations that were useful for establishing how focused bricklayers were on the main value adding activity. Time-lapse video recording was the tool used in some of the case studies as an alternative to work sampling. The observations were continuously compared with previous case studies in order to establish the main differences and bring further insights.

5.3.4.3 KEY INDICATORS

Three indicators were helpful in the pattern-matching process:

a) *Number of bricklayers per labourer*: as explained earlier in this chapter, the analysis of workstation's flow and work sampling against this indicator shows how efficient the use of labourers on site is. The ideal situation would be to have workstations with synchronised movement that allows labourers to support more than one workstation without compromising the bricklayer's focus on the value-adding activity;

b) *% of Auxiliary time* and *% of Productive time:* both indicators were obtained through the work-sampling technique. Bishop (1961) argues that there will always be some auxiliary activity in any productive process (e.g. transport). However, considering that bricklayers usually had the support of labourers in all case studies, they should spend a reduced proportion of their time on auxiliary activities. Obviously, the higher the focus bricklayers have on value-adding activities the higher the percentage of productive time.

5.3.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The literature and previous research carried out by the author were the main source of information for establishing the expected behaviour and practical boundaries for the indicators above, as follows:

a) *Number of bricklayers per labourer*: the works of Pigott (1972) and the observation of the case studies in this research suggest that the minimum is two bricklayers and a practical limit is three. Hypothetically, after three bricklayers the production performance would reduce since the level of support from labourers would be increasingly more difficult. The analysis will investigated whether this would occur in practice, or not;

b) *% of Auxiliary time* and *% of Productive time:* previous research carried out by the author (Santos, 1995) and the work of Thomas (1991) suggested the practical boundaries for these indicators (10 to 25% and 40 to 60% respectively). However, a hundred percent of productive time among bricklayers is impossible in practice since people need time to relax and carry out their own personal hygiene, etc. In the same way, a zero percent of auxiliary time would be the ideal situation, but flow constraints still demand some level of auxiliary activity from bricklayers.

5.3.4.5 SUMMARY OF RESULTS

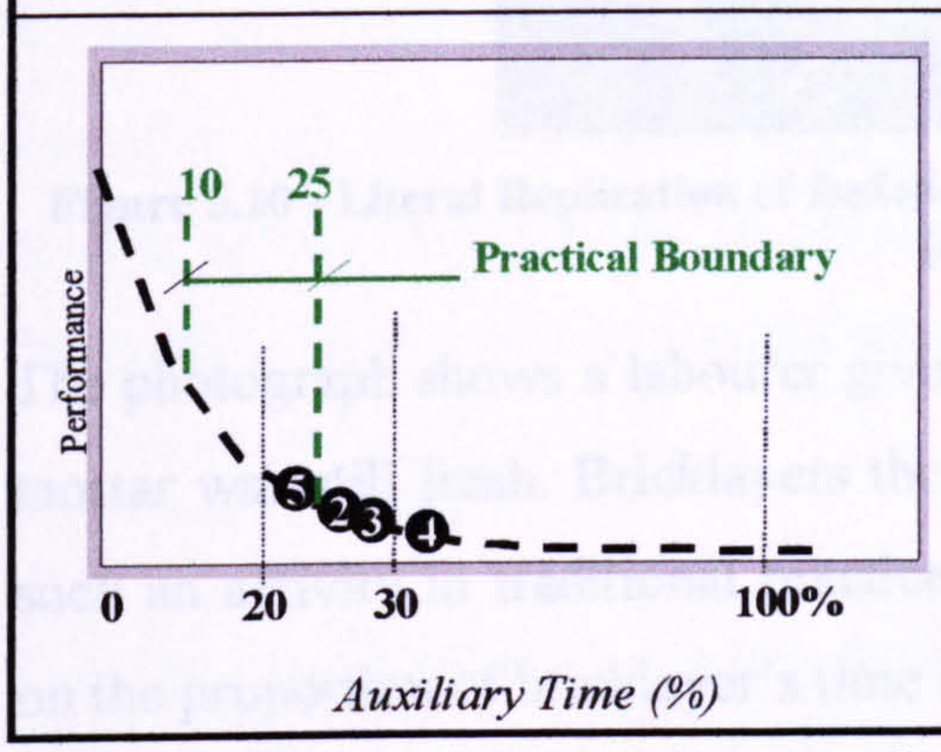
a) General Pattern Across All Cases

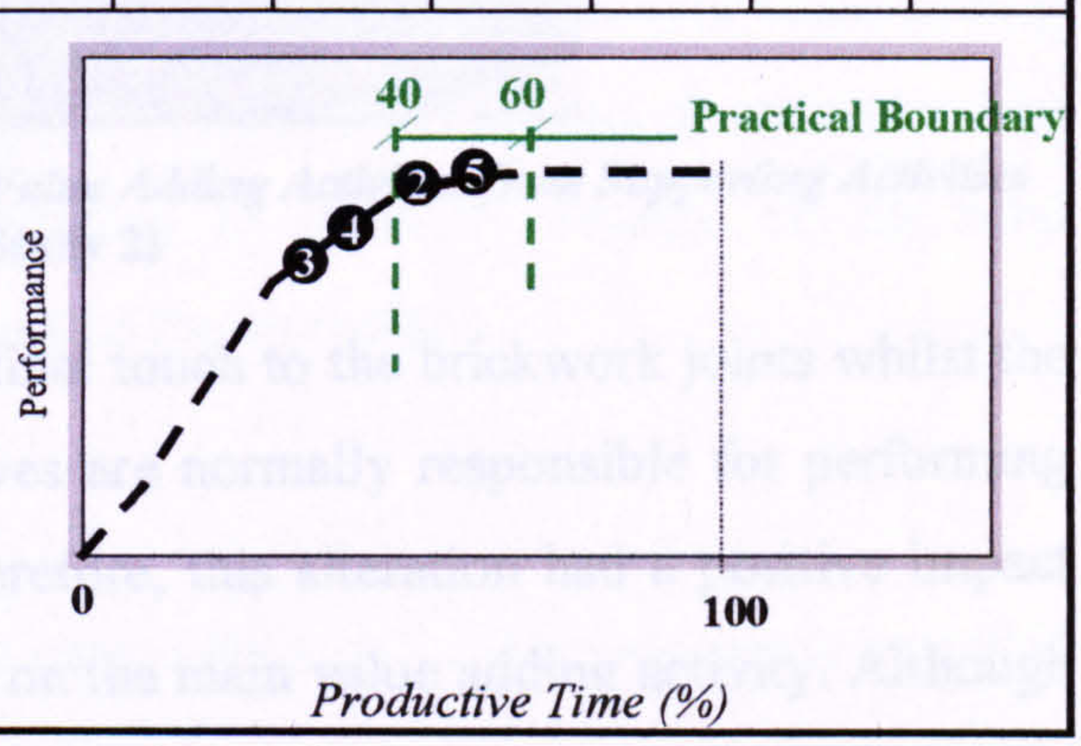
There was a fairly low proportion of production time noted in all case studied with concomitant increase in support activities. This was caused by poor consideration of workflow planning and deficient process design in the first place. Deficient layout and workflow planning resulted in greater percentage of auxiliary activities among bricklayers, as presented on Table 5.4. Supporting (auxiliary) activities such as transport and measurement were the most significant among the auxiliary activities. Analysis of videotapes on the case studies using time-lapse revealed the same pattern.

It was not possible to identify a pattern between the frequency of "literal replications" and the proportion of "value-adding activities". In other words, workstations where the bricklayers were extremely involved in transporting and measurement activities presented examples of supporting activities being externalised. Focus on value-adding activities is not necessarily a signal of good performance of the process if it is not matched by good performance of the flow. Furthermore, excessive use of labourers and wasteful processing activities had overshadowed the benefits of reducing the auxiliary time among bricklayers in some of the case studies.

Table 5.4 - Performance of Case Studies regarding *Isolation of Value Adding Activities from Supporting Activities*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	10	10	15	10	10	6
Number of Bricklayers per Labourer	2	3	2	2	2	1
Number of Bricklayers Observed	6	6	2	4	3	8
Number of Observations (work-sampling)	*	647	397	580	646	*
Productive Time (%)	*	48	37	38	52	*
Auxiliary Time (%)	*	28	29	36	24	*
Number of Workstations Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**6**	**12**	**1**	**22**	**6**	**10**





* It used time-lapse video recording as an alternative to work sampling

b) Individual Case Study Reports

b.1) Case Study 1

Six of the twenty two workstations observed during the ten days of data collection on this site presented some activity moving out of the normal operations of bricklayers (*see* Table 5.4). Usually this activity involved the cutting of blocks on the saw machine or the improvement of joints after the construction of the wall. Despite these "literal replications" of attempting to give more continuity to the main value activity, there was also an excessive proportion of transporting and measurement activities on this site, as discussed earlier.

b.2) Case Study 2

This case study presented the best focus on value adding activities (*see* Table 5.4). Labourers performed activities traditionally carried out by bricklayers and, yet, this case study had more bricklayers per labourer than the other case studies and presented a level

of auxiliary time close to the boundaries established in this research. Figure 5.10 shows a visual evidence extracted from Case Study 2 where an activity usually performed by the bricklayer was removed from the main value adding flow.



Figure 5.10 - Literal Replication of *Isolation of Value Adding Activities from Supporting Activities* (Case Study 2)

The photograph shows a labourer giving a final touch to the brickwork joints whilst the mortar was still fresh. Bricklayers themselves are normally responsible for performing such an activity in traditional practice. Therefore, this alteration had a positive impact on the proportion of bricklayer's time spent on the main value adding activity. Although the operation was simple, it contributed to giving the labourer a higher sense of empowerment and a feeling of progress.

b.3) Case Study 3

This case study presented only one "literal replication" of this approach among the forty five workstations observed (*see* Table 5.4). This literal replication was exactly the same type as the one described in Figure 5.10. Unfortunately, supporting activities constantly interfered with the value-adding activity during the entire fifteen days of observations with all other workstations. Transport of material, in particular, took an excessive time between bricklayers and labourers due to the long distances between workstations and storage. The high level of involvement of bricklayers on supporting activities reflected on the relative low level of productive time measured by the work-sampling technique (37%). The practice of large transfer batches also contributed to an increase in the distances between workstations and, consequently, affected the level of support given by labourers.

b.4) Case Study 4

The 580 snapshot observations carried out by the work-sampling technique showed that the bricklayer spent around 36% of his time with auxiliary activities on this site. Bricklayers spent a great part of this auxiliary time with 'measurement activity' and in helping set-up operations. In this latest aspect, this site clearly showed that planning the workstation flow is a critical point to enable greater concentration of bricklayers on the value-adding activity. The set-up of operations has to be fast enough to enable good synchronisation in the movement of bricklayers from one workplace to another.

Despite the great percentage of auxiliary time among bricklayers, the researcher found twenty two examples of actual isolation of supporting activities from core value adding activities (*see* Table 5.4). Most of these literal replications referred to activities like cutting bricks, refinement of joints, installation of electrical fittings or the total completion of set-up before bricklayers arrived at the workplace.

b.5) Case Study 5

The forty workstations analysed during the data collection in this case study revealed only six "literal replications" of actual isolation of supporting activities from value-adding activities (*see* Table 5.4). The pre-fabrication of upper sills for doors and windows had removed a large number of supporting activities from the main value adding flow (*see* Figure 5.11).



Figure 5.11 - Literal Replication of *Isolation of Value Adding Activities from Supporting Activities* (Case Study 5)

In traditional Brazilian practice, bricklayers usually build these concrete components *in loco*, during the construction of walls. However, in Case Study 5 labourers used their

spare time and the excesses of concrete orders used in the concrete structure to pre-fabricate upper-sills. With the externalisation of these operations, bricklayers were able to carry out their activities faster and with fewer interruptions.

The support from bricklayers was satisfactory on this site and had enabled the bricklayers to perform the highest percentage of productive time among the six case studies (52%). Yet, the actual value added by bricklayers was questionable despite their high level of involvement with value-adding activities. Bricklaying would receive plastering over its surface and, because of that, the quality of finishing was quite poor. The manager himself spontaneously mentioned that there was an expectation of large quantity of problems with vertical alignment, with direct impact on the generation of rework in the processes following bricklaying. Discussion with bricklayers showed a great lack of concern regarding the effects of their job on the performance of subsequent processes.

b.6) Case Study 6

This case study revealed ten "literal replications" and all of them were quite similar to those that had been found in Case Study 4. Quality of design and the bricklaying technology itself were the key factors to determine the removal of some activities from the main value-adding flow. The practice of supplying half bricks to the site, for instance, was only viable due to a modularised design and low variability of the concrete structure. Still, analysis of time-lapse videotapes showed that bricklayers spent a great proportion of their time on auxiliary activities. This happened despite the gang composition on this site presenting the highest proportion of labourers per bricklayer. High variability of processes and material (e.g. dimensional errors) and poor workflow were the main factors contributing to this situation, as described earlier.

5.3.4.6 DISCUSSION

The lessons from the six cases studied regarding the isolation of value adding activities from supporting activities are, as follows:

i. Most of the sites observed already enabled good level of concentration of bricklayers on the value-adding activities. However, inefficient workflow and slow set-up operations constantly forced bricklayers to get involved with

supporting operations. The set-up operations, in particular, took too long to be completed and normally demanded some level of support from the bricklayer;

ii. It became clear the importance of design in enabling the externalisation of activities from the bricklaying process. Indeed, adequate solutions at the design stage could have reduced activities such as 'measurement' and the 'cutting of bricks' in some case studies;

The focus of bricklayers on the main value-adding activities depends very much on the level of synchrony between his movements and the flow of material and equipment. Improving the workstation's flow and speeding up the set-up operations is paramount to enable this synchrony. The externalisation of such supporting activities described by Shingo (1988) is usually based on the assumption that there is a 'sensei' (production expert) analysing the production process. However, none of the construction companies analysed revealed such a person. Thus, this approach will certainly demand better skills and knowledge from the construction workforce and managers.

This approach requires a better dialogue between management and workforce than had been witnessed in the cases studied. Managers usually assigned tasks to bricklayers without allowing them to reflect on the workflow and without making his contribution to smooth the supply of material on site. Bricklayers, on the other hand, did not have enough information regarding next tasks, and had little opportunity to express their views regarding flows to managers.

In this context, it can be said that the fundamental problem regarding the proportion of time spent with value adding activities was less to do with deficiencies in design, or technology, but with deficiencies in the production flows. Improvements in technology and design with the aim of separating supporting activities from value-adding activities has to be matched with reductions in the flow variability in order to be fully effective. Once this variability is removed from the process than it would be much easier to detect and separate supporting activities crossing the main value-adding flow.

5.3.4.7 CONCLUSION

The empirical evidence identified in practice supports the usefulness and applicability of this approach in construction. The observations also revealed that most of the supporting activities that have been incorporated in the main value-adding flow happened more due to inefficient flows rather than deficient process design. Therefore, construction companies would achieve better benefits from this approach if the process flows were sufficiently understood, stabilised and organised. Once this situation is in place there would be greater scope for a more profound and systematic analysis of the possibilities for further removal of supporting operations from the main process flow.

5.3.5 CHANGING THE ORDER OF THE PROCESS

5.3.5.1 WORKING DEFINITION

Change in the process order occurs when there is a clear change of precedence relationships within the bricklaying process or between bricklaying and other process.

5.3.5.2 OBSERVATIONAL FOCUS

The focus of observation for this approach was on the main value adding activity of bricklaying, i.e. the activity of placing mortar and bricks/blocks on the courses. A "literal replication" occurred when there were activities operating simultaneously, or in reverse order, in relation to the main bricklaying activity. Observation started during the exploratory visit with the development of a flow chart of the bricklaying process. The detailed observation of the main-value adding activity and its interaction with other processes was carried out through photographs and video recording. The first visit also supplied most of the information the researcher needed to analyse this heuristic approach. Nevertheless, daily work-sampling observations (or time-lapse video recording) were fundamental to the identification and clear understanding of the actual behaviour of the bricklaying flow.

5.3.5.3 KEY INDICATORS

Koskela (1992) asserts that, in practice, this heuristic often means to change sequential process stages from sequential to a parallel order. However, non-processing activities in

bricklaying change their sequence constantly throughout time and it would be quite complex to access their frequency in this respect. Moreover, it is not possible to expect parallel activities in bricklaying the same way as it is in machine-based processes. Hence, the consideration of 'parallel activities' as being those occurring in the workstation, within a limited period, seems more appropriate for the characteristics of this construction process. In this context, the indicator adopted was the "Number of Different Processing Activities Operating within Each Workstation". This was obtained by direct observation, or through questioning to bricklayers.

5.3.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The minimum value for the chosen indicator has been established based on information and opinions collected during open-ended interviews on site. Bricklayers in the English case studies reported that two parallel value-adding activities were normal practice in the sector, i.e. window-frame and door frame. The maximum value of five parallel activities was obtained by putting all parallel value-adding activities observed in this research together (e.g. window-frame, doorframe, electrical board, air-conditioner-frame and electrical fittings).

5.3.5.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

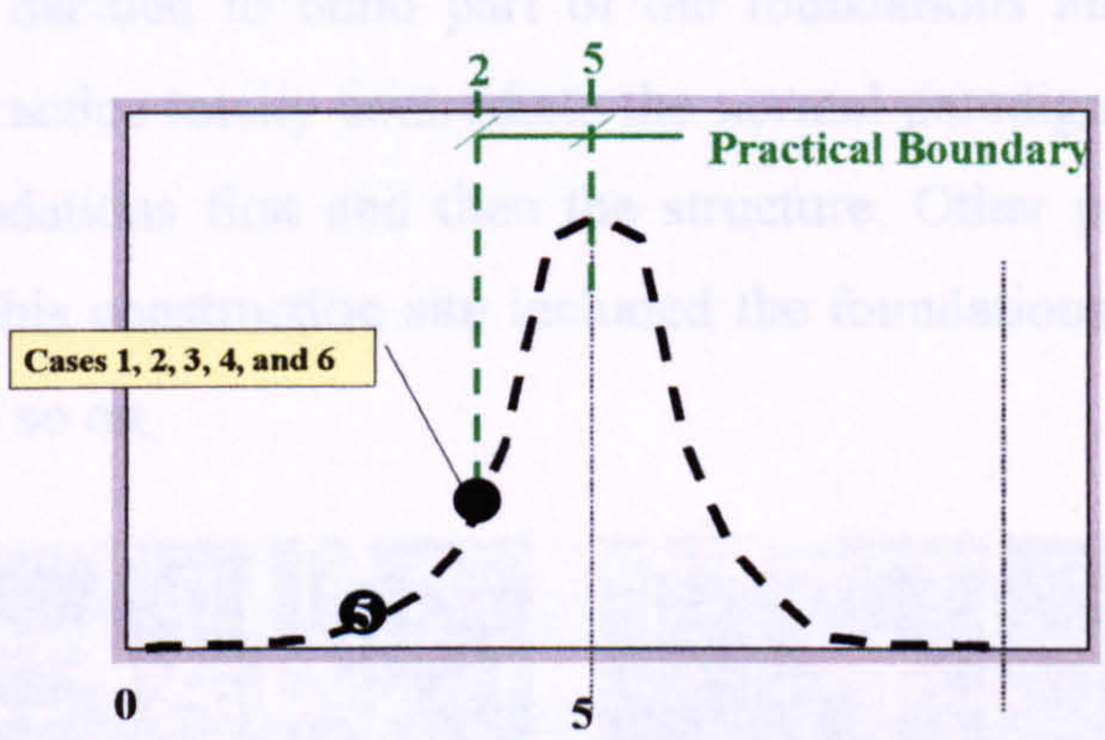
In the majority of case studies, the most significant and noticeable process changes happened on the bricklaying workstation. Bricklaying process stages outside the workstation usually followed dynamic routes where the sequential mode was prevalent. At the workstation, however, the researcher observed bricklayers carrying out, at least, one more value-adding activity while placing bricks on the wall (*see* Table 5.5). The most common parallel activities identified were the fixation of electrical fittings, window-frames and doorframes.

However, none of the case studies reached the maximum referential value established of five simultaneous parallel processing activities. According to most bricklayers, the main reason for them not to get involved in further parallel activities was the lack of a clear defined benefit in doing so. In their view, the use of many parallel activities would

result in a level of complexity that was bound to reduce their production rate and, consequently, their monthly bonus. They acknowledged the positive effect on the total construction cycle time but were not prepared to take on board more activities because there was no trust on the fairness of managers to share the benefits of such an improvement.

Table 5.5 - Performance of Case Studies Regarding *Change in the Process Order*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	10	10	15	10	10	6
Alternative Precedence Orders Between Upstream and Downstream Processes	2	2	2	2	2	2
Maximum Number of Different Processing Activities Operating within the each Workstation	3	3	3	3	2	3
Number of Workstations Presenting more than one Type of Processing Activity	8	14	12	28	6	16
Number of Workstation Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**8**	**14**	**12**	**28**	**6**	**16**



Maximum Number of Parallel Value-Adding Activities

Interpretation of the interviews with managers revealed that they did not intend to promote more parallel activities within bricklaying due to what they believe to be the already high variability of this process. Although the material delivered to some of the sites generally had good quality, the assembling process was highly variable and generated excessive quantity of waste and rework. In their understanding, more parallel activities would simply increase, even further, the amount of this waste and rework.

Additionally, managers expressed their lack of trust on the bricklayer's skills and commitment to handle more activities. Managers understood that changes in the process

order would imply trial an error, since the workforce had no training or experience in production analysis. That feeling was even stronger in those companies employing subcontractors since they believe the bricklayer would not remain with the company for the next projects.

b) Individual Case Study Reports

b.1) Case Study 1

In this case study, bricklayers placed window-frames and the damp proof course in parallel to the main bricklaying activity. Parallel activities were observed in eight of the twenty-two workstations analysed during this research. No more than three simultaneous parallel activities were witnessed at any workstation (*see* Table 5.5).

Although outside the bricklaying scope, this case study presented one of the most striking empirical evidence of creativity in the application of this approach. Pressured by the need of compressing time due to client demands, this construction company and structural engineers decided to build part of the foundations after the structure (*see* Figure 5.12). This practice totally contradicts the normal paradigm in civil engineering of building the foundations first and then the structure. Other processes operating in parallel throughout this construction site included the foundations, steel works, piping, drainage, ceiling and so on.



Figure 5.12 - Literal Replication of *Change in the Process Order* (Case Study 1)

b.2) Case Study 2

Fourteen of the twenty different bricklaying workstations analysed in this research presented more than one value adding activity (*see* Table 5.5). Usually the parallel activities on this site concerning the installation of pre-fabricated undersills or insulation of cavity wall. Interviews with bricklayers and managers revealed that they acknowledged the benefit of this practice on the total cycle time of the project. However, they complained about the difficult design details that made more difficult to operate parallel activities. Since their productivity was lower, the subcontractor had to make a different agreement with the bricklayers regarding productivity bonus. This agreement was based on the estimated proportion of the work in relation to the total price established in contract.

Clearly, all changes in the order of the process on this site occurred more due to an imposition of design than due to a deliberated decision of bricklayers or site managers. Nevertheless, some of the practices were already common among bricklayers and they did not perceive it as a design imposition. For instance, they did not see an alternative of placing concrete undersills other than parallel to bricklaying. When questioned about alternative process orders, bricklayers revealed little knowledge of other possibilities available.

b.3) Case Study 3

This case study had similar bricklaying technology as the previous case study but the design was far less sophisticated and incorporated fewer components. Thus, only twelve of the forty-five workstations analysed had more than the bricklaying activities simultaneously in operation. One important positive point in this case was the low variability of bricks that enabled the easy fixation of window and door frames and application of modularization exactly as defined in the drawing plans. Figure 5.13 illustrates the construction of walls parallel to the installation of doorframes:



Figure 5.13 - Literal Replication of *Change in the Order of Process* (Case Study 3)

Like in Case Study 2, the bricklayers on this site fully understood the implications of assembling bricks in parallel to other activities on the total cycle time. However, they saw this as a burden for achieving higher production rates and, consequently, to higher salary. When questioned about what possible changes they would make to reduce their cycle time, they answered that they would "reduce the number of parallel activities at the design stage".

b.4) Case Study 4

This construction site presented a high number of observations of parallel activities operating in the bricklaying workstations, as demonstrated on Table 5.5. This company had developed a masonry system that allowed bricklaying to operate in parallel to the fixation of electrical fittings, as illustrated in Figure 5.14. The holes in each brick were large enough to enable easy installation of electrical fittings. In addition, the supplier assembled some of the electrical connectors during the fabrication of bricks, making easier the bricklayer's and electrician's assembling operations

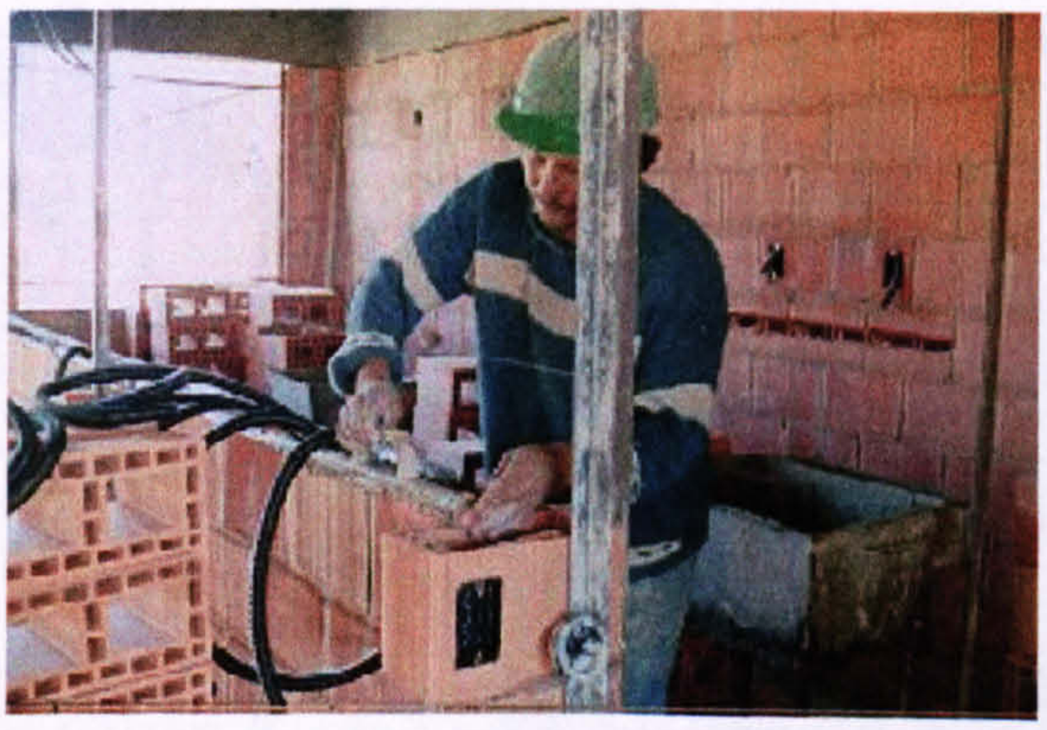


Figure 5.14 - Literal Replication of *Change in the Order of the Process* (Case Study 4)

The basic thrust driving the production manager and designers to place electrical operations in parallel to bricklaying was the reduction of cycle time and reduction of waste. The normal practice in the region demanded the opening of spaces in the brickwall in order to install the electrical fittings. In contrast, the new bricklaying order reduced the rework demanded by the traditional practice since there was lesser need for opening spaces in the brickwall. This change in process order reduced the amount of rework and, therefore, cycle time.

b.5) Case Study 5

This case study presented a reduced number of workstations operating more than one type of value adding activity (*see* Table 5.5). Fixation of concrete undersills was the only parallel activity observed during the ten days of data collection. The site manager expressed his contentment with this practice since it contributed to reduce cycle time. However, this site followed the traditional Brazilian bricklaying practice where door and window frames are usually put after the construction of brickwalls. This sequential process generates waste of materials and time since there is great variability and generalised lack of standards in the fabrication of bricks in that country. The spaces prepared on brickwalls for receiving windows and doors frames also often have to receive adjustments and, as a result, this practice increases cycle time. Furthermore, the installation of electrical and plumbing services usually is carried out by cutting openings in the finished brickwall, as illustrated on Figure 5.15. This practice is also very wasteful and generally results in great difficulties to keep an adequate level of housekeeping in the workplace.



Figure 5.15 - Theoretical Replication of *Change in the Order of the Process* (Case Study 5)

b.6) Case Study 6

This case study presented similar technological solutions to those identified in Case Study 4. Therefore, the process stages operated in parallel in the workstation were also the same. Sixteen of the thirty-five workstations observed during the six days of data collection presented more than one value adding activity. In general, these 'extra' value-adding activities were the installation of electrical fittings, window frames and air-conditioner frame.

The workers did not see the parallel activities as benefiting the reduction of cycle time since they produced less than in the traditional sequential method. They were still learning to work with the new technology and struggled with the high variability of components and poor transparency of drawings. They perceived no benefit in reducing the cycle time in the overall project. Hence, in their view the company should return to the traditional sequential system in the forthcoming projects.

Managers, on the other hand, firmly believed in the efficacy of the new technology since they have seen it working well in other construction sites. However, they recognised that the system was not offering the best possible performance. They blamed the low skill of workers and the problems in design for the difficulties in operate bricklaying in parallel to other activities. During conversations, they revealed that their strategy was to handle delays in bricklaying through an increase in the number of bricklayers and resources on site.

5.3.5.6 DISCUSSION

The lessons from the six case studies regarding 'change in the order of the process' are, as follows:

i. Design is the main enabler of changes in the order of construction processes. Simplification of interfaces and reduction of inter-dependencies between activities helps production to apply this approach more thoroughly;

ii. Changes in the order of the process without previous reduction of variability from material and components, and without proper training of the workforce, can increase cycle time;

iii. The case studies revealed that when bricklayers began to incorporate other activities within bricklaying there was an initial negative effect in holding the levels of production rate due to the need for initial adjustments in the process. Thus, the implementation of this approach in other settings is likely to demand the establishment of new forms for assessing productivity bonuses that consider the value added and not the volume produced.

The observations in the six case studies have shown that solutions at the design stage are critical to enable changes in the production process. Reducing the interdependence between processes at the design stage, in particular, can enable processes to operate in different orders without increasing improvisations. Nevertheless, designers should consider the intrinsic variability of construction processes in the development of solutions. Although deviations should be eliminated from production, some degree of deviation will always occur. Hence, Taguchi & Clausing's (1990) concept of "robust design" seems well appropriate and relevant for enabling changes in the order of construction processes.

The attempts for changing process order in some of the construction companies were extremely expensive "trial and error" exercises. Moreover, these exercises were also very risky in terms of customer satisfaction taking in consideration that the experiments were carried out in the final product. The idea of making small prototypes of new components, or developing small pilot implementations of new sequential orders, was not clearly identified in the cases studied. Small-scale models, or even virtual reality, should be used more frequently in construction companies facing such challenges.

Finally, the incorporation of more activities around and within the bricklaying workstation demands bricklayers with higher skills. Hence, further training of bricklayers will be required if construction companies want to reduce the cycle time further by changing the order of the process. The need for improvement in such skills needs to be extended to suppliers as well since, with parallel activities, material and components have to arrive on site with low levels of dimensional variability in order to enable perfect fitting.

5.3.5.7 CONCLUSION

The cases studied all applied this heuristic in some form of practice but, in different degrees and with different levels of perceptions regarding the benefits of such approach. Some parallel activities were even considered as representing the natural process order in some of the companies. Observations showed that changing a process precedence order demands careful and detailed preparation of design solutions and adequate training of the workforce. In addition, suppliers have to offer products with lower variability and be willing to participate with ideas at the design stage. The case studies have clearly shown that changes in process order, without contemplating and integrating these basic conditions, can result in even further disruptions in the production system.

5.3.6 DEVELOPING SYNCHRONOUS AND SMOOTH FLOWS

5.3.6.1 WORKING DEFINITION

This approach means to reduce the waiting time between phases of the bricklaying process to a minimum while maintaining a continuous pace in workstations.

5.3.6.2 OBSERVATIONAL FOCUS

The attention during data collection with respect to this heuristic focused on the speed of set-ups, the distances between different workstations and the timing of deliveries. Observations initiated from the first visit with the identification of workstations, work-in-progress and storage in a layout diagram. Photographs and video recording were carried out throughout the entire data collection with the aim of documenting practices that affected the waiting time during the movement of workstations and material throughout the site. Time-lapse and work sampling helped the analysis by bringing insights into the way that bricklayers interacted with the main process flow. The comparison between the average storage on site and productivity measured how synchronous was the relationship between the main processing activity and non-processing activities.

5.3.6.3 KEY INDICATORS

Three indicators were found very useful for assessing the application of this heuristic in practice, as follows:

a) *Workstation Changeover Time:* these indicators measured the time between the end of a processing activity in one workplace to the moment the bricklayer started the same processing activity in other workplace. Thus, it indicated the degree of synchronisation between workstations and between bricklayers and labourers. The time was measured while the researcher applied the work-sampling or time-lapse technique.

b) *Flow Efficiency:* (presented earlier in this Chapter) this indicator measures how lean is the flow of material was and, therefore, how closer is the delivery orders were to the actual needs of bricklayers. A high level of 'flow efficiency' would certainly indicate a high level of synchronisation among flows;

c) *Number of Bricklayers per Labourer:* (presented earlier in this Chapter) this indicator is directly connected with the level of synchronisation and smoothness of the relative movements between workstations. The better is this synchronisation and smoothness in the process the lesser labourers would be required to help bricklayers;

5.3.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and practical boundary for the chosen indicators are, as follows:

a) *Workstation changeover time*: according to bricklayers, ten to twenty minutes was a reasonable time boundary for moving the workstation to another workplace, in normal site conditions. Obviously, the bigger this changeover time the bigger would be the negative effects on process performance;

b) *Flow efficiency*: (*minimum = 0.50; maximum = 0.90*) ideally, the material flowing on site should match exactly with the throughput. Beyond that boundary, production performance would naturally decay due to the interruptions caused by the lack of material;

c) *Number of bricklayers per labourer*: (*minimum = 2; maximum = 3*) production performance is likely to decay after three bricklayers due to the difficulties of keeping the workstations with adequate levels of support (Pigott, 1972) (*see* previous discussion).

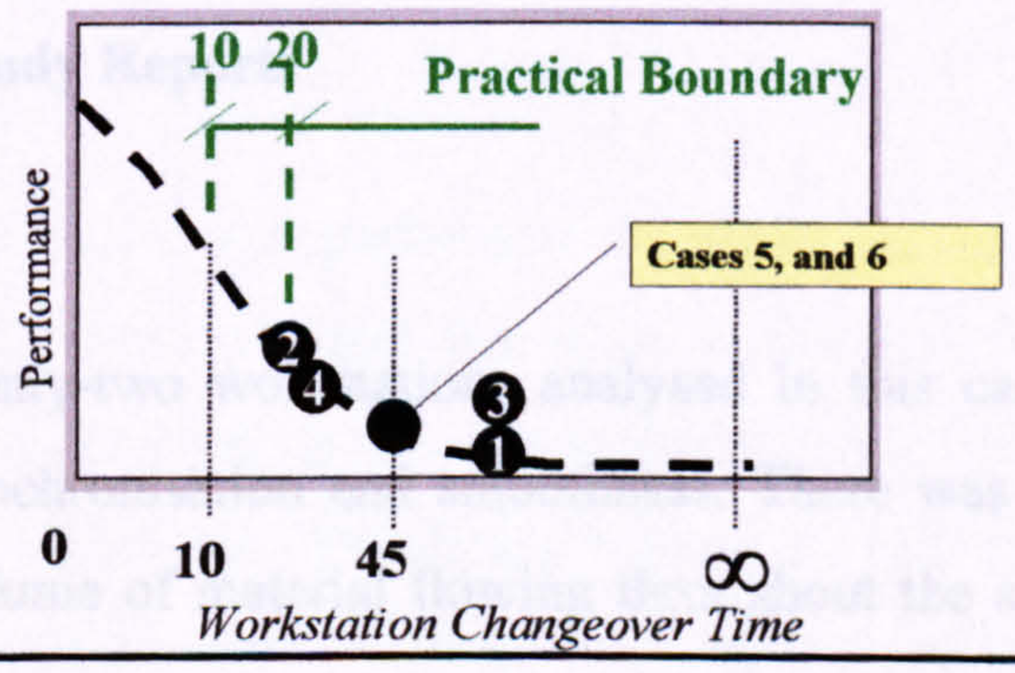
5.3.6.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

In general, there was a poor level of synchronisation and smoothness between workstations and supporting activities. This situation extended to the pace of deliveries and the production rate of workstations since there was excessive storage on site. The 'flow efficiency' levels were far below from the minimum established for this indicator, as Table 5.6 demonstrates. Bricklayers spent between 10% to 15% of their working day to change their operations from one workplace to another. Their workstations usually moved slowly throughout the site and there were serious incompatibilities between the workstation needs and the size of pallets delivered to the site.

Table 5.6 - Performance of Case Studies Regarding *Synchronisation and Smooth of Flows*

INDICATOR	CASE STUDY					
	1	**2**	**3**	**4**	**5**	**6**
Number of Days Observed	10	10	15	10	10	6
Flow Efficiency	0.05	0.06	0.03	0.07	0.03	0.04
Number of Bricklayers per Labourer	2	3	2	2	2	1
Maximum Workstation Changeover Time (min)	110	30	75	40	60	60
Minimum Workstation Changeover Time (min)	15	15	30	20	35	35
Average Workstation Changeover Time (min)	60	20	60	30	45	45
Number of Workstation Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**3**	**18**	**0**	**12**	**0**	**0**



The clear confirmation of practices matching this heuristic approach was only possible in those cases where operations had a reduced waiting time. Moreover, the widespread practice of large batches, in most cases studied, camouflaged the synchronisation problems. According to the practitioners, the main reason for adopting large 'transfer batches' was the need for a "cushion" to protect schedules against unexpected process variations. In this way, upstream or downstream processes often waited for days, or even months, to receive the next operation.

Only one site presented three bricklayers per labourer and this had a clear link with the good level of workflow planning. In general, managers planned the overall sequence of all processes but gave little attention to the flows amongst workstations. Bricklayers argued that they did not interfere in the workflow of other colleagues because it was not their responsibility. They did not believe that zero changeover time was achievable since they always would need to walk from one workstation to another. Even when the workstation was close enough, allowing rapid movement, bricklayers argued that resting was a necessary part of their daily routine in order to avoid fatigue.

There were rare examples of managers trying to keep a continuous and stable bricklaying workload across different projects throughout the company. Bricklayers working for subcontractors in particular had to move constantly from one construction company to another. This practice had a negative impact on cycle time and on the bricklayer's commitment to improve and maintain standard practices. Managers and bricklayers agreed with the researcher's findings regarding the serious lack of synchronisation and poor smoothness of flows on site. However, when asked about their future actions, they often pointed to causes that were not under their control, such as financial constraints, contracting format, bidding process and so on.

b) Individual Case Study Reports

b.1) Case Study 1

Only three of the twenty-two workstations analysed in this case study presented an acceptable level of synchronisation and smoothness. There was excessive changeover time and excessive volume of material flowing throughout the site. In the worse case,

the changeover time was 110 minutes due to a large number of interruptions from other subcontractors and lack of transparency regarding measurements. The researcher observed, during the data collection, an average of twenty times more material on site than the actual workstation consumption (*see* Table 5.6).

b.2) Case Study 2

Case study 2 presented good examples of synchronisation between the delivery of materials and the pace of production, as reflected in the relative good levels of *Flow Efficiency* obtained for bricks. Truckloads arrived on site at the exact moment the storage reached minimum levels. Figure 5.16 illustrates this practice for the case of cement and sand. Nevertheless, this site was still far from the minimum boundary established in this research.



Figure 5.16 – Literal Replication of *Developing Synchronous and Smooth Flows* (Case Study 2)

The restricted space available and the short timetable demanded closer attention of the subcontractor to the workstation flow, leading to a better balance between the number of bricklayers and labourers (3:1). Due to the good workflow planning, labourers were able to set-up the workstations in advance to the bricklayer. Consequently, this site presented one of the fastest changeover times among all six case studies (*see* Table 5.6).

b.3) Case Study 3

This site was one of the worst performers in terms of synchronisation between workstations, supporting activities and the flow of material. Figure 5.17 shows an example of an operation observed on this site presenting an excessive waiting time. The photograph shows a pre-fabricated foundation waiting for the bricklaying and drainage operations. This foundation was waiting next operations throughout the entire

observational period and there were no clear decisions from management in this respect. One of the consequences of this lack of synchronisation was the risk of damage in the pre-fabricated components. Furthermore, operatives needed to check measurements again and again since they no longer remembered if there had been variations during the assembling of these components.

The low level of 'flow efficiency' was flagrant, as explained earlier, and could be easily identified just by looking the amount of storage on site (*see* Table 5.6). Large and concentrated deliveries led to the establishment of large storage distant from the workplaces. Therefore, poor synchronisation, associated with poor workflow and layout planning, resulted in long transportation distances and, therefore, long cycle time.



Figure 5.17– Theoretical Replication of *Developing Synchronous and Smooth Flows* (Case Study 3)

b.4) Case Study 4

Decisions in the workflow planning that put each bricklayer in different apartments within the same floor increased the changeover time on this site. Long distances between workstations had a direct effect on their synchronisation with supporting activities and the delivery of material. Even so, this site presented only thirty minutes of average changeover time, which is the second best value observed in the case studies.

Bricklayers and electricians had to work simultaneously in the same area due to the technological constraints of the masonry system adopted in this company. This situation forced both trades to work at a satisfactory level of synchronisation and smoothness. Among other activities, the electrician was responsible for determining the exact position of the electrical fittings that were inserted into the brickwall. Any lack of

synchronisation would result in a reduction of productivity and, consequently, in lesser financial bonus for both trades (*see* Figure 5.18).



Figure 5.18 - Literal Replication of *Developing Synchronous and Smooth Flows* (Case Study 4)

Interview with the site manager revealed that the company tried to keep a smooth bricklaying flow through the maintenance of constant process workload across different projects and through intense design standardisation. The design standardisation tried to segment the project into small elements that were common across different projects. It increased the speed of the bricklayers' learning curve and enabled better estimation of the time required for producing each single brickwall.

b.5) Case Study 5

This site showed no "literal replications" and this was a direct consequence of the poor workflow planning, large transfer batches and large volume of material flowing across the site. It had one of the worst 'flow efficiency' levels among the six case studies. Bricklayers spent excessive time on changeover activities because of the workstation itself was too heavy and bulky to transport. In the worst case observed they spent one hour between finishing operations in one workplace and re-starting them in another (*see* Table 5.6).

In contrast to Case Study 4, there has been no attempt to standardise elements of brickwalls in this case study. Even worse, the company changed the brick size during construction, without reflecting on the consequences to modularization. Consequently, the flow of bricklayers was severely affected by difficulties to respect the distances within the concrete structure. This problem brought enormous disruptions of workflow and added further difficulties to achieve a synchronised bricklaying workflow.

b.6) Case Study 6

The observations on this construction site revealed no evidence of synchronisation and smoothness within bricklaying. The site presented great lack of synchronisation between the pace of deliveries and the pace of production, as reflected on the indicator of 'flow efficiency' (0.04). The most direct and visible consequence of the poor performance of this site in this respect was the fact that the site had one labourer per bricklayer in order to give adequate support to the workstations (*see* Table 5.6).

5.3.6.6 DISCUSSION

Three factors were highlighted by the conversations with site managers and bricklayers with respect the application of this approach.

i. Managers need to pay more attention to the need for maintaining continuity of bricklaying workload across different projects. There should be more co-operation and communication between construction companies in order to keep the workload among subcontractors;

ii. Standardisation of design elements is definitely an essential factor in keeping the flow of bricklaying smooth, to speed up the learning curve of bricklayers and to enable higher predictability of delivery dates;

iii. Workflow planning should be a regular and formal practice at meetings on site. However, in order to be efficient and effective, the set-up of the bricklaying workstation need to be faster and the communication manager-bricklayer need to be more open and dynamic.

This approach had a close link with other heuristic approaches and that makes its identification in practice rather complex, particularly with respect the approach of 'reducing work-in-progress'. As proposed earlier, 'reduction of work-in-progress' refers to the reduction in the number of batch units that received a visit to the workstation and still wait for the completion of the entire bricklaying process. 'Reduction of work-in-progress' tries to bring closer the amount of work undertaken by the workstation and the level of throughput. 'Synchronisation and smooth of flows', on the other hand, focuses on the waiting time and regularity between process stages.

The extensive use of buffer times in their schedules was one of the fundamental reasons for the lack of concern amongst most site managers with the poor levels of synchronisation. These buffers helped managers cope with the high variability of bricklaying. The lack of actions to reduce variability led the researcher to believe that the protection given by these time buffers clearly contributed to the creation of a culture of "complacency with variability". Reducing these time buffers is seen in this research as a necessary to an implementation this approach because it brings greater transparency to the stages of processes presenting poor synchronisation.

The maintenance of workloads across different projects was pointed out by many managers as a critical aspect of this approach. In situations where there was no bricklaying contract ahead, bricklayers should be able to re-direct their efforts to other value adding activities in order to keep working within the same production environment. In this respect, the case studies showed that there was a generalised lack of flexibility of bricklaying workstations and workforce in construction.

5.3.6.7 CONCLUSION

The empirical evidence indicated that the approach 'synchronous and smooth flows' is applicable in construction. The approach not only contributes to a reduction of cycle time but also has a significant role in the reduction of waste in construction. Yet, most of the case studies had severe problems of synchronisation within, and between, processes. High variability forced managers to establish time buffers within bricklaying and at the interfaces with other processes, making synchronous and smooth flows almost a meaningless exercise. Reducing time buffers is an important step to bring to surface the synchronisation problems and drive improvements throughout the bricklaying process.

5.3.7 SOLVING CONTROL PROBLEMS AND CONSTRAINTS TO A SPEEDY FLOW

5.3.7.1 WORKING DEFINITION

This approach simply means the reduction or elimination of time consuming controls and constraints that interrupt the bricklaying flow.

5.3.7.2 OBSERVATIONAL FOCUS

The main observational focus during data collection with respect this heuristic was on the time consumed in each bricklaying process stage and the root cause of any interruption in its flow. The researcher defined 'constraints' as any barrier interrupting the continuity of the flow. 'Controls', on the other hand, were associated with inspections, measurements and checks of positions within the bricklaying process.

Observations started with the development of a flow chart and a layout diagram with the aim of assessing how many stages the materials had to pass through before reaching the workstation. The layout diagram, in particular, showed the main restrictions for enabling a direct flow to the workstation and between workstations. Subsequently, the researcher applied the 'process maturity check-list' in order to assess the general state of the site in relation to current practices in the sector (*see* Appendix 3). A particular interest here was the situation of transportation practices since it was these which were the most time consuming activities in bricklaying.

The days of data collection were dedicated to understanding how bricklayers spent their time (*work sampling*) and what interrupted their concentration on the main value adding activity. In parallel, the researcher measured storage and productivity levels in order to establish the excess of material circulating throughout the site. According to the theoretical framework, excess of material in production can increase the occurrence of disruptions in production. The identification of contrasting practices for the same process across the case studies also helped to generate valuable insights for identifying what constitutes a constraint in bricklaying.

5.3.7.3 KEY INDICATORS

The analysis of this heuristic approach in the bricklaying practice of each case study used five key indicators, as follows:

a) *Number of Process Stages until Workstation*: this indicator showed how many transporting, inspecting, waiting and processing activities were present in the main flow of bricks/blocks. An excessive number of process stages may be an indication that there are constraints affecting the flow such as a bulky package system or the lack of appropriate accesses;

b) *Flow Efficiency:* as explained earlier in this chapter, this indicator shows the relationship between the average storage level and productivity. A poor level of 'flow efficiency' means that there are deficiencies in the synchronisation between the rate of consumption of materials and the pace of deliveries. With excessive storage on site, there is a risk of creating further disruptions in pathways and increase the amount of time spent on transportation;

c) *Number of Bricklayers per Labourer:* when the workflow is well planned and the workstations are easy to assemble and transport, one labourer should be capable of supporting various bricklayers without demanding extra effort. In this way, the level of constraints on site should affect the number of bricklayers a labourers required by bricklayers;

d) *% of Auxiliary Time:* this indicator was obtained using the work-sampling technique on bricklayers. Control and constraint problems on the workstation and surroundings affect the level of auxiliary activities in each case study;

e) *Process Maturity (transportation) (%):* the application of the 'process maturity check-list' showed the amount of good practices present in the construction site regarding transport, safety and facilities. The main interest here was the process maturity regarding transportation since it is directly connected with the speed of the process;

5.3.7.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and practical boundaries expected for the indicators presented above are, as follows:

a) *Number of Process Stages until Workstation*: ideally, bricks and blocks should be delivered straight on the workstation and promptly used by the bricklayer (three process stages). However, in all cases studied some sort of storage was demanded due to the size of the truckloads and restrictions in layout. Thus, the researcher established a minimum of six process stages as a viable minimum, based on the critical analysis of the case studies. Ten stages was established as the maximum and represents the average number of process stages identified across all cases;

b) *Flow efficiency*: (*minimum = 0.50; maximum = 0.90*) hypothetically, the production performance should increase until the storage matches exactly with the throughput. After that, production performance should naturally decay due to the interruptions caused by the lack of material;

c) *Number of bricklayers per labourer*: (*minimum = 2; maximum = 3*) after three bricklayers the production performance should decay due to the difficulties of keeping the workstations with adequate levels of support;

d) *% of Auxiliary time* and *% of Productive time:* previous research carried out by the author (Santos, 1995) and the work of Thomas (1991) inspired the practical boundaries established for these indicators (10 to 25% and 40 to 60% respectively);

e) *Process Maturity (Transport) (%):* since the researcher considered only the items assessed as 'applicable' on the check-list, the case studies should reach one hundred percent of this indicator.

5.3.7.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

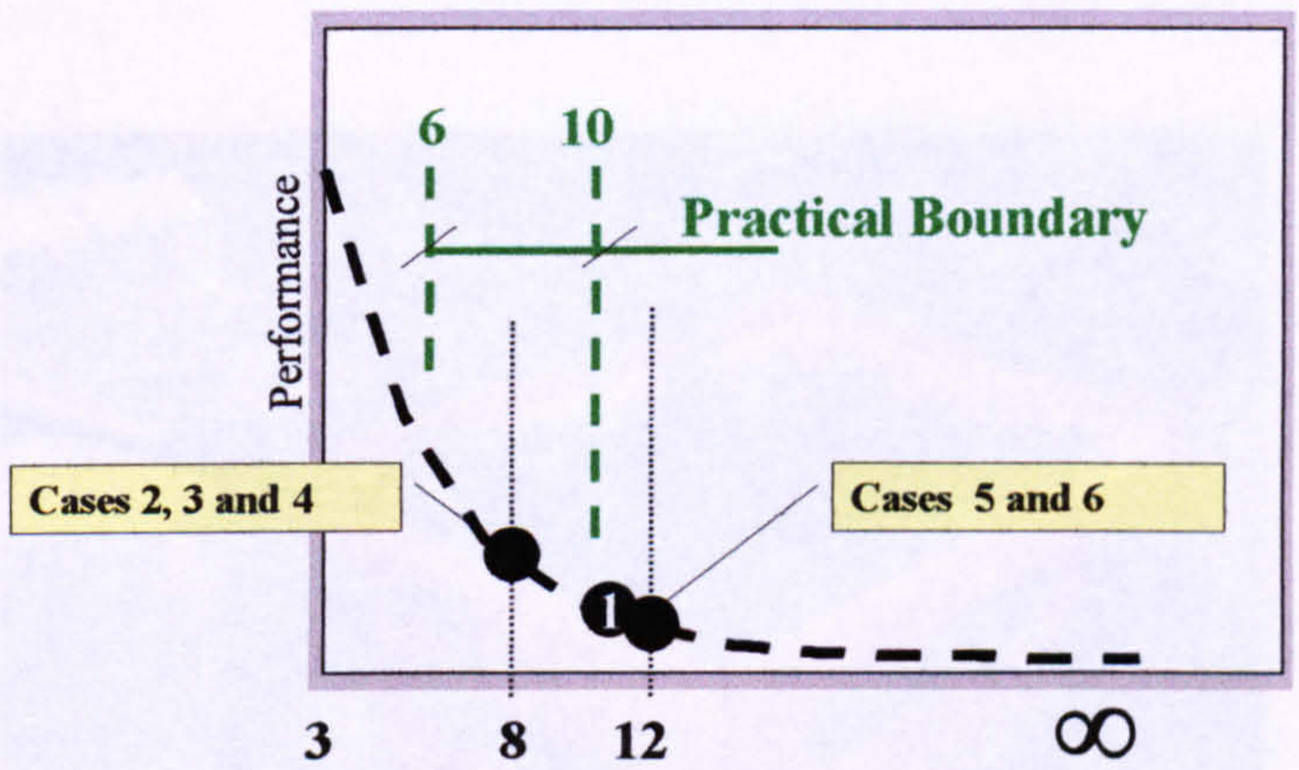
The six case studies revealed few examples of practices increasing process speed through the solution of control and constraint problems. At managerial level, controls were usually restricted to schedule and inventory controls. Such controls did not present any significant effects in the main flow of everyday operational activities. At the operative level, nevertheless, there was great proportion of time spent controlling horizontal and vertical distances. Indeed, 'measurement' occupied between 12% and 15% of the time among bricklayers in the case studies where the work sampling had been carried out, as presented on Table 5.7.

There were several constraints in the characteristics of tools and equipment that limited the speed of bricklaying activities. Some of their equipment was too heavy for transportation between workplaces. Others equipment were too slow to dismantle after the bricklayer had finished their principal operations (e.g. scaffolding). Adding to the problem, pallets were too heavy and too big and, foremost, beyond the daily needs of

workstations. Therefore, these pallets always demanded extra handling and intermediary storage.

Table 5.7 - Performance of Case Studies Regarding *Solution of Control and Constraint to Speedy Flow*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Flow Efficiency (A/B)	0.05	0.06	0.03	0.07	0.03	0.04
Number of Bricklayers per Labourer	2	3	2	2	2	1
% Auxiliary Time	-	28	29	36	24	-
% Bricklayers Spent Measuring	-	12	15	13	12	-
Process Maturity (%) (Transport)	0.43	0.69	0.28	0.49	0.36	0.43
Number of Process Stages Until Workstation	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**2**	**2**	**1**	**2**	**0**	**2**



The constraints on site were further increased by the large volume of material circulating on site. Managers often adopted central storage areas as a way to facilitate the unloading operation. This practice inevitably increased the distances until the workstations and caused further disruptions in pathways. These problems taking altogether have affected the ability of most construction sites to operate within more efficient gang compositions. Only one of them presented three bricklayers per labourer (*see* Table 5.7).

b) Individual Case Study Reports

b.1) Case Study 1

During the ten days of data collection on this site, the researcher observed only two clear "literal replications". The first one consisted of a tape that guided bricklayers on building according to the vertical module, thus, it reduced the time spent controlling vertical positions. The second consisted of a thin plastic sheet that covered the containers of mortar on the moment of delivery (*see* Figure 5.19). This practice reduced a very common problem in bricklaying: the need for frequent addition of water in order to correct the consistence of mortar. This correction is usually necessary due to the natural evaporation of water into the atmosphere. However, by covering the container with a thin plastic, it was possible to sustain the consistency of mortar for much longer time.



Figure 5.19 - Literal Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 1)

Unfortunately, the delivery of large batches of mortar practically suppressed the benefits of this practice. Large quantities of containers were kept waiting for excessive length of time. The practice of batch sizes also affected the number of process stages on this site. At least three of the eleven process stages mapped on this site were directly relating to the need of storing the large volumes of material arriving on site (*see* Table 5.7). Many of the pallets of blocks were placed in piles and without the wooden support of a normal pallet. The lack of these wooden supports was a major constraint to move blocks from the storage to the workstations.

b.2) Case Study 2

One of the two "literal replication" identified in this case study was the use of a spray to identify the starting line of modularization so that bricklayers had a clear guide to control the starting line of the first brickcourse. Another was an adjustable tie system linking metallic columns and brickwalls. This tie system allowed certain flexibility to bricklayers regarding vertical positions of brickcourses (empirical evidence supporting this is described under the 'transparency' principle).

The 'flow efficiency' on this site reflected the good synchronisation between deliveries and the pace of production and, consequently, reduced the disruptions in pathways. Again, the good condition of flows reflected in the use of three bricklayers to one labourer and on the positive assessment to 69% of the 'transport' items presented in the 'process maturity checklist'. Nevertheless, further improvements were still needed since bricklayers wasted 8% of their time with the measurement activity (*see* Table 5.7).

b.3) Case Study 3

This site was the worst overall performer in many aspects of flow. Firstly, it had approximately thirty times more bricks on site than the actual daily need of workstations. The application of the 'process maturity check-list' revealed that the site had just 28% of the transport practices considered as applicable. With large batch sizes and large quantities of work-in-progress, the major constraint on this site was the managerial decisions themselves that culminated in a poor workflow and poor layout.

The equipment bricklayers used on this site were very basic and, furthermore, the scaffolding was very slow to assemble and dismantle. The accesses to the second level of the scaffolding were improvised and restricted the speed of transportation. In this environment it was not surprise to find out that bricklayers spent around 15% of their time in measurement activities (*see* Table 5.7).

b.4) Case Study 4

A 'light scaffolding' developed by the managers of this company was one of the literal replications found on this site. This 'light scaffolding' gave more agility and flexibility of movement to workstations because it was assembled in modules and was quite light

in comparison with more traditional scaffoldings. Before this solution was adopted, the installation of a workstation in small spaces, such as toilets and kitchens, was a great burden to bricklayers.



Figure 5.20 - Literal Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 4)

The transportation equipment that had been customised to the large size of blocks was another literal replication witnessed on this site. This equipment eliminated the need for manual handling of blocks. Fast set-ups and an adequate transport system had contributed to the relative good level of synchronisation and smoothness of flows in comparison to other case studies. Indeed, 'flow efficiency' on this site reached the highest mark among all case studies (0.07) (*see* Table 5.7).

Yet, bricklayers spent 36% of their time on auxiliary activities. Interviews with bricklayers showed that, although the fast set-up and transport speeded up the process flow, the masonry technology adopted was considerably more complex. There was a large amount of measurements to check and more components to be installed. The activity of 'measurements' alone took 13% of the bricklayers time during the data collection on this site (*see* Table 5.7). Bricklayers argued that the size and weight of the blocks was also major constraint for a speedy flow.

b.5) Case Study 5

The ten days of observation on this site revealed a large number of "theoretical replications" but no "literal replication". A good example of a constraint to a speedy, flow that contrast with example presented in the previous case study, was the scaffolding. The scaffolding was made of wood and its size and weight made quite

difficult to move the workstations across the site (*see* Figure 5.21). Furthermore, bricklayers argued that this wooden scaffolding gradually became impregnated with cement and, consequently, heavier and more difficult to transport.



Figure 5.21 - Theoretical Replication of *Solution of Control Problems and Constraints for a Speedy Flow* (Case Study 5)

The length of the process on this site was excessive (12 stages) and this was clearly due to the fact that managers insisted on using an equipment that was not compatible with the way bricks were delivered and packed. This decision consisted of loading bricks manually in a four-wheel trolley and lifting it with a crane until the pavement where bricklayers were working. This activity was totally wasted since when the trolley reached the workstation, it had to be manually unloaded again. Discussions with managers showed that there was an urgent need for improving the supplier's packing system in order to enable direct transportation of bricks to the workstations.

b.6) Case Study 6

The "literal replications" identified on this site were similar to those identified on Case Study 4. Nevertheless, although the design and masonry technology used on this site was very similar in both cases, it was observed four extra handling of material in the process flow. There was excessive handling because of the lack of appropriate accesses for transportation. Moreover, labourers had to move bricks manually in most of the process stages observed. The activity was slow and severely affected the poor composition of the bricklaying gang (1:1) (*see* Table 5.7).

5.3.7.6 DISCUSSION

The analysis of the case studies showed two major aspects of the application of this approach in construction:

i. Constraints such as excessive weight or size are clearly distinguishable from other approaches. On the other hand, practices such as large batches and long distances, for instance, could also be considered as constraints;

ii. The reduction of controls in bricklaying has close links with the application of visual controls, poka-yokes and the reduction of interdependencies, since they all involve a reduction in the degree of control. In practice, these approaches should be combined in order to reduce the amount of control required by the process.

Observations on all construction sites have shown that one of the major constraints to a speedy flow was the lack of a discipline for developing workflow and layout planning. Workers often had to walk a long way around the storage and improvise access routes in order to get to the workstation. Since managers and bricklayers were more concerned with the production rate of the workstation rather than its efficiency, there was lesser attention on the flow problems surrounding the workstation. Koskela (1992) attributes this behaviour to the conversion paradigm, where managers tend to see production as a conversion of input to output. The interviews with managers showed that one of their reasons for this behaviour was the lack of information on the actual cost of flow activities.

Control is a non-value adding activity and should be reduced or eliminated from the bricklaying process. 'Heuristic implementation approaches', derived from the principle of transparency, could give significant contributions to reduce the amount of control necessary to run bricklaying. Reduction of interdependencies and installation of visual controls, in particular, seem to be the most useful complementary heuristic approaches in this respect. For instance, designers could incorporate reference measures and additional devices in their components in order to guide positions and measurements in bricklaying without taking too much of the bricklayer's time.

Finally, Koskela's (1992) classification of heuristic principles puts 'improvements in production technology' under the primary principle of 'increasing the efficiency of value-adding activities'. However, the analysis of the case studies showed that improving production technology can also 'reduce the share of non-value adding activities' as long as the focus is shortening the time between process stages. Obviously, cycle time will not be reduced if there are changes in production technology that only affect the amount of operations and do not reduce the time between process stages. The list of technological constraints that increase the amount of non-value adding activities in bricklaying included aspects like the size of packs, the weight of equipment and the excessive number of operations to set-up the workstation. In the English case studies, for instance, it became clear that the lack of an appropriate container to storage the mortar in the workstation increased the transportation time for that material.

5.3.7.7 CONCLUSION

"Solution of control and constraints" is applicable in construction, but the case studies revealed reduced number of actual "literal replications". This implementation approach still needs further development in order to clarify its interfaces with other principles and concepts and the exact nature of its actions. In this research, 'control' of positions of brickcourses was the most common control among bricklayers. In this respect, the principle of transparency could give significant contributions to reduce the need for such controls. 'Constraints', on the other hand, were often relating to the lack of appropriate workflow and layout planning and to problems in the technology.

5.3.8 CONCLUDING REMARKS

Time, particularly the avoidance of delays, was among the main preoccupation of construction managers in all case studies. Alkass, Mazerolle & Harris (1995) have already recognised that such delays are often the most common and costly problem encountered in construction projects. However, the observations revealed manager gave little attention to actions aimed at compressing cycle time at the operational level during construction. The few actions observed in this respect have been produced previously to construction, during the design and planning stage. Indeed, there was no consistent systematic activity aimed at reducing the waste of time, or non-value adding activities or in increasing the efficiency of value adding activities.

The principal aim of construction managers was to accomplish the design specifications, under the right budget and schedule specified rather than challenging them with ideas and questions for more efficient and faster practices. Since waste and delays always seemed to be included in the estimations and schedules, the result was the perpetuation of historically poor levels of performance. Moreover, the inefficiencies of construction decreased the benefit of solutions developed in the design stage.

The case studies revealed that, individually, all approaches for reducing cycle time presented in the theoretical framework are applicable in construction. However, the case studies also revealed very few "literal replications" matching the approaches of "reducing batch size" and "reducing work-in-progress". These implementation approaches are central to the successful reduction of cycle time since all other approaches are strongly inter-connected with them. Indeed, the lack of understanding of the rationale behind the theory, the adversarial work atmosphere and deficient production structure did not present favourable conditions for integrating all approaches for reduce cycle time into practice

5.4 REDUCTION OF VARIABILITY

5.4.1 MEASURING, FINDING AND ELIMINATING ROOT CAUSES

5.4.1.1 WORKING DEFINITION

This approach aims at reducing variability in bricklaying through systematic measurement, identification and elimination of the root causes of variations.

5.4.1.2 OBSERVATIONAL FOCUS

The focus during data collection was on any measurement activity and their relationship with improvements in the bricklaying process. In the first visit, site managers were asked if there was any systematic activity to identify and eliminate the sources of variability. Their answers were cross-checked with archival records and documents available on site. Improvement reports and the agenda of meetings were the kind of documents that could contribute to certifying the presence of this approach in practice.

Daily discussions with the workforce reveal their perception on the effectiveness of any systematic process analysis that occurred before or during the data collection.

5.4.1.3 KEY INDICATORS

Two indicators were adopted to analyse this approach in practice, as follows:

a) *Number of Improvement Developments Based upon Data*: there should be examples of improvements developed under a systematic inquire if the company really practice this approach. This information was gathered directly from conversations with the site manager and workforce and cross-checked with documents;

b) *Number of Performance Indicators Collected Regularly:* regular measurement of indicators could indicate intent of management in investigating the root cause of problems in production. Open-ended interviews with managers were the main instrument used to gather this information.

5.4.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and respective boundaries for the chosen indicators were, as follows:

a) *Number of Improvements in Bricklaying during the Project Based on Data:* not all improvement decision can be based upon hard data and insisting in doing so can have decreasing benefits in terms of production performance. The literature review does not show references for this indicator. Still, feedback from the personnel interviewed indicated that it should be possible to develop between two and four improvements per month in current construction practices;

b) *Number of Performance Indicators Collected Regularly:* the minimum practical boundary for this indicator has been established as four. This is based on the four measurements used in this thesis (productivity, waste, average storage and flow efficiency). Other indicators were considered as applicable and valuable for bricklaying and contributed to define "eight" as the maximum boundary (gang composition, work-in-progress, variability of production rate and the size of transfer batches). There is no suggestion in the literature regarding the correlation between

the number of indicators collected regularly and performance. However, it seems reasonable to infer that the benefits of increasing further the number of indicators becomes gradually smaller.

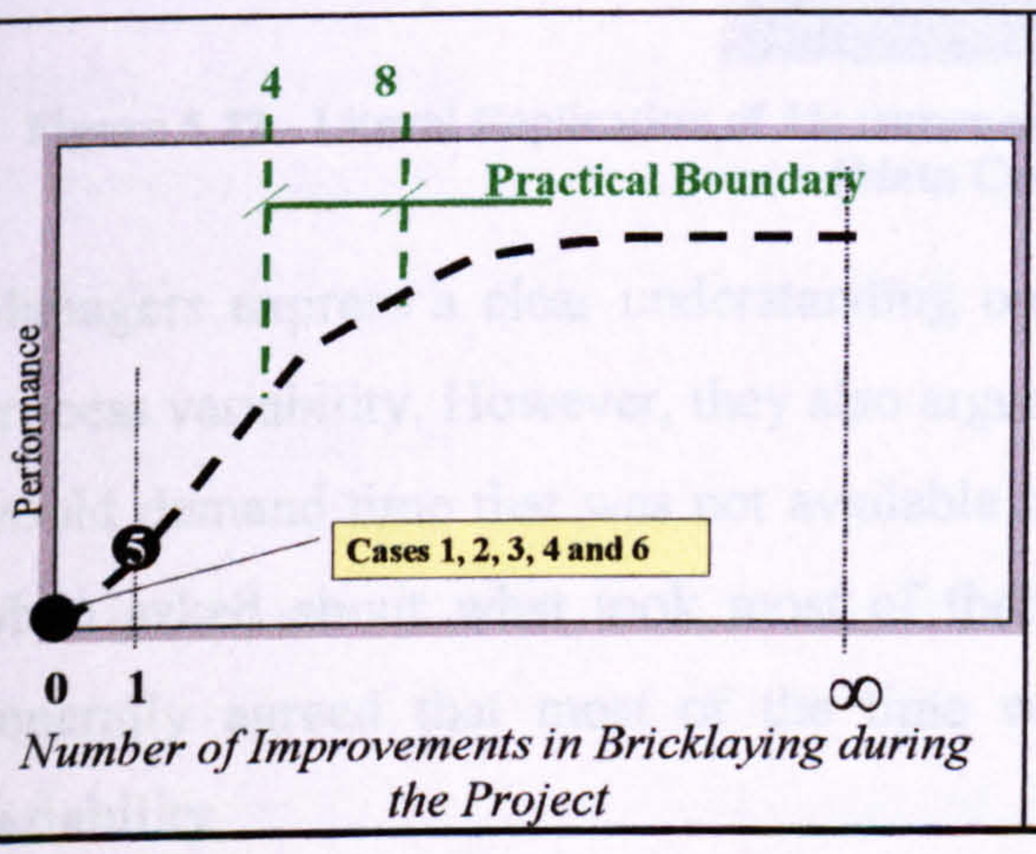
5.4.1.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

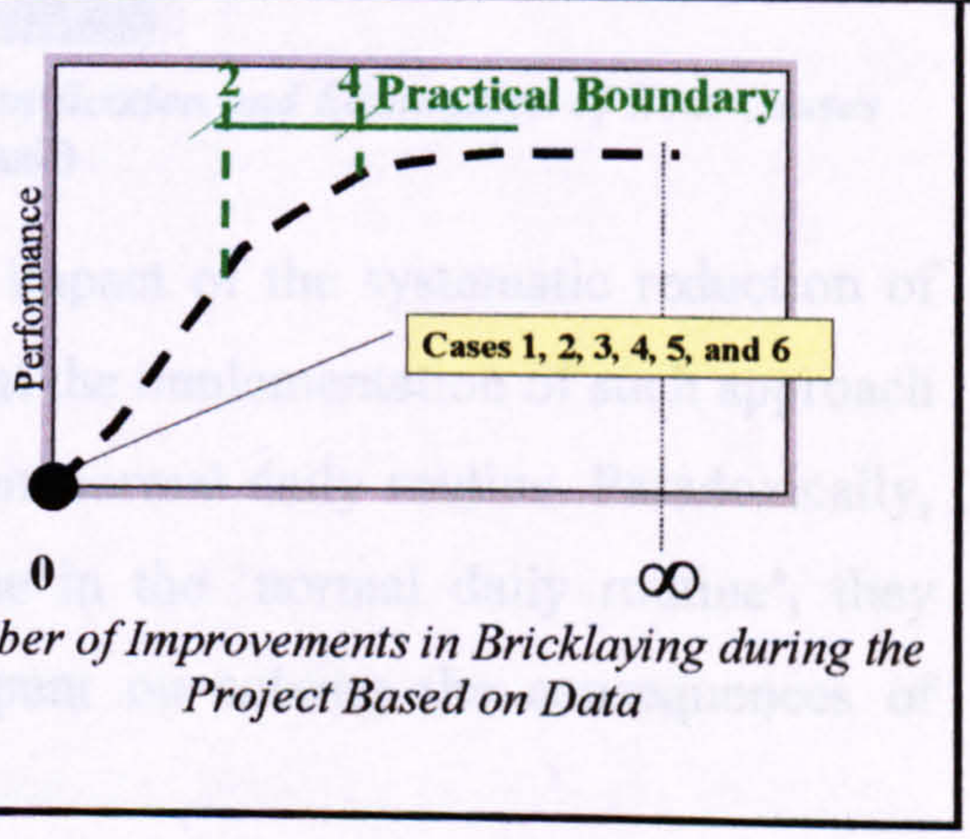
The case studies presented only one example of a company involved in measurements of the bricklaying process, as shown on Table 5.8. Managers and workers of other case studies argued that this approach was not practised because measurements, and other monitoring activities, take too much time and workers/mangers were too busy to be able to carry out such activities. This situation created a vicious cycle since, with no time invested on the reduction of variability, the process inefficiency get worse and, consequently, there was even less time for eliminating the causes of variability.

Table 5.8 - Performance of Case Studies Regarding *Measurement, Identification and Elimination of Root Causes*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Performance Indicators Collected Regularly	0	0	0	0	1	0
Number of Improvements in Bricklaying during the Project	0	0	0	1	1	3
Number of Improvements in Bricklaying during the Project Based on Data	0	0	0	0	0	0
Number of Process Stages	11	8	8	8	12	12
Number of Workstations Analysed	22	20	45	60	40	35
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications	**0**	**0**	**0**	**0**	**2**	**0**



Number of Improvements in Bricklaying during the Project



Number of Improvements in Bricklaying during the Project Based on Data

Despite the scarce empirical evidence collected from the six case studies, the meta-cases have supplied empirical evidence that substantiates the validity of this approach in the construction sector. For instance, Figure 5.22 shows a blackboard where a construction company documented information about waste of material removed from the various construction units. The left column contains the date of removal; the middle column contains the quantity; the right column the name of the material. The company used the analysis of this data to define, and refine, improvement priorities in design and production. They used the same data to estimate the benefit of improvements and carry out benchmarking studies.

The failure in establishing a systematic analysis of the sources of variability in the cases studied was heavily influenced by the lack of participation of workers in improving activities. Bricklayers expressed that they did not get involved with improvement activities because of the lack of support from management and the lack of clarity regarding how benefits would be shared. Some of the bricklayers even expressed certain level of mistrust with any form of process analysis by arguing that productivity enhancement could result in the unemployment of their fellow colleagues.

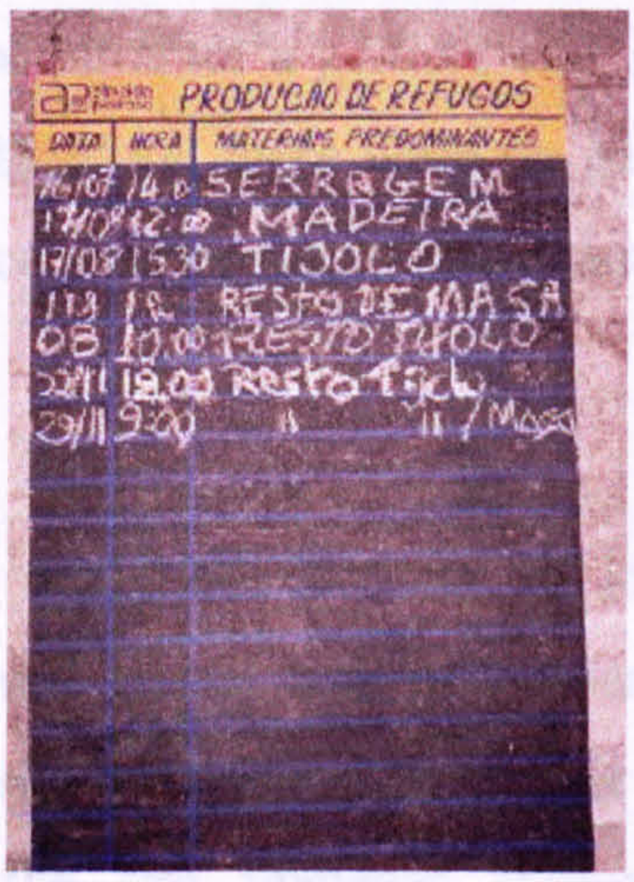


Figure 5.22 - Literal Replication of *Measurement, Identification and Elimination of Root Causes* (Meta Case/Brazil)

Managers express a clear understanding on the impact of the systematic reduction of process variability. However, they also argued that the implementation of such approach would demand time that was not available in their normal daily routine. Paradoxically, when asked about what took most of their time in the 'normal daily routine', they generally agreed that most of the time was spent on solving the consequences of variability.

b) Individual Case Study Reports

b.1) Case Study 1

Conversation with managers and workers revealed an underlying belief that all they needed to decide about bricklaying was already decided. Drawings, blocks, mortar, bricklayers, scaffolding and all other input where on site and their focus was on controlling the timing of the job. In the words of the site manager, "...*they* (bricklayers) *have all their need on site. Now they just need to do their work properly*". In such an environment, it was no surprise to find out that a complete absence of systematic problem solving activities at the operative level.

b.2) Case Study 2

In contrast to Case Study 1, the subcontractor on this site was actively involved in solving flow problems in advance to bricklaying and tried to keep a smooth and synchronised flow. Notwithstanding, his work was totally *ad hoc* and there were no attempts in address any other fundamental problems causing variability in bricklaying, such as the deficient production of mortar or the difficulties with design details. Furthermore, none of the subcontractor's actions and solutions were documented or transformed into standards. Therefore, there were no guarantees that the solutions and procedures adopted by the subcontractor would be replicated in the next project.

b.3) Case Study 3

This case study showed no systematic activity in identifying the root causes of variability. Bricklayers perceived a total lack of concern from the site manager with respect to the large number of site problems such as poor layout and deficient pathways. Indeed, conversations with the site manager showed greater concern with the commercial aspects of the business rather than production. Controlling finances and deadlines were clearly his main priorities.

b.4) Case Study 4

Bricklayers and managers expressed their satisfaction with the low levels of variability of bricklaying on this site. Nevertheless, it was clear that most of the actions taken to reduce variability were not the result of a systematic analysis of process problems.

Managers admitted that this low level of variability resulted from the learning curve of bricklayers and standardisation of design details. Moreover, the supplier was able to produce bricks strictly within the tolerance limits and there was already a strategy for adopting industrialised mortar in all future buildings.

The total reliance on solutions coming from designers and suppliers was reflected in the lack of participation of those who actually had a daily involvement with production problems. Managers considered the lack of formal education and training among bricklayers a major barrier for involving them in any systematic process analysis. However, the ten days of data collection revealed that bricklayers had an accurate notion of the main sources of variability. Hence, bricklayers could certainly give a valuable contribution in identifying and reduce the root cause of variations on site.

b.5) Case Study 5

This site was the only one that presented any actual measurements of production performance with the aim of identifying the root cause of problems. Researchers from the local university were measuring waste and analysing its causes as part of a national study. The result could have helped the company to identify and prioritise its own improvement activities. Nevertheless, there was absolutely no participation of the workforce in measurement activities. Bricklayers demonstrated total lack of information when the researcher asked them about the objectives of the data collection. In their understanding, this study was only likely to be used by managers as a way of blaming them for the large quantities of waste produced in this site.

b.6) Case Study 6

This site did not have any sort of systematic activity to analyse process problems despite the large amount of rework observed during the period of data collection. Figure 5.23 gives an example of process inefficiency that could benefit from the application of this practice. The photograph shows electrical conduits that have been misplaced during the launch of concrete. These conduits were supposed to be under the wall and not outside it. Due to this error, bricklayers had no option but to leave the conduits outside of the wall and hope that the plasterer would be able to solve the problem by increasing the depth of plaster. The early identification and solution of root causes of such problem would reduce the amount of resources wasted with rework and adjustments.



Figure 5.23 - Theoretical Replication of *Measurement, Identification and Elimination of the Root Causes of Problems* (Case Study 6)

When the site manager was asked about the existence of systematic activities to reduce production problems, he declared that "*...there were ongoing activities to improve the design and the technology*". Indeed, there had been three improvements in bricklaying during that project. However, he clearly did not recognise the magnitude of production problems generated within his construction site, such as the lack of standard practices or the excessive number of intermediary storage. Most problems in the interface between bricklaying and the concrete structure, for instance, occurred because of the variability of formwork and bricks, and not because of poor design.

5.4.1.6 DISCUSSION

The main lessons from the comparison between the descriptions found in the literature and the construction practice are:

i. Most case studies have not applied this approach mainly because there was no structure and support in the organisation to investigate process problems. The benefits of getting involved in such activity were not clear to the workers and this added to the problem of low commitment and trust between the workforce and the construction companies;

ii. There was a generalised lack of knowledge among managers and workers regarding the techniques available to investigate the bricklaying process. Generally, companies relied on external advice when they need to investigate a particular problem in production;

iii. There is a strong need for developing techniques that automate the process of data collection in order to free workers and managers from this time consuming activity and higher concentration on the actual analysis of production problems.

Problem solving activities involving measurement and monitoring of construction processes demand a level of commitment and knowledge that was clearly not available among most of workers and managers interviewed in this research. In addition, the application of this approach in construction will certainly demand a change of attitude of companies towards variability. Improvements derived from systematic analysis of production processes would bring clear benefits to both manager and worker but it will be necessary to get their commitment and motivation.

Managers constantly argued, during conversations with the researcher, that there was a lack of time to study production problems. In this respect, Ballard & Howell's (1994) suggestion of using time "cushions" in schedule seems a good alternative for breaking the cycle of variability in construction. As Ballard & Howell (1994) argue, these "cushions" give managers and workers the breath of time necessary to investigate and eliminate the root causes of their problems.

As suggested earlier, the researcher believes that it is important to develop instruments that make easier and faster the data collection on construction sites. This could mean a more intense use of electronic devices and information technology in the sector. The experience of the BRE - *Building Research Establishment* (England) with the CALIBRE project shows that this is a feasible solution for construction (Calibre, 1999). Obviously, there would be no point in developing new techniques and devices if there is no ongoing activity on site using the data to investigate and eliminate the root cause of problems.

5.4.1.7 CONCLUSION

Despite the high variability of construction processes, the case studies revealed almost no literal replication of this approach. Managers argued that there was little time available for systematic analysis of process problems. However, the absence of this approach in practice resulted in a reinforcing vicious cycle where more variability

diminished even further the time available for collecting data. In this context, the use of "time cushions" in schedule, suggested by Ballard & Howell (1994) appears to be an adequate approach for breaking the vicious cycle of variability.

5.4.2 STANDARDISATION

5.4.2.1 WORKING DEFINITION

Standardisation consists of the formal establishment of the desired bricklaying procedures and outputs with the aim of reducing variations in the final product.

5.4.2.2 OBSERVATIONAL FOCUS

Detection of the practice of standardisation in the case studies occurred in the first three or four days of observations. Open-ended interviews with the workforce and managers extracted the actual use of standards in the daily life of the construction sites. During these interviews, the researcher tried to understand how they were involved in the development and revision of these standards. One of the ways to assess if the workforce actually new the company's written standards was simply taking a random part of the process and ask some questions about it (e.g. *How long can the mortar remain in the workstation without being used? What is the procedure for setting up the position of brickwalls?*). Their answers were immediately compared with the actual standards of the company.

5.4.2.3 KEY INDICATORS

Open-ended interviews led to the establishment of the following indicators:

a) *Number of Bricklayers that know the Written Standard:* bricklayers should be able to describe the content of the written standards relating to their own processes. The researcher asked bricklayers key questions on random parts of the process and, subsequently, checked their answers against the company's own standards;

b) *Number of Revisions of the Standards per Year*: at the beginning of the research bricklayers and managers were asked how many times they revised standard procedures each year. Their answers were checked against archival records and the

information contained in the written standards themselves. This indicator would help to show the actual commitment of the organisation towards the maintenance and improvement of standards.

5.4.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The items below describe the expected behaviour and practical boundaries of the chosen indicators:

a) *Number of Bricklayers that know the Written Standard:* the effect of standardisation in production performance should be directly linked with the percentage of people that actually knew these standards. Ideally, everyone working in production should know the standards relating to their own process. However, usually there is significant number of new employees moving in and out of construction companies. Thus, based on the opinion of fellow academics, the researcher established eight percent as the minimum value for this indicator.

b) *Number of Revisions of the Standards per Year*: the practical boundary (2 to 4 revisions/year) for this indicator has been established using the opinion of specialists and academics involved in the implementation of improvement programs. They also agreed that more than four revisions in the bricklaying process per year would have increasingly smaller effects on performance.

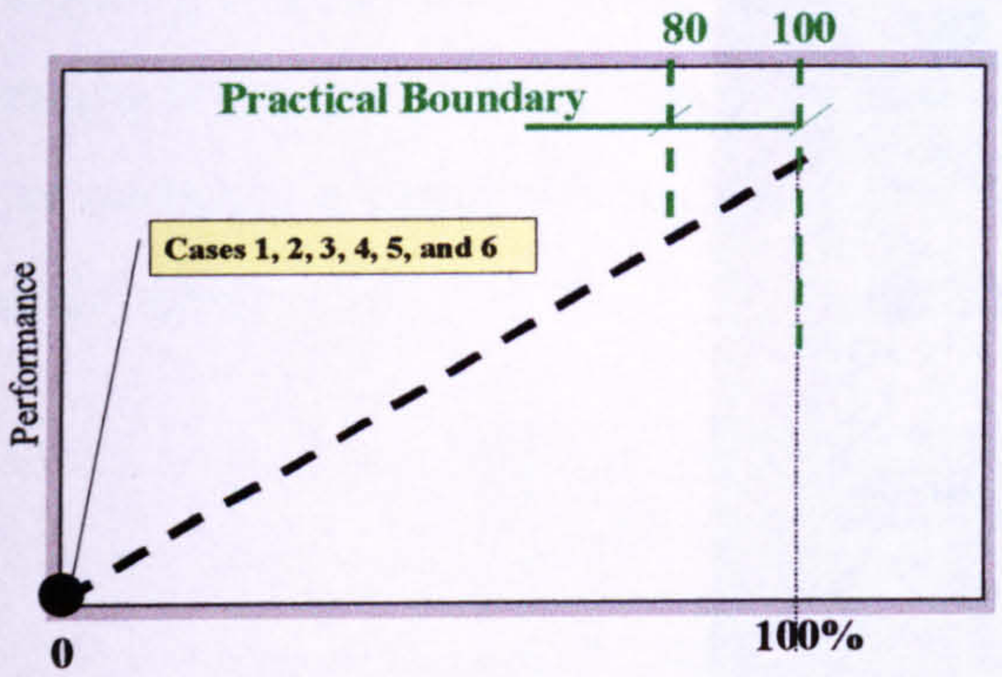
5.4.2.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

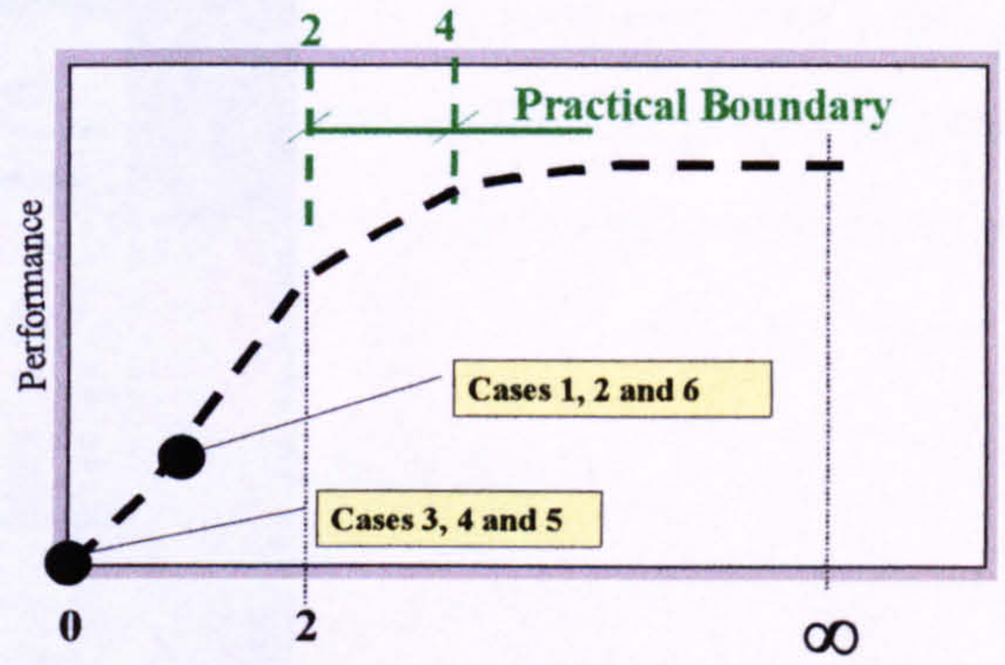
There were standards for most of the process stages observed in three of the six case studies analysed in this research, as presented on Table 5.9. However, despite the general appreciation for standardised processes across the case studies, scepticism regarding the usefulness of this massive exercise still abounded. Workers argued that the consultation to a written standard took too much time and it was too burdensome. Moreover, none of construction companies would compensate bricklayers for the time spent consulting standards.

Table 5.9 - Performance of Case Studies Regarding *Standardisation*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	3	3	3	3	3	3
Number of Bricklayers Observed	6	6	2	4	3	8
Number of Revision in Standards per Year	1	1	*	*	*	1
% of Operatives Knowing the Written Standards	0	0	*	*	*	0
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**8**	**8**	**0**	**0**	**0**	**6**



% Operatives Knowing the Content of Written Standards



Number of Revision in Standards Per Year

* Absence of written standards

Furthermore, the effectiveness of these standards was hampered by the generalised lack of participation of the workforce in their development and regular revision. The standards were normally developed away from the sites under investigation. The revision of these standards was also carried out away from the site. Moreover, there were no attempts from the site manager to discuss their content with the workforce. There were no instruments to motivate the workforce to fully implement these standards in all construction companies analysed.

The written standards had clear recommendations concerning the expected characteristics of the production procedures and final product of bricklaying. However, this information was not used to control the bricklaying process, or its products. Quality control was carried out in an *ad hoc* basis, without any sort of checklist or formal procedure for approval.

Standardisation activities in the case studies were not integrated with other complementary practices such as "visual controls" or "information displays". Indeed,

there is an urgent need for improving the media used to communicate standard procedures to the workforce in all cases studied. In this respect, the meta-case revealed a variety of instruments that show the creativity of other construction companies when facing such problem. Figure 5.24 shows a board that presents the standard composition of mortar for every particular use (e.g. internal plastering, external plastering, brickcourse). Although it does not avoid entirely variations in the production of mortar, it can certainly contribute to achieve that aim.



Figure 5.24 - Literal Replication of *Standardisation* (Meta-Case/Brazil)

Standardisation was clearly effective at the design level where, in some of the companies investigated, there was intensive use of modularization and on-the-shelf components. In some of the construction sites, this standardisation helped to increase the efficiency of production by reducing the need for cutting bricks and enabling the use of window and doorframes. Bricklayers themselves argued that the repetition of individual shapes and sizes of brickwalls throughout the design had contributed to speed up their learning curve and productivity.

b) Individual Case Study Reports

b.1) Case Study 1

Eight process stages amongst the eleven stages mapped in this case study had a corresponding written standard (see Table 5.9). The other three remaining stages referred to an extra handling of pallets within the workstation that were not anticipated in the written standards. The effectiveness of these standards was very poor since the interviews revealed that the workers did not have a clear knowledge on their content.

Most of their knowledge was based on past experience with other companies and on formal training received at the beginning of their careers.

b.2) Case Study 2

This company maintained training centres throughout England where instructors used the company standards as hypothesis of best practice (*see* Figure 5.25). Young apprentices studied in these training centres in three periods of eight months. Between those periods, they worked side-by-side with experienced bricklayers in one of the company's construction sites. The site analysed in this research presented two trainees coming from one of these training centres. This indoctrination of the company standards was certainly a major factor influencing the relatively homogeneous practice observed on this site.



Figure 5.25 - Literal Replication of *Standardisation* (Case Study 2)

The content of written standards, nevertheless, had little influence on the daily life of this construction site. Bricklayers never consulted these standards and did not have a clear idea about their precise content. In other words, their knowledge about bricklaying was more tacit and based on the previous experiences in other construction sites and early training.

b.3) Case Study 3

This case study had no written standards and their practices on storage, transport, safety and the bricklaying itself were extremely variable throughout the site. The main value-adding activity suffered directly the consequence of this situation. The quality of mortar, for instance, was always variable in consistency and demanded constant correction

during application. Another example of highly variable practices caused by the lack of an effective standardisation process concerned accesses and pathways. Each bricklayer and labourer developed a different access to the building that was often unsafe and difficult for the transportation of materials.

The reason that bricklayers did not attempt to develop a standard practice was the lack of an appropriate organisational structure and support for such activity. Their contract was based on price alone, and the manager on site did not show any interest on the poor quality of the bricklaying process. Indeed, when asked about his perception on the quality of bricklaying he answered "...*we are on time and under budget. That is enough information for me*".

b.4) Case Study 4

The practice among bricklayers on this site was reasonably homogeneous but the company had no written standards. Open-ended interviews with managers revealed that the repetition of design details across different projects was the main reason for the relative standard way of bricklaying on this site. The design could change across projects but remain the same when looked at the small elements, such as kitchen or bathroom.

Another strong factor for the relative homogeneous practice on this site was the long period the bricklayers had been working with the same company as employees (three to four years). They all had followed the implementation of the new masonry technology since the beginning. Hence, they were aware of the main sources of problems in the process and tried to avoid before them as much as they could.

b.5) Case Study 5

There was no standardisation in this construction site. The observation of practice revealed a great variation on procedures throughout the entire bricklaying process. Managers relied completely on the competence of bricklayers to obtain brickwalls with good quality. However, high variability of bricks and concrete structure, associated with poor modularization, denied bricklayers the opportunity of being more efficient. The bricklaying equipment varied from workstation to workstation and even the most basic operations were carried out in slight different manner from bricklayer to bricklayer. As

a result of these practices, the final product had a visible poor quality in aspects such as thickness of joints and vertical alignment.

b.6) Case Study 6

This site had written standards but, like in the previous case studies, these standards were not fully implemented. Bricklayers had not participated in the development of these standards and there were no individual or group benefits in consulting and implementing them. During open-ended interviews and daily conversations, it became clear that some of the bricklayers were not even aware of the existence of such written standards. Figure 5.26 shows one of these standards.

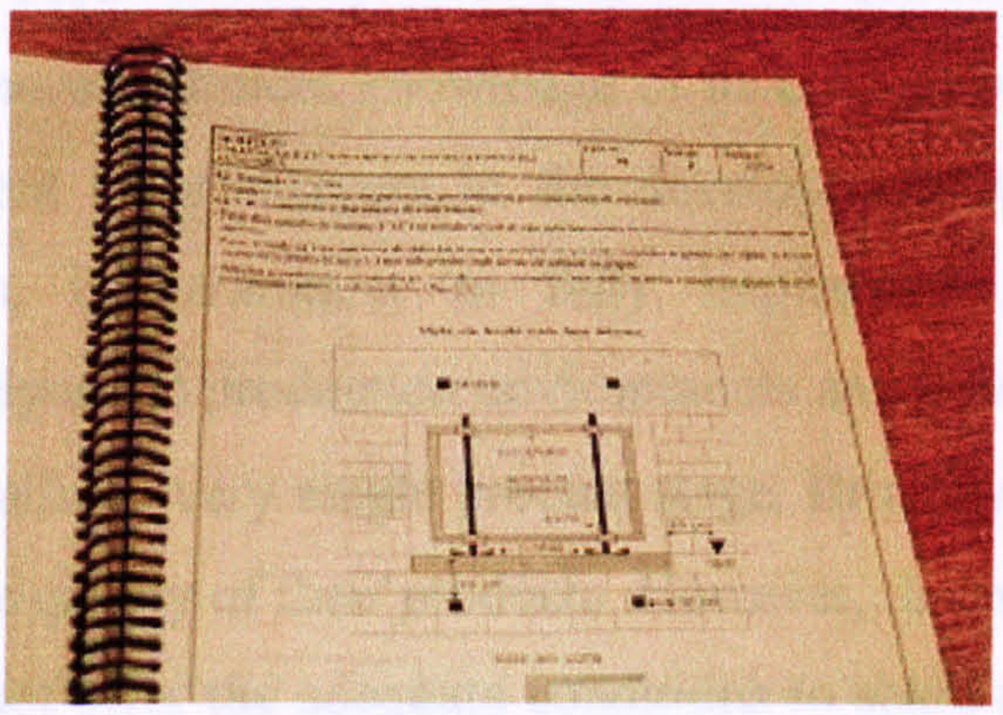


Figure 5.26 – Theoretical Replication of *Standardisation* (Case Study 6)

Even if bricklayers were applying the written standards completely in practice, the researcher has doubts regarding their effectiveness since the upstream processes were highly variable. In other words, the achievement of standard procedures in bricklaying was likely to be hampered by the variability of the concrete structure, brick supplies, electrical fittings and so on (*see* Figure 5.23).

5.4.2.6 DISCUSSION

The clear message obtained from the evidence collected within these case studies was, as follows:

i. The case studies showed some construction companies developing standards but failing to implement and maintain their standards in practice. This failure was a result of poor participation of bricklayers in improvement activities and absence of clear benefits for applying these standards in practice;

ii. The case studies with the most homogeneous practice and better brickwalls were those employing experienced designers and experienced workforce. Drawings were well detailed and modularised in these sites and the workforce had received formal training or worked for long periods with the same technology.

iii. Standardisation of bricklaying alone is not effective if there is no standardisation of the preceding upstream processes. Variability on the inputs of bricklaying result in rework and waste and have a direct effect on the quality of the bricklaying process.

Critical analysis of the observations revealed that well written standards have little value if the workers do not have sufficient knowledge of its content or motivation to apply it in practice. Involvement of bricklayers in the development stage, or in the regular revision of standards, is paramount to fully implement standards in practice. Construction sites are dynamic production environments and it does not seem feasible to expect managers controlling every single process stage. Bricklayers have to be the ones that actually control the quality of their products. However, the environment observed in most case studies did not offer the adequate conditions to share this responsibility since there was little trust between managers and bricklayers and no incentives in doing so.

Although the genesis of the word "document" is *"to teach"*, none of the companies observed used documents to actually teach workers the desirable characteristic of products and processes as recommended by Imai (1997). In fact, the apparent incompatibility between written standards and the worker's learning style did not favour the effective transfer of their content into practice. Some of the workers, for instance, argued that they would prefer an illustrative video rather than written documents. Others express that they would prefer regular training on site or a visit to a 'best practice' site in order to learn the content of standards rather than read a standard.

Any construction worker should have immediate and direct access to information on standards when and where necessary without wasting time with unnecessary movements ("pull information"). Thus, the researcher understands that standards would be more effective in construction if the workstations could incorporate their content and, thus, follow the bricklayer wherever he goes. Galsworth (1997) already shows examples of

intense practice of this approach in the manufacturing industry. In particular, a weak point on the bricklayers expertise was on the aspects relating to the interfaces with downstream processes. In general, they did not have sufficient information and knowledge on the content of subsequent processes. This lack of knowledge restricted their views on what bricklaying could do to help downstream processes.

One important aspect of this approach is that the term 'standardisation' automatically brings in people's mind the idea that this approach means simply to obtain written documents. However, the researcher understands that the objective of standardisation is to reduce variations in processes and the products of production. This objective can be achieved through different manners such as the intensive use of visual displays in the workstation, continuous training or construction of real-size models. Thus, there should be a more abstract term to describe this heuristic approach such as "promoting homogeneous practices" or "formalisation and dissemination of the desired practices and products".

5.4.2.7 CONCLUSION

Isolated initiatives aimed at standardisation observed throughout the cases and in the meta-case suggest that this approach is applicable in the construction sector. However, it became clear that construction managers have to change their focus from the pure achievement of written documents to the achievement of actual standardised practices. In this respect, standardisation needs to be considered as a continuous "process" that does not end with the first written document. Standards have to be continuously reviewed, improved and disseminated if the intent is effective reduction of variability.

5.4.3 POKA-YOKE

5.4.3.1 WORKING DEFINITION

Poka-yoke is a mistake-proof mechanism that guarantee one hundred percent inspection by taking over tasks or actions that depends on vigilance or memory from bricklayers or labourers.

5.4.3.2 OBSERVATIONAL FOCUS

The focus was mostly on the equipment and tools used in bricklaying and the observation was carried out entirely in the first day on site. The researcher was also attentive to any poka-yoke device that have been built into the building design or components delivered on site. The observation followed carefully through every step that had been mapped in the bricklaying process in order to identify all mechanisms in the process and their connection with avoidance of errors. Further questions were made of the workforce and management regarding their experience and knowledge on mechanisms that resembled poka-yoke devices.

5.4.3.3 KEY INDICATORS

The "*number of mechanical/electrical devices avoiding errors*" and the "*number of design solutions avoiding errors*" are both direct indicators of the development and sophistication of a process regarding poka-yoke devices. Comparison of this indicator with the number of process stages is useful to establish the relative position of each case study regarding this heuristic approach. This indicator could also supply relevant information relating to the most common poka-yoke device in use and potential areas for development.

5.4.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The literature shows that the number of poka-yoke required in a production process depends on the sources of variability and on the desired degree of independence between machines and operators (Shingo, 1989; Monden, 1998). There were no references on the typical number of bricklaying poka-yoke devices at the time of this research. Thus, for analytical purposes and based on discussions with site managers, the researcher established a minimum and maximum value for these indicators as multiple of eight since it is the shortest number of process stages observed in this research. The logic here is that every process stage should be able to receive a poka-yoke device.

The literature review has shown that poka-yoke devices can make a significant contribution to reduce process variability. Variability is itself a measure of process performance. Therefore, the researcher is led to believe that bricklaying performance should progressively increase with the number of poka-yoke devices.

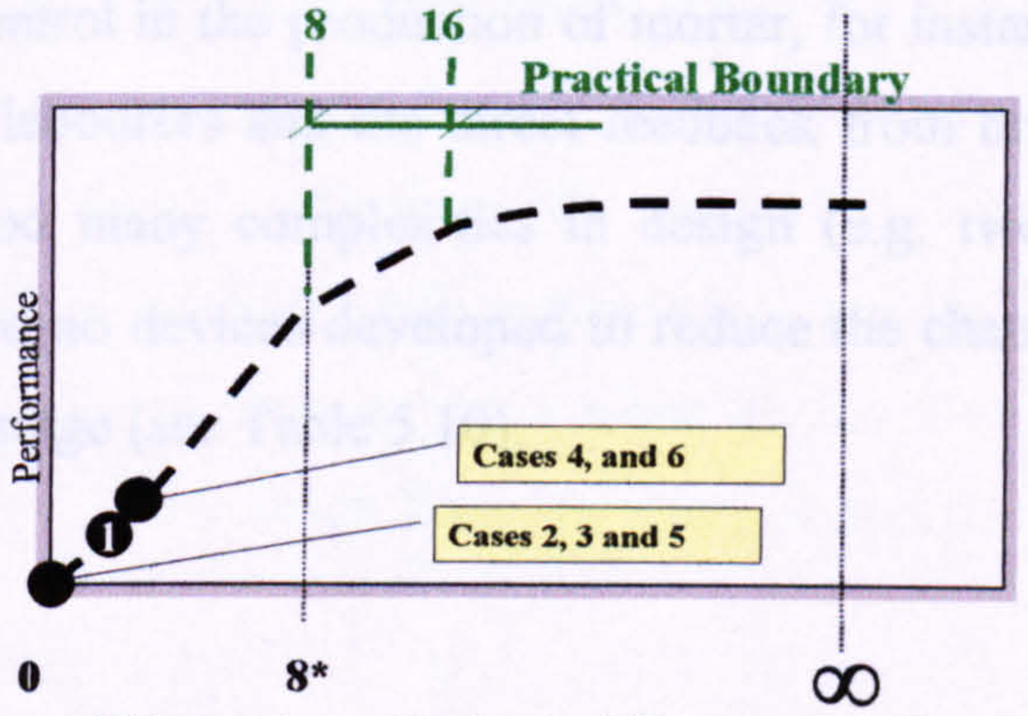
5.4.3.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

The six case studies unveiled a reduced number of practices matching the working definition of poka-yoke device, as indicates Table 5.10. All five literal replications observed referred to safety devices installed in transportation machinery. These literal replications have been developed and implemented by companies outside of the construction site. Discussions with workers and managers revealed that they probably would not have sufficient expertise to elaborate any of the poka-yoke devices observed.

Table 5.10 - Performance of Case Studies Regarding Poka-Yoke

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	1	1	1	1	1	1
Number of Process Stages	11	8	8	8	12	12
N° of Electronic/Mechanical Devices Avoiding Errors	1	0	0	2	0	2
N° of Design Solutions Avoiding Errors	**0**	**0**	**0**	**0**	**0**	**0**
Number of Literal Replications	**1**	**0**	**0**	**2**	**0**	**2**



The critical analysis of observations also showed no attempts from designers or suppliers to build mistake-proof mechanisms into components of the building (*see* Table 5.10). Site managers and bricklayers also revealed little understanding on how mistake-proof devices could be applied into the building design. Their creativity was hampered by the lack of elucidative examples taken from the construction sector. They only began to understand the practical implications of poka-yoke when the researcher mentioned

examples of poka-yoke devices used in their own daily life (e.g. optic sensor in elevator that avoids doors to close when people are crossing it).

b) Individual Case Study Reports

b.1) Case Study 1

A forklift used to transport pallets presented the only "literal replication" clearly identified among the eleven process stages in this construction site (*see* Table 5.10). This literal replication consisted of a siren alerting all workers that the machine was moving backwards. It avoided accidents caused by lack of attention since there was a large number of activities operating simultaneously throughout this site. All other equipment used by bricklayers relied heavily on the attention and skill of workers in order to produce the desired results without accidents.

b.2) Case Study 2

None of the eight process stages observed on this site presented poka-yokes in the machines and tools used by bricklayers or on the components delivered by suppliers. The only sources of control in the production of mortar, for instance, were the instincts and experience of the labourers and the direct feedback from bricklayers. In addition, although there were too many complexities in design (e.g. two different colours of bricks). There were also no devices developed to reduce the chance of occurring errors during the assembling stage (*see* Table 5.10).

b.3) Case Study 3

Despite the large amount of process problems causing variability on this site, there were no poka-yoke devices within the bricklaying process. A typical example observed was the addition of water and sand during the production of mortar (*see* Figure 5.27). Labourers carried out this activity manually and without rigorous control of quantities. The resulting poor quality of mortar severely affected the productivity of the main value adding activity.



Figure 5.27 - Theoretical Replication of *Poka-Yoke* (Case Study 3)

Once the bricklayers understood the meaning of poka-yoke they promptly expressed some ideas to solve problems on site. They agreed that electronic and mechanic devices could effectively help them to reduce the variability in activities such as the one described in the figure above. Nevertheless, although they recognised potential areas for application of poka-yoke, there was not sufficient knowledge on poka-yoke and no support from management to invest time in the development of such devices.

b.4) Case Study 4

Here, like in the previous case studies, the "literal replications" were safety mechanisms attached to transportation equipment. Figure 5.28 illustrates literal replications that contributed to reduce the risk of accidents on the elevator. It shows a device that did not permit the movement of the elevator while someone was loading or unloading materials. In other words, the elevator could only move when its doors were closed. In addition, the operator could easily tell in which floor the elevator was just by looking the lights on the panel.

The actual impact of these two poka-yoke devices on variability was not visible since they tackle problems that have never occurred in this company. Nevertheless, managers and workers pointed out the undeniable benefit of such devices in the avoidance of even longer delays caused by accidents. They also recognise the need for poka-yokes in other aspects of the bricklaying process such as the production of mortar or the maintenance of vertical distances.

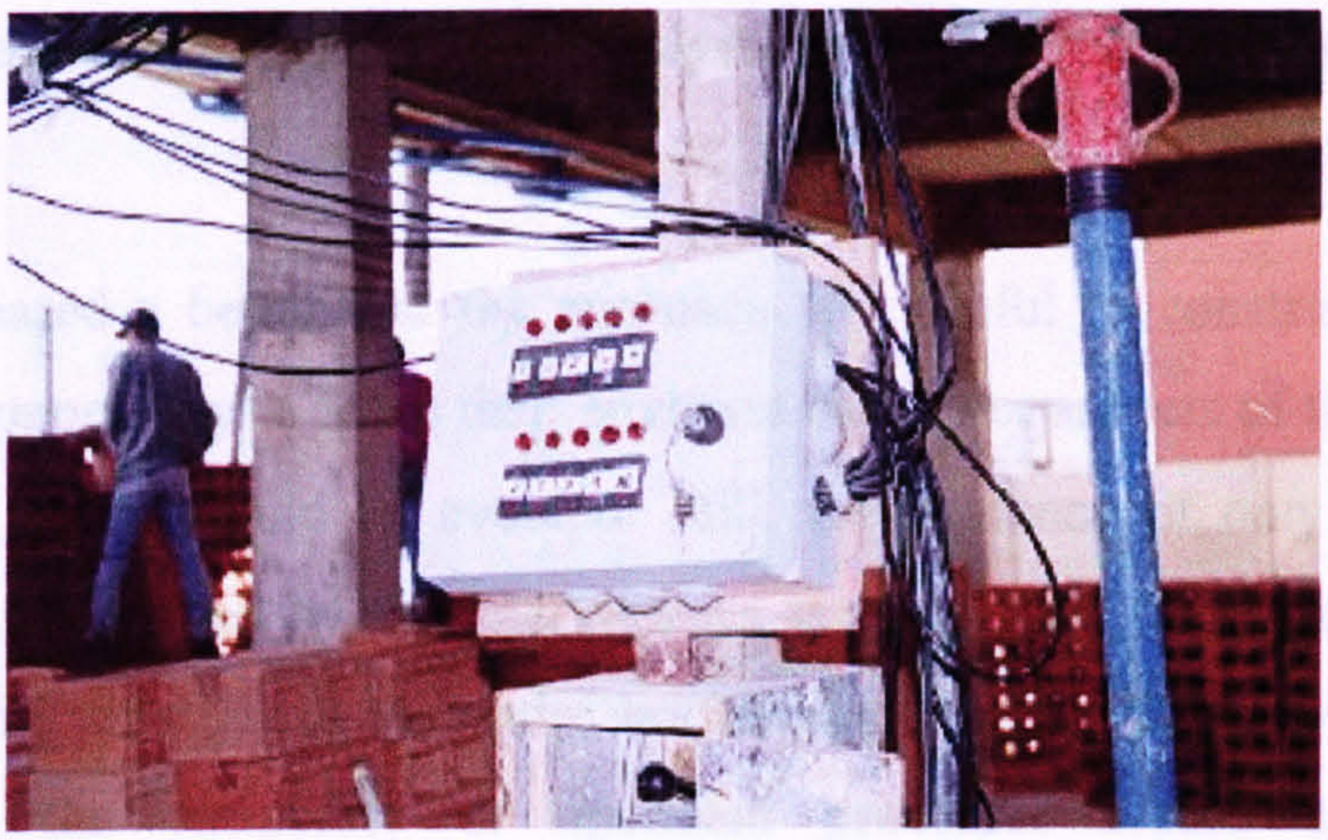


Figure 5.28 - Literal Replication of *Poka-Yoke* (Case Study 4)

b.5) Case Study 5

This case study used a very basic masonry technology that relied on the skills and attention of bricklayer and labourers. The implementation of poka-yoke devices on this site was likely of offering reduced benefits since the largest sources of variability were beyond the boundaries of bricklaying. Indeed, the lack of modularization in design and the high variability of bricks were the main cause for the high level of rework and waste observed in bricklaying.

Bricklayers reported that they had encountered, in previous sites, mechanisms that resembled poka-yoke devices. However, they remained sceptics about the effectiveness of such devices since the inputs received from upstream operations in their present site were extremely variable. The site manager also described examples of poka-yoke devices that he had witnessed in previous construction sites. In his view, there would be enormous difficulties in implementing such an approach since he did not have staff with sufficient knowledge to maintain and improve poka-yoke devices.

b.6) Case Study 6

This construction site presented exactly the same "literal replications" identified on Case Study 2. The impact of these devices on variability was difficult to identify and quantify since they were relating to safety aspects of the process that have never occurred in this company. Nevertheless, managers and bricklayers shared the opinion that, in the strict production sense, these poka-yoke devices contributed to avoid even more severe interruptions in the process. An accident could interrupt the activities in the

construction site severely and this was likely to cost more than the poka-yoke device itself.

They also expressed a belief that the approach was useful to construction because it gave them the opportunity to focus their attention into other aspects of the process in the knowledge that errors would be avoided. Still, the presence of only two poka-yoke devices was acknowledged by the interviewees as too little if compared with the high level of variability throughout the entire bricklaying process. It was also clear for the researcher that the variability of upstream processes would compromise the effectiveness of poka-yoke devices in bricklaying.

5.4.3.6 DISCUSSION

The two main lessons from the analysis of poka-yoke devices in construction are, as follows:

i. Construction does not use this approach in the same intensity as the cases reported in the manufacturing literature. In order to change this situation, more efforts would be required to improve the know-how of managers and workforce on the range of alternatives for implementing this approach in practice;

ii. There is great potential for developing innovations by applying mechanical and electronic poka-yoke devices into the existing construction machinery. Likewise, there is great potential for applying this approach in the design of components and material delivered on site.

The emphasis given by the manufacturing literature on the topic of poka-yoke devices is almost entirely on machinery. However, the observations in the case studies led the researcher to the conclusion that the assembling character, and reduced number of machines present on construction sites, will demand a shift of emphasis of this approach in the construction sector. Indeed, there is great scope for building poka-yoke devices into design details and building components themselves.

One example of installation of poka-yoke device in the design of a building component was found in a traditional window factory in the south of Brazil. This company was

facing growing complaints of problems that originated on the lack of face putty[3] during installation. The subcontractor often forgets to put enough putty for glazing the wooden window frames. "Forgetfulness" is also a common problem identified in manufacturing, according with NKS (1987). In order to avoid the occurrence of this mistake this company developed a new window design where the fixation of the glass necessarily demanded the removal of a component from the window. The removal of this component exposed a layer of putty that reduced the risk of mistakes caused by "forgetfulness".

The evidence from the case studies does not allow the identification of which area should be a priority for concentrating improvement efforts regarding poka-yoke devices. However, the development of this approach into the existing construction machinery has created more excitement among the personnel interviewed since it can have immediate effect on production performance.

Finally, despite their undeniable contribution for better safety in production, the poka-yoke devices observed in the case studies were not tackling the actual bottleneck problems in the case studies. In case of growth on the number of application of poka-yokes in construction, the most frequent sources of process variability should be addressed with more intensity.

5.4.3.7 CONCLUSION

The observations in the case studies suggest that construction is making little use of the poka-yoke approach. The few "literal replications" observed focused almost entirely on the safety aspects of production. In this way, there is great scope for developing mechanic and electronic mistake-proof devices in the existing construction machinery. The research also revealed that suppliers and building designers should reflect on the idea of installing poka-yoke devices into their products and, in this way, contribute to reduce the amount of variability present in construction.

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[3] **Face putty, front putty.** The triangular fillet of traditional glazier's *putty* on the outside of a window *pane*. **Putty.** A plastic substance made of *whiting* (chalk powder) mixed with *linseed oil*, which hardens on exposure to air, used for *glazing* glass into wooden window frames. (Dictionary of Building, 1995).

5.4.4 CONCLUDING REMARKS

The empirical evidence indicated that all three approaches aimed at reducing variability presented in this thesis (standardisation, systematic identification and solution of problems and poka-yoke) are applicable in the construction environment. The six cases analysed in this research offered just a few examples of "literal replication". The observations suggest that reduction of variability is a principle that still needs considerable efforts to be completely integrated in the wisdom and practice of construction people.

Segmented division of responsibilities and the individualistic bonus system in all case studies resulted in a culture of cumulative re-pass of process variability from upstream operations to downstream operations. Variability of the construction processes is often claimed as inherent to construction process. While it is true that variability is always present in any production process, it is also true that complacence has contributed to the high levels of variability observed in the sector. Without people's awareness of the full impact of variability in performance, it will continue to affect all aspects of the construction production processes.

The lack of continuity (smooth flow) of work across different projects was a significant source of variability in the case studies. In addition, due to high variability, most of the construction sites were practising large batches and using buffer time in their schedules. Analysis, detection and solution of root cause of problems did not support these conservative protections against variability (e.g. deficient workflow planning). In this context, the gradual reduction of transfer batches and buffer times associated with systematic solution of problems is understood as a valuable strategy for driving the reduction of variability in construction.

The best case studies (2 and 4) achieved low variability by concentrating only on design standardisation and by virtue of an experienced workforce, that itself did not have to rely on written standard practices. Most of the workforce was not even aware of the content of the standards since there was not an actual process of standardisation in any of the case studies. Consequently, the lack of continuous revision of standards also resulted in discredit of its usefulness in construction. Finally, the involvement of the electronic and mechanical industry, construction designers, and the producers of

building components have been identified as an important opportunity and a necessary step to developing more poka-yoke devices for construction processes.

5.5 INCREASE OF TRANSPARENCY

5.5.1 REDUCING THE INTERDEPENDENCE BETWEEN PROCESSES

5.5.1.1 WORKING DEFINITION

This approach means to reduce the number of connections between processes that cause disruption in the main bricklaying flow.

5.5.1.2 OBSERVATIONAL FOCUS

The central focus of observations here was on the interactions between bricklaying workstations and other processes. These interactions could happen when bricklaying shared space, equipment or material with other processes. The researcher tried to detect if each interaction was interrupting the main bricklaying flow and the magnitude of the interruption. For analytical purposes, empirical evidence was considered as literal replication when there was no visible interaction between the bricklaying workstation and other processes. Process mapping and work sampling were the main tools used to carry out systematic observation of the bricklaying workstations. Open-ended interviews and informal conversations with the workforce revealed further information that increased the robustness of findings.

5.5.1.3 KEY INDICATORS

Two main indicators were chosen to quantify the state of practice in the case studies regarding the reduction of interdependencies, as follows:

a) *Number of Different Processes interfering in the Main Process Flow*: this indicator quantifies the number of processes that interacted with the bricklaying workstations during the observational period. Information gathered from the workforce complemented those periods where the researcher was not on site;

b) *Number of Alternative Precedence Orders between Downstream and Upstream Processes*: this indicator was obtained through daily observation of the workstations and by questioning the workforce on the possible alternative orders of their process. Comparison across the case studies and with the literature, generated further insights into the full range of possibilities for changing the order of the bricklaying process.

5.5.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

Critical analysis of the literature led to the following judgement regarding the practical boundary of the indicators above:

a) *Number of Different Processes interfering in the Main Process Flow*: this indicator should be reduced to a zero in order to reduce complexity and, thus, increase transparency. However, observations of practice and conversations with the workforce led to the establishment of "one interdependence" as the maximum value. An empirical evidence was classified as a "literal replication" when there was no interference in the operations of the bricklaying workstation;

b) *Number of Alternative Precedence Orders between Downstream and Upstream Processes*: a process with infinite possibilities of precedence order should enable the reduction of disruptions between processes to a minimum. In addition, greater availability of alternative precedence orders is clearly an important factor to enable higher flexibility in production. The minimum (2) and maximum (4) value established for this indicator have been obtained from the comparison of different alternative sequences witnessed across the case studies.

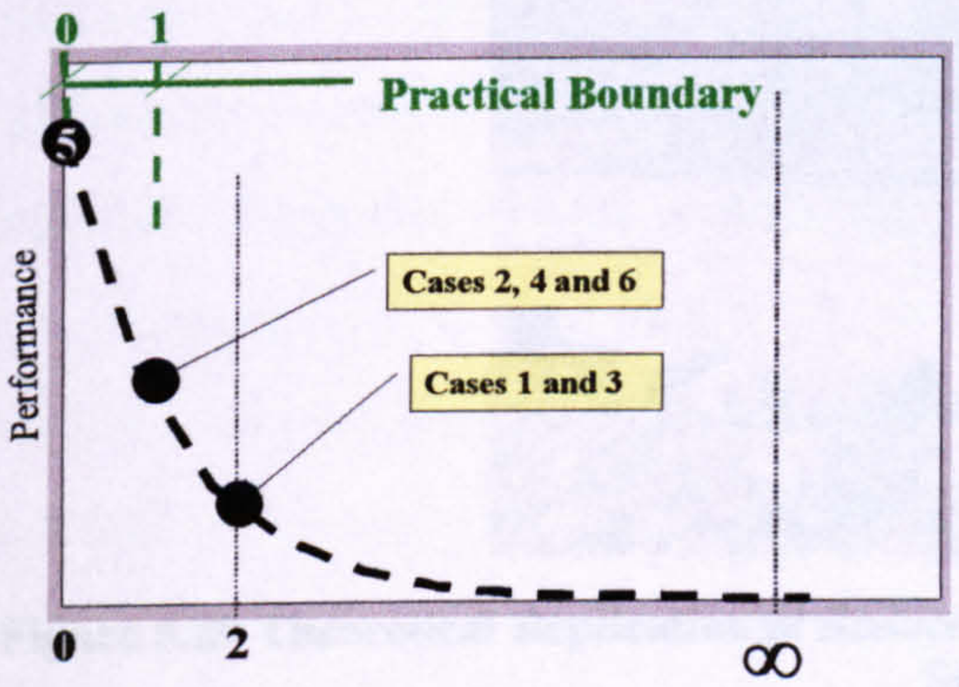
5.5.1.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

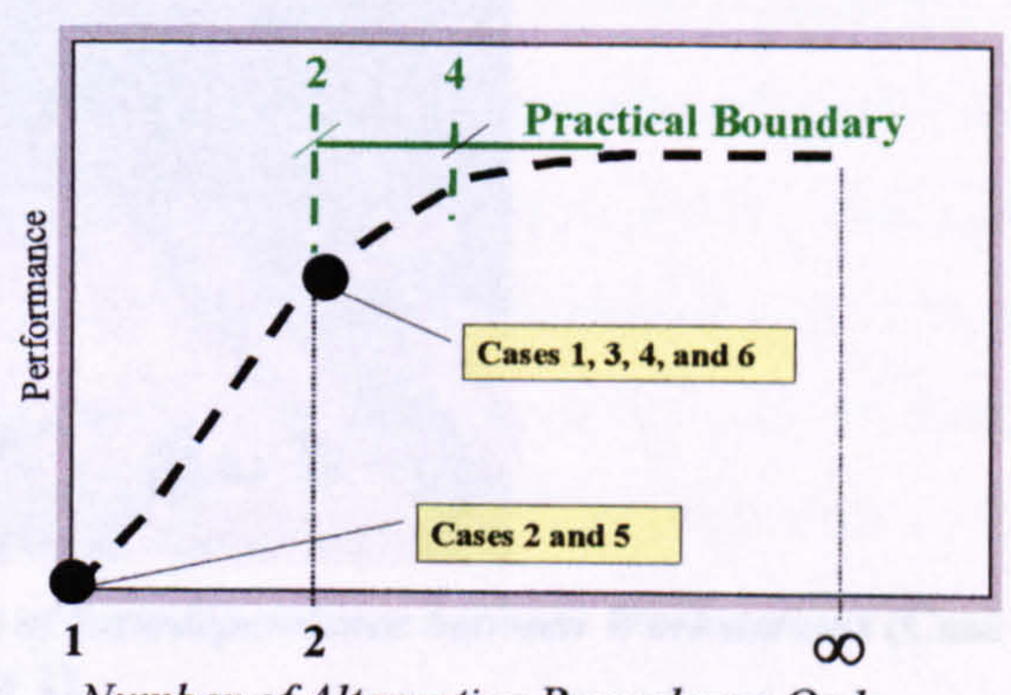
The case studies revealed large variations in the level of interdependence between bricklaying and other processes, as the assessment shown on Table 5.11 illustrates. Daily observations revealed that the workstations with lesser interdependence were able to carry out their main activities more smoothly and with far better housekeeping than other workstations. Nevertheless, the opinion among bricklayers was quite diverse in this respect. Some bricklayers explained that they felt higher responsibility for maintaining good housekeeping when they were the only ones working in a particular area. Other bricklayers acknowledged that the presence of other gangs, working side-by-side with them, forced the practice of better housekeeping in order to avoid conflicts.

Table 5.11 - Performance of Case Studies Regarding *Reduction of Interdependencies*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	10	10	15	10	10	6
Number of Alternative Precedence Orders Between Upstream and Downstream Processes	2	1	2	2	1	2
Number of Different Processes Normally Interfering in the Main Bricklaying Flow	2	1	2	1	0	1
Number of Workstations Presenting no Interference from other Processes	3	15	24	18	5	7
Number of Workstation Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**3**	**15**	**24**	**18**	**5**	**7**



Number of Different Processes Normally Interfering in the Main Bricklaying Flow



Number of Alternative Precedence Orders between Upstream and Downstream Processes

The observations on site revealed that bricklayers applied more frequently the traditional sequential mode of production. The graphic on the right side of Table 5.11 shows that the processes observed in the construction sites enabled very little room for alternative precedence orders. During interviews, however, bricklayers revealed some knowledge on alternative bricklaying sequences based on their experiences on previous construction sites. Yet, the range of their ideas that they presented was still restricted and they clearly lacked information on other bricklaying practices used elsewhere in the globe.

b) Individual Case Study Reports

b.1) Case Study 1

Only three of the twenty-two workstations observed in this case study were free from direct interference of other processes, as Table 5.11 illustrates. This interference usually results in the obstruction of bricklaying pathways and workflow. The clearest example of *theoretical replication* observed in this case study was the rigid dependence between concrete slab and bricklaying at the dpc[4] level, as illustrated on Figure 5.29. Bricklayers on this site had to build the wall up to the dpc level and then wait for the conclusion of the concrete slab in order to continue with their operations. This rigid dependence forced an increase in the number of bricklayer's visit to the same workplace and created more disruptions between processes.



Figure 5.29 Theoretical Replication of *Reduction of Interdependence between Workstations* (Case Study 1)

[4] **Damp-proof course (dpc) or damp course**. A strip of impervious material the same width as a brickwork or blockwork wall, or a *brick damp course*, to keep out moisture (Dictionary of Building, 1995)

Bricklayers acknowledged the problem described above and considered it one of the main barriers for better housekeeping throughout the workplaces and workstations. They could not set-up their workstations properly due to the priority given to slab workflow. However, managers did not recognise this interdependence as a major factor for poor transparency in the bricklaying process. In their view, the delays that occurred on the early part of the project were the main reasons for disruptions in bricklaying. Hence, the problem was the maintenance of buffers between processes and not process interdependence.

b.2) Case Study 2

Almost seventy percent of the workstations observed on this site were able to conduct their activities without interference from other processes. During the ten days of data collection, it became clear that constant attention to workflow was the main reason for the reduced amount of interference between bricklaying and other processes. Even in those cases where there was clear interference from other processes, the prompt action of labourers kept the site clean and tidy. The subcontractor established financial incentives to labourers for maintaining good housekeeping, baring in mind that the client was a hospital and it was quite demanding in terms of dust in the air.

b.3) Case Study 3

Twenty-four of the forty five workstations observed in this construction site revealed direct interdependence with other downstream or/and upstream process. In some cases, bricklayers had to delay the construction of walls in order to wait for the completion of drainage or electrical works. In other situations, as the one illustrated on Figure 5.13, carpenters depended on the inputs from bricklayers and vice-versa, during and after floor framing[5]. The occurrence of interdependence between bricklaying and floor framing occurred because the wooden beams needed to rest upon the brickwall itself. Although carpenters strove to reduce the delays caused by this interdependence, the immediate consequence was less clarity in understanding their workflow and more disruptions in the workplace.

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[5] **Floor framing**. The floor *joists*, their *strutting* and support (Dictionary of Building, 1995)

A direct contrast to the practice described above was found in a meta-case where a construction company faced a similar problem but adopted a more imaginative solution. As Figure 5.30 illustrates, the wooden structure on this site rested upon metallic joists[6] and, in this way, almost eliminated the direct link between bricklayers and carpenters.



Figure 5.30 - Literal Replication of *Reduction of Interdependence between Processes* (Meta Case/England)

b.4) Case Study 4

Despite the proven value of reducing interdependencies in the previous case studies, empirical evidence gathered from this construction site shows that interdependence is not always a signal of problems in the process. On this site, part of the electrical operations had been incorporated into the bricklaying process, and that increased the degree of interdependence between electricians and bricklayers (*see* Figure 5.14). The high degree of interdependence did not cause great disruptions because the workforce had mastered the technology and most design details had been simplified and standardised. Foremost, the fact that both processes worked in parallel in the same area was useful for promoting the early recognition of problems and significant reduction of work-in-progress.

b.5) Case Study 5

Bricklayers in this case study relied less on the accuracy and quality of upstream processes to carry on their operations since there were no processes interfering with their main operations. These characteristics could certainly indicate a low level of

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[6] **Joist.** A wooden or steel beam directly supporting flooring or a ceiling lining, in common with other joists. They are either full-length intermediate joists, trimmer joists, or trimmed joists (Dictionary of Building, 1995)

interdependence between bricklaying and other processes and, consequently, more transparency. However, Case Study 5 presented these characteristics only due to the rudimentary technological state of the bricklaying process.

The low level of interdependence between bricklaying and other processes was contra-balanced by a high level of rework and continuous generation of clutter. For instance, electrical and plumbing operatives did not interfere with bricklaying but, subsequently, they had to cut the brickwalls in order to install their components. The lack of problem solving activities and direct communication between those processes contributed to increase even further the effects of variability. It is a direct contrast with Case Study 4, where strong interdependencies among processes had forced a better dialog and co-operation between workers.

b.6) Case Study 6

The technology and design of components in this building were similar to Case Study 4 but the effect of interdependencies was almost opposite. High variability of materials, lack of effective standards and poor workflow planning has transformed the original process design into a sequence of improvisations. Whilst in Case Study 4 there was a smooth flow between electricians and bricklayers, here electricians interrupted the bricklayer's flow continuously throughout the day. All these problems add to the difficulties in understanding the dynamics between bricklaying and other processes.

Conversations with the site manager revealed that the company had reduction of interdependencies as one of the main topics in the agenda for improvements. However, the emphasis of his words was entirely on technology and design solutions. There was no mention to the urgent need of organising and improving the actual bricklaying flow in the construction site

5.5.1.6 DISCUSSION

The main findings from the analysis of this approach in construction practice are:

i. Reducing interdependence between processes increases transparency in bricklaying because it allows the separation of processes in time and space.

Also, this separation reduces disruptions in process flows and creates unambiguous responsibilities for each process regarding housekeeping;

ii. This approach cannot be adopted blindly since high and low levels of interdependence can also be found even in transparent environments. The essential issue in this respect is how interdependence interacts with other practices.

Reduction of interdependencies should be included as a main topic in the designer's agenda for improvements. However, the literature review showed scarce guidelines throughout the operations management literature that could support construction in this respect. The observations in the case studies showed that the solutions for the interfaces between bricklaying and structure, or bricklaying and plumbing/electrical services, for instance, generally relied on the creativity and improvisation of the bricklayers themselves. The resulting waste and the frequent interference between different processes increased the difficulties in understanding the direction of flows and the source of problems.

This heuristic approach contributes to reduce complexity and, thus, it facilitates the co-ordination of processes within a production system. However, existing relationships between internal client and internal suppliers within the production system should not be eliminated. The more independent the bricklaying process is the more important it is maintaining these internal relationships in order to keep alive the stream of ideas for continuous improvements. Communication has to remain dynamic and problem-solving activities need to continue in order to enhance the overall production performance.

Buffers in schedules or inventory can have the same effect as reduction of interdependencies in terms of avoiding direct interference between processes. However, people may lose understanding of the overall production system and, therefore, there is a risk of reducing transparency. Another problem of this practice is the reduction of direct contacts between people, which is fundamental for driving continuous improvement and better process transparency.

5.5.1.7 CONCLUSION

The cases studied confirmed that when there is a rigid link between two or more processes, leading to different gangs working in the same area, disturbances in the workplace are more likely to occur. Nevertheless, the case studies shown that a process with high level of interdependence can also present a good level of transparency. Likewise, a process with a low level of interdependence can present a low level of transparency. The effectiveness of this practice in increasing transparency will depend on the network of complementary practices surrounding the production process.

5.5.2 USE OF VISUAL CONTROLS TO ENABLE IMMEDIATE RECOGNITION OF PROCESS STATUS

5.5.2.1 WORKING DEFINITION

This approach means installing visual devices that affect any of the human senses in order to allow the immediate recognition of the status of the bricklaying process.

5.5.2.2 OBSERVATIONAL FOCUS

The detection of visual controls was carried out in the first two days of data collection in each case study. The focus was on any practice that used colour, touch (e.g. temperature), sound, taste or smell to control any aspect of the bricklaying process. The observations followed systematically through each process stage, using a flow chart as an observational guide. Open-ended interviews helped the researcher to understand how bricklayers operate the visual controls identified and capture their perception on the effectiveness of such devices.

5.5.2.3 KEY INDICATORS

The assessment of each case study on the application of this approach was carried out using the "total number of visual controls" as the main indicator. This indicator sums all types of visual indicators that have been detected throughout the entire bricklaying process.

5.5.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

Ideally, every single source of variation in the process should have attached a visual control. Therefore, the adequate quantity and type of visual controls for a production process is likely to be different from case to case and, after all, there is unlimited possibilities for implementing visual controls in production processes. For analytical purposes, this research uses the shortest number of process stages observed in the case studies (8) as the lower value of a 'practical boundary'. This is because most process stages observed across the case studies have presented variations from one cycle to another. The upper value for the practical boundary has been established, after discussions with site managers, as double of the minimum value.

5.5.2.5 SUMMARY OF RESULTS

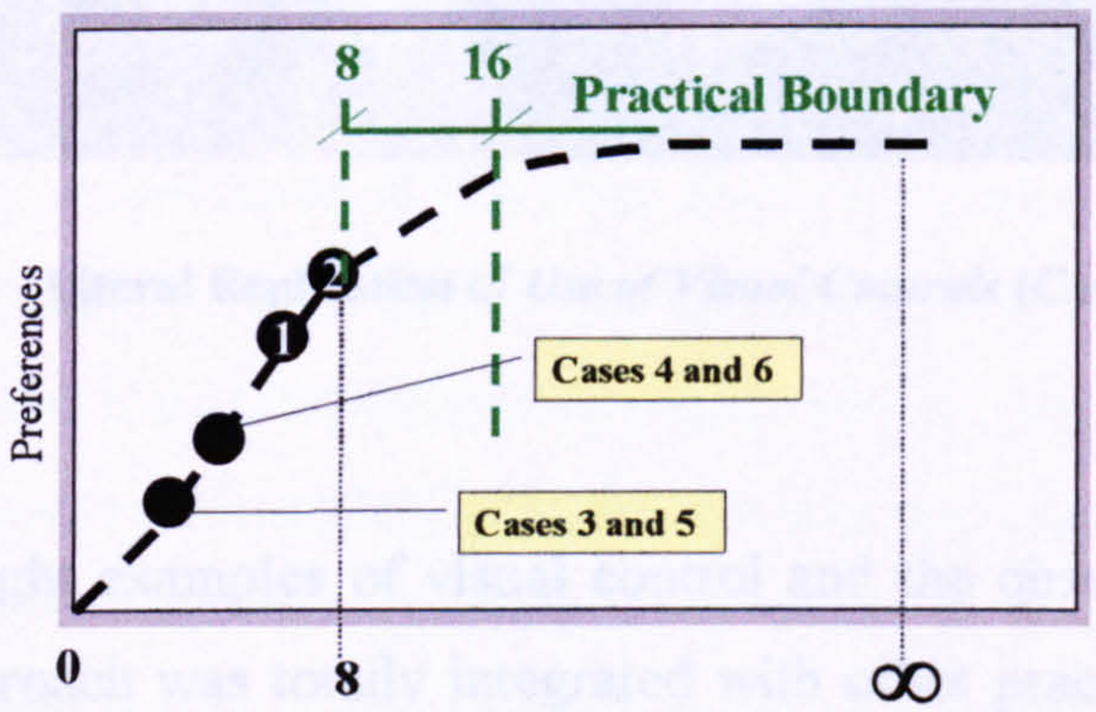
a) General Pattern Across All Cases

Only one of the construction sites have presented a level of visual controls below the practical boundary established for this research, as Table 5.12 demonstrates. Bricklayers and managers admitted this practical boundary is an achievable target. Nevertheless, they showed a serious lack of knowledge on the meaning and potential applications of visual controls in the bricklaying process. The only examples of visual controls that they could remember were the ones traditionally used in the region surrounding each construction site

Safety signs were the most common types of visual control observed across the construction sites. Managers revealed during open-ended interviews that law enforcement was the main reason driving their implementation. Yet, pathways lacked clear delimitation and, often, one could walk through areas of high safety risk without seeing a single sign of alert. Only one of the sites observed presented a 'safety risk map', where it was clearly indicated the areas to be avoided by the workforce and clients.

Table 5.12 - Performance of Case Studies Regarding *Visual Controls*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	2	2	2	2	2	2
Number of Visual Controls Using Smell	0	0	0	0	0	0
Number of Visual Controls Using Taste	0	0	0	0	0	0
Number of Visual Controls Using Touch	1	2	1	2	2	2
Number of Visual Controls Using Sound	1	0	0	0	0	0
Number of Visual Controls Using Reference Measures	2	1	1	0	1	0
Number of Visual Controls Using Colours	3	5	2	3	1	3
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**7**	**8**	**4**	**5**	**4**	**5**



Most of the visual controls observed in the English construction sites followed standards and were factory-made. In contrast, the Brazilian construction sites used the workforce to produce their own visual controls and did not follow any standards. Visual controls in both countries demanded excessive time to assemble and dismantle and, generally, were separate parts from the bricklaying workstation.

b) Individual Case Study Reports

b.1) Case Study 1

This site presented only seven visual controls throughout its eleven process stages (*see* Table 5.12). Figure 5.31 illustrates an example of visual control observed on this site. This example consists of tape containing various measures for alternative brick modules that was used as reference to guide the work of bricklayers. Bricklayers declared having

no need to carry out further measurements once this tape was in place. Traditionally, measuring vertical position of brickcourses is a time consuming activity and subject to error since bricklayers has to measure many times the same item. However, with this tape bricklayers could easily adjust brickcourses to the modularization specified in the plans without losing time in the operation.



Figure 5.31 - Literal Replication of *Use of Visual Controls* (Case Study 1)

b.2) Case Study 2

This site presented eight examples of visual control and the observations have shown that this heuristic approach was totally integrated with other practices. Visual controls played an important role in organising flows since the area available for transportation was very small. This approach was also used to help the focus of bricklayers on the main value adding activity. An example of this was the creative use of spray to set-up positions and distances. The operator presented on Figure 5.32 is setting up the level that bricklayers should take as reference to start the brickcourses. The spray is rapidly spread over a line of nylon, conferring good precision to the operation. Conversations with the bricklayers and daily observations confirmed that this practice reduced the need for excessive measurements and helped to guarantee the production of brickwalls according to the design module.



Figure 5.32 - Literal Replication of Use of Visual Controls (Case Study 2)

b.3) Case Study 3

This site unveiled only four visual controls throughout the entire bricklaying process (*see* Table 5.12). Great amount of improvisations in storage, pathways and workflow were the most evident consequence of this poor level of visual controls. Truck drivers did not know where exactly there should be unloaded their deliveries. Bricklayers themselves did not have this information since they had no participation in decision making and had received no orientation from the site manager. Thus, daily observations revealed that truck drivers decided for themselves where it was more appropriate to unload pallets, etc. Their decision often resulted in the concentration of storage in large piles and excessive transportation distances for labourers and bricklayers.

b.4) Case Study 4

Observations on this site revealed only five visual controls across its eight process stages (*see* Table 5.12). Nevertheless, workflow and storage were better planned and the need for visual controls was less evident. Clearly, they benefited from the learning on previous projects where they had worked with similar design and technology. Pathways were well organised, workstations flowed smoothly and brickwalls were visually of better quality than the local competitors. Yet, open-ended interviews with managers and bricklayers revealed that they were clearly unaware about the range of possibilities on visual controls. Use of visual controls to reduce the amount of time spend on measurement was never an issue mentioned by the interviewees.

b.5) Case Study 5

This site presented the worst situation in terms of visual controls since there was only four literal replications throughout the twelve process stages observed (*see* Table 5.12). The site manager and workforce presented little concerns about this weakness in their practices even when the researcher presented good examples of visual controls from other construction sites to them. Further questioning showed that while the practical benefits of this heuristic approach were understood, they had not fully appreciated it because of the poor relationship between bricklayers and the contractor. The site manager declared having "*...no interest in promoting improvements in bricklaying practice, as long as bricklayers continue to delivery their product according to the planned budget and schedule*". Thus, achieving a transparent production environment was not one of his priorities.

b.6) Case Study 6

The observations on this site have shown bricklayers spending considerable amount of time doing measurements, locating positions and searching for material/equipment. Figure 5.33, for instance, shows two workers setting up the position of brickwalls with a very time consuming method since this method did not leave a permanent visual control. Therefore, it did not eliminate the possibility of further measurements of the same area in future operations. In fact, the researcher observed the same professionals measuring the same workplace twice during the observational period.



Figure 5.33 - Theoretical Replication of *Use of Visual Controls* (Case Study 6)

This site presented only five literal replications across its twelve process stages, as shown on Table 5.12. Like in the Case Study 5, managers and bricklayers on this site

did not understand the importance of visual controls mainly because they had never experienced a true transparent environment before. The discussion of examples with bricklayers showed that they had difficulty in understanding the practical implications of visual controls since they have witnessed very few examples throughout their careers.

5.5.2.6 DISCUSSION

The main lessons from the analysis of visual controls in construction practice are, as follows:

i. All construction sites emphasised the use of visual controls in some way, mainly in the safety aspects of production, and normally because of law enforcement. Clearly, more visual controls are required in transportation (e.g. borders in storage) and processing activities (e.g. support to measurement activities);

ii. A critical issue for implementing visual control in construction is the need for mobility. Visual controls would work better in construction if they were portable and easy to install and update;

iii. Effective application of visual controls depends on the degree of responsibility for process improvement shared with the workforce.

Visual control is a supporting approach and works better when it is surrounded by other complementary approaches. Indeed, the sites with the best level of standardised practices in this respect, and smooth flows and shared responsibilities, have used visual controls more effectively. In contrast, visual controls in sites with poor workflow planning, high process variability and poor relationship between managers and workforce had reduced contribution on process performance.

A range of innovative solutions could be generated by installing visual controls in all current equipment, material and components used in the construction industry. For instance, bricklayers and labourers should not spend time measuring bricks/blocks or wandering if the consistency of mortar was adequate. Thus, installing visual controls for this purpose should be a topic in the agenda of improvements in the construction supply chain. It is worth emphasising that the personnel interviewed in the construction

companies have shown a great lack of knowledge on the possibilities of such an approach. More training and hands-on experience is required in order to make them fully knowledgeable on the benefits and potential of such an approach in construction.

It also became evident during the study that effective maintenance of visual controls is a critical factor identified for the successful implementation of this approach in the construction sector. In order to achieve that, and transform visual controls in a regular and natural practice among the construction workforce, such an approach should be implemented involving everyone in all stages. Top managers have great importance in this regard. According with NKS (1991), periodic checks and follow-ups conducted by top managers can motivate people to use and maintain the visual controls in place.

5.5.2.7 CONCLUSION

According to the available empirical evidence, the implementation of visual controls is viable and already in use in the construction environment. Nevertheless, the number of applications observed in the case studies still is too small if taking into consideration the variety of problems and high level of variability observed in this research. In addition, comparison of empirical evidence collected in construction against the possibilities presented in the literature shows that construction uses only a limited set of alternatives. In this respect, the study and implementation of visual controls is a potential source of innovative ideas for the sector.

5.5.3 MAKING THE PROCESS DIRECTLY OBSERVABLE

5.5.3.1 WORKING DEFINITION

This approach means to plan the positions within the layout and workflow in a way that allows direct observation of the bricklaying process status by as many positions as possible.

5.5.3.2 OBSERVATIONAL FOCUS

The focus of observations here was on the visibility of the material and components since they arrive on site until their use in the workstations. Special attention was also given to the possibility of direct eye contact among workstations. The assessment of

each case study used the flow of bricks/block as reference because it was the most frequent material moving across the site.

The first activity carried out during the observational period was the elaboration of a process flow chart and a layout diagram. The layout diagram captured the position of each workstation and the visibility that each bricklayer had of others workstations. The researcher plotted in this layout diagram the position on site where one could see most of the process sages. The observations were cross-checked with the opinions of site managers and bricklayers at the end of the data collection.

5.5.3.3 KEY INDICATORS

Two main indicators were used in the assessment of this approach in construction practice:

a) *% of Process Stages Observed from a Single Viewpoint*: this indicator shows the maximum number of bricklaying stages that the researcher was able to see from a single observational point. The focus were on the flow of bricks and blocks and the assessment covered since the unloading of pallets on site until the delivery on the workstation;

b) *Flow Efficiency:* this indicator helped to measure how lean was the flow of bricks/blocks on site. With leaner flows, it should be easier to see across the various bricklaying stages. This indicator is obtained by dividing the values of 'productivity' by the 'average storage'. It is a relative measure and has no dimensional unit since both 'productivity' and 'average storage' is measured in terms of m^3/hour/bricklayer.

5.5.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and practical boundary for the indicators above are, as follows:

a) *% of Process Stages Observed from a Single Viewpoint*: at least ninety percent of the process should be seen from a single viewpoint. This practical boundary was established after visits in other industries and critical analysis of the literature. Daily

observations supported by data gathered from layout diagrams reinforce the judgement in this respect.

b) *Flow Efficiency:* ideally, the value of these indicator should be "one", which could be interpreted as a process carrying the exact quantity material for a single batch unit. However, the researcher set a more realistic minimum value of 0.50 based on the discussions with practitioners in the case studies. In addition, based on discussions with site managers, a value of 0.9 has been established as a challenge for the sector since there was no benchmarks for such indicator at the time of this research.

5.5.3.5 SUMMARY OF RESULTS

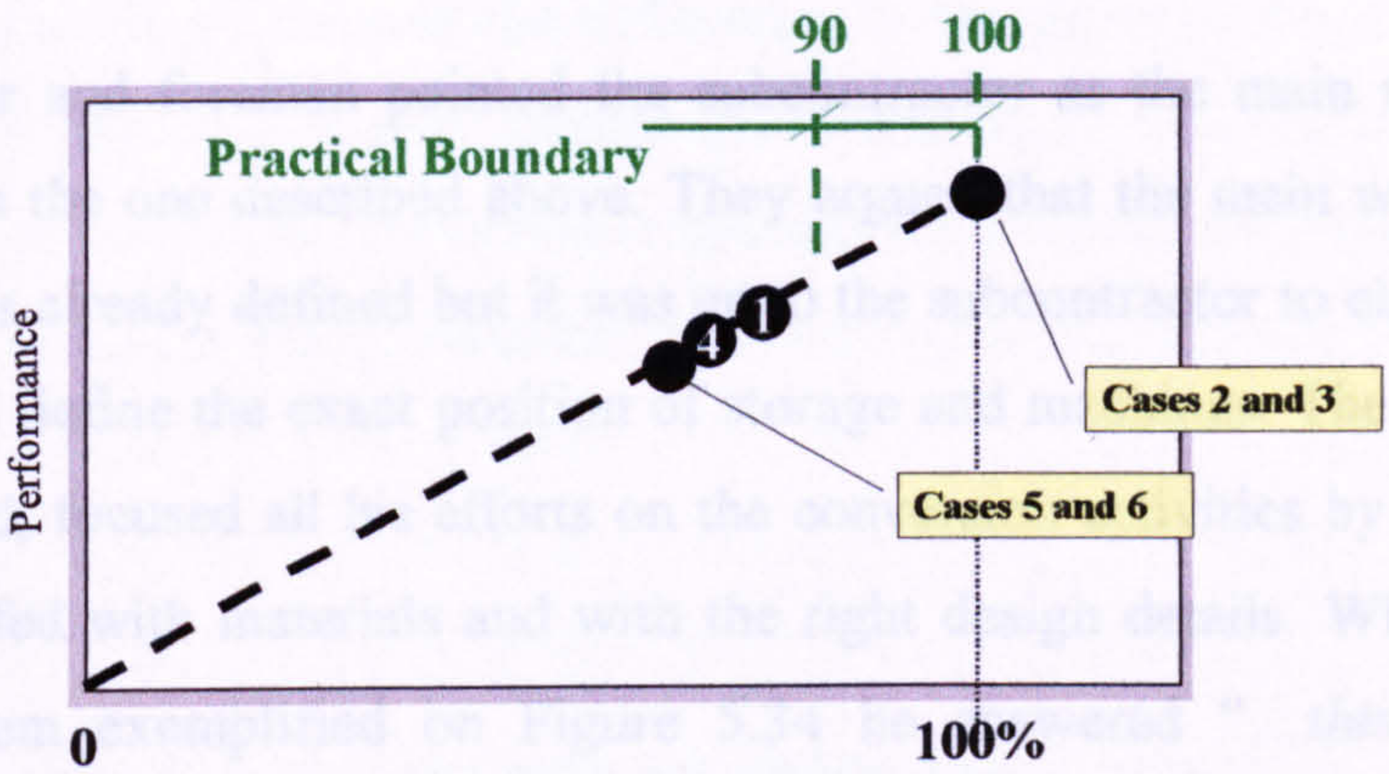
a) General Pattern Across All Cases

The case studies presented a satisfactory visualisation of all process stages, as shows the indicator *% of Process Stages Observed from a Single Viewpoint* presented on Table 5. 13. However most process stages were directly visible because to the intrinsic characteristics of bricklaying and not due to a deliberated attempt of making the process more transparent. Indeed, lack of an effective workflow planning was a frequent cause of poor visibility in the construction sites. In many occasions, for instance, pathways suffered premature closure and bricklayers could no longer communicate directly with each other.

The widespread practice of large transfer and delivery batches allied to poor workflow planning also had a severe impact on process visibility. Workstations demanded only a small part of the average storage available on site, as the values of 'flow efficiency' presented on Table 5. 13 indicate. The excess of bricks/blocks flowing across the site obstructed the direct eye contact with equipment and workstations and increased the difficulties to evaluate the amount of storage on site.

Table 5. 13 - Performance of Case Studies Regarding *Making the Process Directly Observable*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	2	2	2	2	2	2
Flow Efficiency (A/B)	0.05	0.06	0.03	0.07	0.03	0.04
% of Process Stages Observed from a Single Viewpoint	81	100	100	77	67	67
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replication	**9**	**8**	**8**	**6**	**8**	**8**



b) Individual Case Study Reports

b.1) Case Study 1

Despite the ample area of construction, only nine process stages were observable from a single viewpoint in this case study. Daily observations revealed that the most common consequence of poor process visibility was the waste of time searching for material/equipment and reduction in the quality of communication. For instance, Figure 5.34 shows a store of blocks between the saw machine and the bricklayer's workstation that obstructed the communication between bricklayers and labourers. This situation increased the amount of errors and disruptions in the main value adding activity.



Figure 5.34 -Theoretical Replication of *Making the Process Directly Observable* (Case Study 1)

The site manager and foreman pointed the subcontractor as the main responsible for problems such as the one described above. They argued that the main workflow of the entire project was already defined but it was up to the subcontractor to elaborate a more detailed plan and define the exact position of storage and machines. The subcontractor, on the other hand, focused all his efforts on the conversion activities by trying to keep the workstation fed with materials and with the right design details. When questioned about the problem exemplified on Figure 5.34 he answered "*...this was the site manager decision and I cannot interfere on that*".

b.2) Case Study 2

Table 5. 13 shows that all process stages could be observed from a single viewpoint in this construction site. One of the literal replications identified was a mobile fence that allowed direct eye contact with the production process inside the construction site (*see* Figure 5.35). This practice was valuable for the hospital administration since it allowed anyone to identify practices that could put the patients health in danger (e.g. use of mobile phone next to buildings operating sensitive equipment).



Figure 5.35 - Literal Replication of *Making the Process Directly Observable* (Case Study 2)

b.3) Case Study 3

Like in the previous case study, the researcher was able to watch all process stages on this site from a single viewpoint on this site. The area around the house under construction was ample and, because of that, all bricklaying stages could be scrutinised from different angles. Nevertheless, the poor workflow planning had placed the bricklayers in distant workplaces. This situation reduced the quality of communication and the co-ordination of resources among bricklayers.

Large volumes of storage increased the difficulties to recognise which pallet was in use or which pile was part of a 'safety' storage (flow efficiency = 0.03). Moreover, truck drivers did not receive precise instructions regarding the position for unloading material. Thus, often the position of storage was not the most convenient for site transportation or storage visualisation.

b.4) Case Study 4

Part of the process stages on this site were not visible from a single viewpoint because it was a multi-storey building and, naturally, the building itself obstructed the observation of the complete process (*see* Table 5. 13). However, the smooth and continuous flow of material throughout the eight process stages allowed rapid understanding of the exact requirement of workstations. Since there were no piles of blocks obstructing the vision, clutter and equipment outside of the designed area were quickly recognised.

b.5) Case Study 5

Only eight of the twelve process stages could be observed from a single viewpoint. This was partially caused by the intrinsic difficulties of visualisation in multi-storey buildings. However, it was also a direct consequence of poor workflow planning and excessive focus on operations rather than process. Firstly, bricklayers worked distantly from each other and, because of that, they presented poor levels of communication and co-ordination of resources. Secondly, the equipment adopted for transportation demanded excessive number of transport and storage steps and that increased the complexity for understanding the production flow.

In the opinion of the site manager and foreman, the current workflow was satisfactory because it helped them to establish the productivity bonus. Each bricklayer was responsible for constructing the brickwalls for an entire apartment. In their view, if more than one bricklayer worked in the same apartment, there would be confusion regarding the amount of brickwalls produced by each bricklayer.

b.6) Case Study 6

Table 5. 13 shows that on this site one could see from a single viewpoint only eight of the twelve process stages that have been mapped. The technology and design was similar to Case Study 4 but there were four extra process stages in this case study. The lack of synchronisation of deliveries, associated with the lack of direct access to vertical transportation, increased the number of process stages and the amount of storage on this site. Labourers working on the ground floor did not know exactly the amount of material available in the workstations and, similarly, bricklayers did not have an exact notion about the amount of material available in the ground floor.

5.5.3.6 DISCUSSION

There were two main lessons from the case studies regarding this approach:

i. The batch size policy in each company was a major factor in enabling better visibility of process status. The sites with leaner flows enabled faster understanding of flow sequence and production rate;

ii. Direct observation of all process stages is not possible in multi-store buildings or large construction sties. In these situations, 'visual controls' should be used more intensively. CCTV cameras in particular offer great potential for enabling direct process visualisation and extending process visualisation to even remote stakeholders.

In construction processes like bricklaying, it should be easier to have direct eye contact with all process stages. The rooms in the building are still open and, usually, there is a reduced variety of materials flowing across the site. However, the observation in the case studies showed that the batch size policy in each site has a serious negative effect on the degree of process visibility. The concentration of material in large piles, in

particular, generally led to the creation of different pathways for transportation and isolation of workstations.

The full application of this approach in the processes following bricklaying is likely to be more difficult. They certainly will be affected by the presence of brickwalls and other construction components. Thus, layout and workflow planning is not enough to apply this approach in the construction environment. Alternative practices such as the use of CCTV cameras or the installation of other visual controls need to be considered if the objective is enabling fast recognition of process status. The construction equipment observed in the cases studied did not allow direct observation of all process stages. Indeed, producers of equipment for the construction industry should reflect more on the idea of anticipating areas for direct visual contact with the material being processed or transported.

The number of process stages was another factor that had a negative effect on the visibility of bricklaying. Case Study 5 showed that decisions oriented towards 'operations' rather than 'process' can lead to an excessive number of process stages. In that particular case the company increased the number of process stages due to the insistence of production managers in using transporting equipment that was not compatible with the packing system. Labourers had to load bricks manually onto a four-wheel trolley and, then, use a crane to lift this trolley to the floor where bricklaying was in operation. After that, they had to unload all bricks again on the floor and send the trolley back to the ground floor.

5.5.3.7 CONCLUSION

Sufficient empirical evidence has been identified to conclude that "making the process directly observable" is a viable approach for increase transparency in construction sites. The researcher believes that it is totally feasible to establish a target of one hundred percent visibility for a construction flow. In order to achieve that, construction companies should plan the workflow with focus on the guarantee of transparency. In addition, visual controls should be used as a supportive tool in those places where it is not possible to have direct eye contact with the process flow. Finally, equipment producers should consider this approach in the design of their product and include more areas for direct visual contact with the flow of material.

5.5.4 INSTALLING INFORMATION INTO THE PRODUCTION ENVIRONMENT

5.5.4.1 WORKING DEFINITION

This approach means to promote better process understanding by fixing useful bricklaying information into workplaces, workstations, products and pathways.

5.5.4.2 OBSERVATIONAL FOCUS

The researcher's attention focused here on any display of information directly relating to bricklaying. The identification of information displays took usually two days, and started with the drawing of a process flow-chart. The researcher then scrutinised every process stage, the equipment used in the workstations, pathways, workplaces and any material or component delivered on site. Open-ended interviews, and daily conversations with the workforce, brought further insights into the actual use of the information displays identified.

5.5.4.3 KEY INDICATORS

The total "number of information displays", particularly those presented with respect to information boards, or occurring in products delivered on site, has been adopted as the main indicator to assess each case study regarding this approach. When this indicator is placed against the "number of process stages" it can show the relative intensity of information throughout the bricklaying process in each case study.

5.5.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The literature does not discuss any criteria for the level of information that should be present in the production environment. Inference on Greif's (1989) and Galsworth's (1997) writings suggests that every process stage should have an information display. Thus, for analytical purposes, this research admits the minimum quantity of information displays as equal to the shortest number of process stages identified among the case studies (eight). The upper limit of information displays has been admitted as double of this minimum value.

5.5.4.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

All case studies presented a level of information in the production environment below the minimum value established for this research. The best case study presented information displays in only half of the process stages. Furthermore, as Table 5.14 shows, boards were the only media used to displays process information. None of the components, material and equipment flowing across the site has displayed useful process information for bricklayers.

The need for displaying information was evident since bricklayers revealed great lack of knowledge on the basic aspects of the products and equipment they handled everyday. When questioned about the procedures for maintaining their own equipment, for instance, they generally argued that they did not have sufficient knowledge on the subject. Empirical evidence available in the meta-case showed that the equipment of workstations could be the channel to present such information.

Table 5.14 - Performance of Case Studies Regarding *Installation of Information into the Production Environment*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	2	2	2	2	2	2
Number of Boards Displaying Process Information	1	4	0	2	2	2
Number of Products Displaying Process Information	0	0	0	0	0	0
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replication	**1**	**4**	**0**	**2**	**2**	**2**

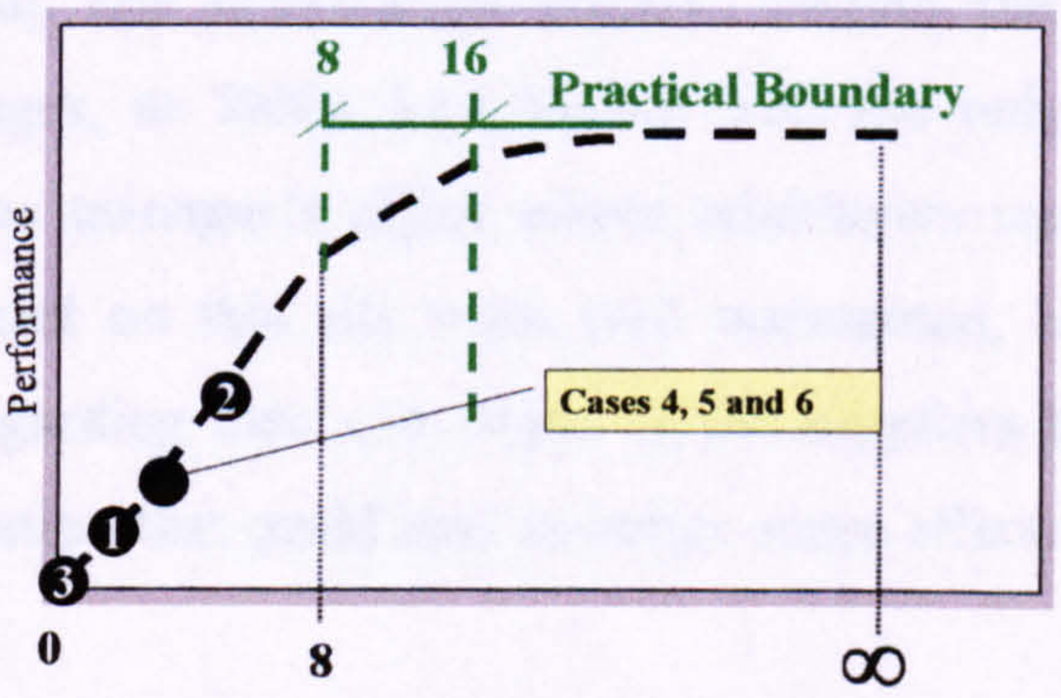


Figure 5.36 shows a maintenance manual attached to the equipment that it refers to. The equipment consists of manual lift used to transport pallets of bricks. With this 'maintenance manual' attached to this equipment, any technical information regarding maintenance problems could be easily obtained in the workstation itself, when and where necessary.

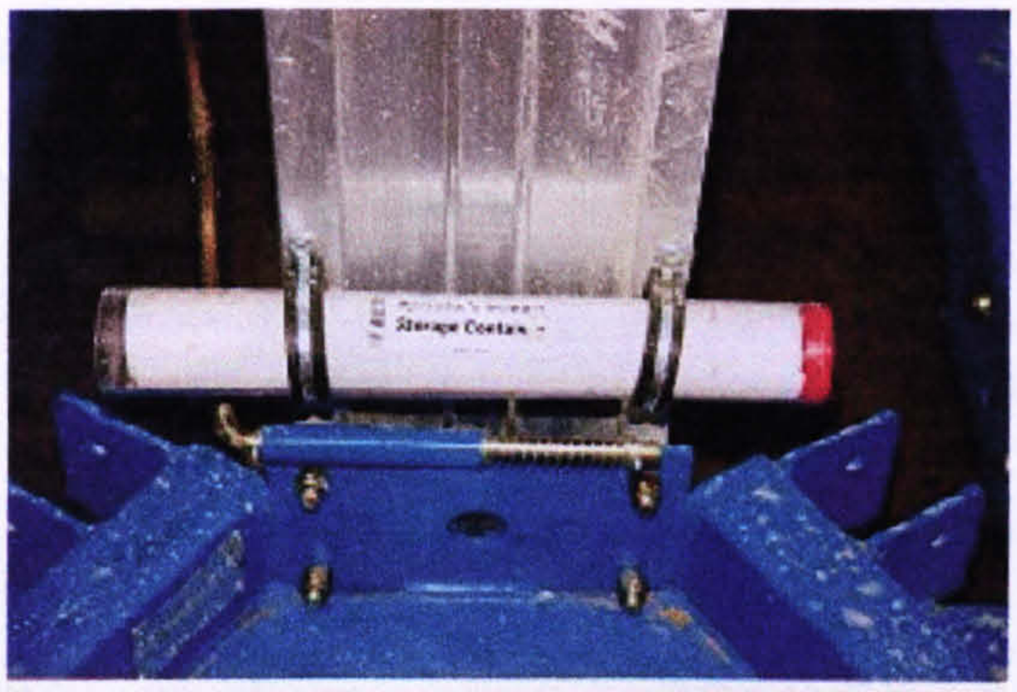


Figure 5.36 - Literal Replication of *Installation of Information into the Production Environment* (Meta Case/England)

Site managers argued that there were not much information displayed to bricklayers because the process was relative simple and, furthermore, handling of the most critical information was the manager's responsibility. Consequently, bricklayers did not have sufficient knowledge about the workstation flow or date of deliveries on site. They relied on the site manager for such decisions and he did not normally take any responsibility for problems occurring in the workflow or layout.

b) Individual Case Study Reports

b.1) Case Study 1

This site presented only one information display, despite the existence of eleven bricklaying process stages, as Table 5.14 shows. Yet, the only information display identified was inside the manager's office where bricklayers rarely have access. The tools and equipment used on this site were well maintained, but did not have any information attached regarding their use. None of the suppliers had included, in their packing system, information that could lead to better, more effective and more efficient bricklaying practices.

b.2) Case Study 2

The four information displays identified in this case study have no direct effect on the main processing activity. Safety was the main topic of these displays as Figure 5.37 illustrates. This empirical evidence consists of a blackboard fixed in the lunch area. Site managers used this blackboard to communicate a variety of informations to the workforce, mainly regarding safety precautions.

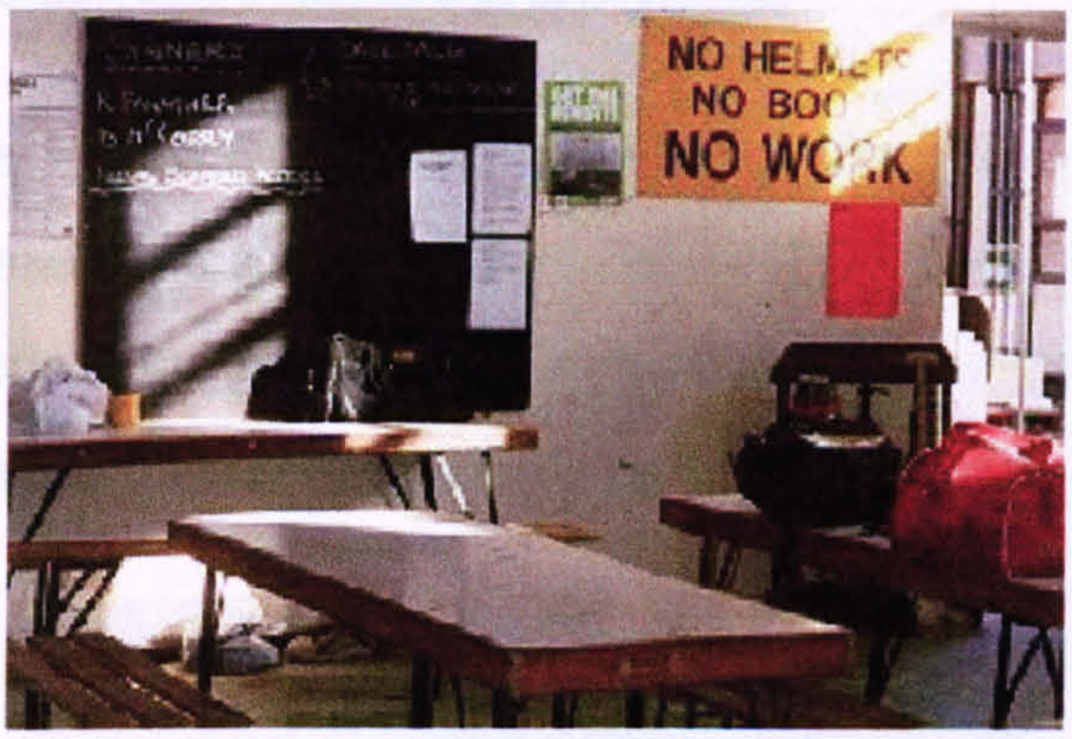


Figure 5.37 - Literal Replication of *Installation of Information into the Production Environment* (Case Study 2)

Despite the lack of information displays, the workforce revealed satisfactory knowledge regarding workflow, maintenance of equipment and general characteristics of material. Daily observations revealed that the daily direct contact between the workforce and site manager have compensated for the lack of information displays.

b.3) Case Study 3

This construction site did not have any information displayed throughout the bricklaying process or surroundings, as Table 5.14 shows. The site manager centralised the control of information and even declared certain scepticism in showing information to the bricklayers. In his words "*...all information that bricklayers could possibly need have already been supplied such as drawings, the date of payments and deadlines*". He emphasised that the site office was always open to solve any queries or doubts that bricklayers might have. However, during the fifteen days of observations on this site there has been no exchange of ideas between the site manager and workforce.

b.4) Case Study 4

Table 5.14 shows that this site presented only two "literal replications" throughout its eight process states. The consequences of not having sufficient information displays in the workplace, workstation or pathways was subtle, but easily captured when questioning new workers about their own process. Quite often, they were told what to do but did not know what was the purpose of such activities, or if there were any better ways of doing it. The empirical evidence presented on

Figure 5.38 shows the workstation responsible for producing pre-fabricated undersills without a single information display. Information such as the typical quality problems, characteristics of materials and so on, could effectively help workers in this workstation to understand and improve their own practices in this construction site.



Figure 5.38 – Theoretical Replication of *Installation of Information into the Production Environment* (Case Study 4)

b.5) Case Study 5

Only two information displays have been found among the twelve process stages mapped during the observational period on this site, as Table 5.14 shows. These information displays focused mainly on safety aspects of production and general administrative information. None of the equipment, components or material present on site contained useful process information despite the clear deficiency of knowledge among bricklayers and labourers on their own process. The site manager also agreed that more information should be given to the workforce. In this respect, best practice instruction could be incorporated into the products received on site in order to elevate the practices identified by the researcher to become part of everyday working.

b.6) Case Study 6

This case study presented similar levels of information on the production environment as in Case Study 5. The consequence in terms of transparency were also similar to that case since the open-ended interviews revealed that the workforce have little knowledge about managerial decisions affecting their workflow or even the technical aspects of bricklaying. Neither did they have any information on standard bricklaying procedures, despite the existence of written documents describing every step of the bricklaying process held in the site office (*see* Figure 5.26). The site manager retained all information but did not seem to agree for the need to disseminate information in the workplace, or at workstations. In his view, bricklayers would not pay any attention to process information, because of their low level of formal education.

5.5.4.6 DISCUSSION

The analysis of case studies resulted in two main lessons:

i. Information displays were mostly used to transmit safety and administrative information despite the deficiencies in "know-how" identified among the workforce;

ii. More information is required in material, components and equipment in order to adapt this approach to become the everyday of bricklaying;

There was an incompatibility between the characteristics of site display mechanisms and the characteristics of production in construction across all case studies. In this sense, construction processes demand better ways of exhibiting information in the workplace/workstation. Process information, like visual controls, should be incorporated in all the equipment, components and materials that move throughout the construction site. The constant movement of workstations is an automatic distribution channel for process information. Unfortunately, this is still not fully appreciated by construction managers and suppliers.

The distribution of information throughout the production environment demands a different relationship between managers and workforce. Greif (1997) argues that trust between both parties within a collaborative environment is one of the conditions to

obtaining adherence from the workforce to the content of information. Hence, the reduced amount of information available in the construction sites analysed in this research reflects the environment of mistrust and poor teamwork between managers and workforce. In such a context, managerial decisions will always be questioned by the workforce. Therefore, an appropriate mechanism for discussions needs to be in place beforehand.

5.5.4.7 CONCLUSION

The installation of information in construction workplaces and workstations is a practical and viable alternative to increasing transparency according to the observations made in the case studies. However, the empirical evidence showed that construction makes very limited use of such an approach despite the problems caused by the lack of information among the workforce. Further developments have to be carried, aimed at the creative installation of information in equipment and materials in order to make the distribution channels more compatible with the continuous movement of construction workstations.

5.5.5 MAINTENANCE OF A CLEAN AND ORDERLY WORKPLACE

5.5.5.1 WORKING DEFINITION

This approach includes any practice that contributes to the maintenance of a clean and orderly workplace throughout the bricklaying process.

5.5.5.2 OBSERVATIONAL FOCUS

The focus of observations here was on any activity that contributed to maintaining cleanliness an order in each process stage. The assessment of housekeeping effectiveness started just after the research had undertaken the process mapping, and proceeded daily throughout the entire observational period (two weeks in average). There should have been no obstruction in the smooth and continuous flow of material, equipment or workers. Special attention was given to the presence of housekeeping activities on the various workplaces after bricklayers had finished their operations. An individual workplace was considered clean if there was no wastage, tools or any other

object that could obstruct operations of the next process. The frequency and quality of housekeeping was checked with workforce and managers at the end of the data collection using an open-ended interview.

5.5.5.3 KEY INDICATORS

The *"percentage of process stages kept clean and tidy"* throughout the entire observational period was the key indicator used in the pattern matching process. This indicator showed the researcher's daily perception of the degree of housekeeping in each process stage, since unloading of bricks/blocks on site, to their delivery in the workplace. Again, a process stage was classified as 'clean' when there was no obstruction to flow of material, workers or equipment.

An entire construction site could never be classified as a full "literal replication" since there was some process stage without adequate housekeeping. Hence, the researcher has defined the number of "literal replications" as equal to the percentage of process stages kept clean during the entire observational period. The comparison of this indicator described above with the gang composition ("number of bricklayers per labourer") indicates the level of efficiency of the housekeeping operations. In theory, there should be no trade-off between housekeeping and lean gang compositions.

5.5.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The *"percentage of process stages kept clean and tidy"* throughout the entire observational period shows the company's dedication to achieving an orderly and clean environment. Daily observations with the workforce and managers revealed that one hundred percent of process stages maintained clean and tidy is an achievable objective in construction. Additionally, the analysis of housekeeping practices in the case studies suggested that eighty percent of process stages clean and tidy was the normal condition in the most organised construction sites.

Highly performing production environments described in the literature show a great preoccupation with housekeeping (Greif, 1989; Monden, 1998). Thus, there should be a direct correlation between the level of housekeeping and performance of a production process. Nevertheless, it is important to emphasise that because housekeeping is a non-

value adding activity, managers and workforce should strive to eliminate the need of this activity from production. Still, the history of lean companies teach us that in order to reach this stage, workers need to realise the importance of having a clean and orderly work environment in the first place.

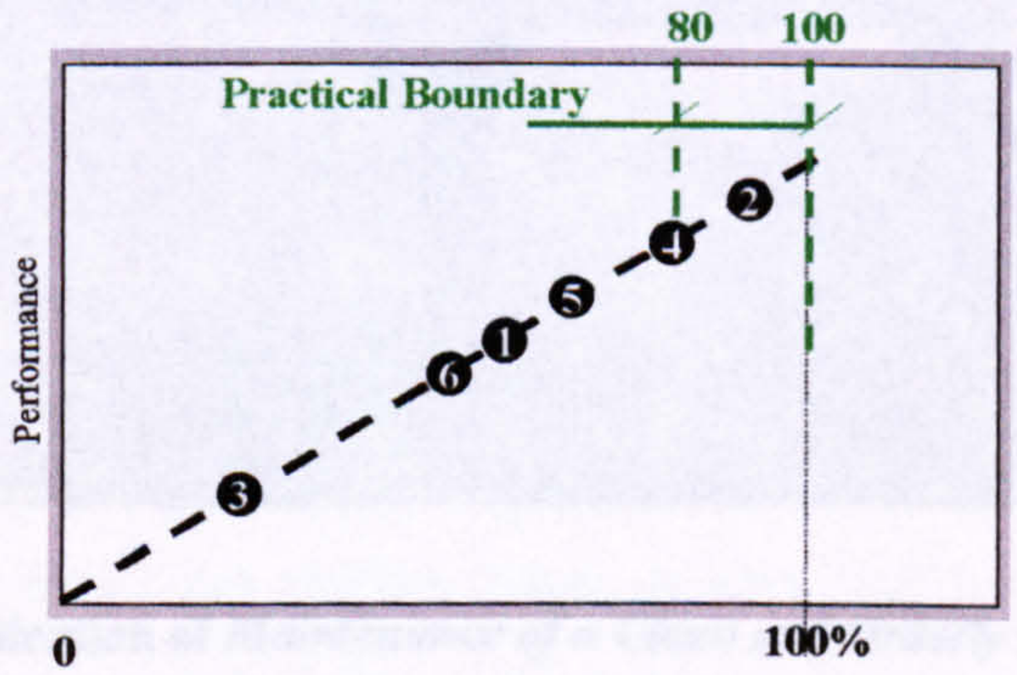
5.5.5.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

Daily assessment of housekeeping revealed great variations across the case studies, from 35% to 87% of order and cleanliness, as presented on Table 5.15. The reasons for such variation ranged from large batch sizes to lack of a leadership willing to promote the maintenance of good housekeeping. Short term contractual relationships have restricted the level of co-operation between managers and workforce in this respect since their focus was generally on the accomplishment of time and budget objectives and not on the increase of production efficiency.

Table 5.15 - Performance of Case Studies Regarding the *Maintenance of a Clean and Orderly Workplace*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	10	10	15	10	10	6
Number of Bricklayers per Labourer	2	3	2	2	2	1
Number of Observations of each Process Stage	110	80	120	80	120	120
N°. of Positive Assessments on Housekeeping	64	70	42	64	87	60
% of Process Stages Kept Clean and Tidy	58	87	35	80	72	50
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**6**	**7**	**4**	**6**	**9**	**6**



Cleaning workplaces and machines was more an occasional, and contingent, activity than a planned and systematic practice in the majority of companies visited during this research. The most common strategies used to achieve good housekeeping was severe managerial control and the links of housekeeping to payment incentives. There were no mechanisms in the construction companies aimed at motivating workers to maintain clean workplaces through their own initiative.

It was clear from the interviews that the preoccupations of managers with good housekeeping would only turn into actions in the later stages of the project, when clients started to visit the construction site. Consequently, only four of the six case studies reached the practical boundaries established for this approach, as illustrated on the graphic inserted on Table 5.15.

b) Individual Case Study Reports

b.1) Case Study 1

Bricklayers and labourers used to clean the workplace at the beginning or end of each working day on this site. Figure 5.39 shows an example where the labourer cleans the floor after the bricklaying operations. However, the overall assessment showed that this site have only 58% percent of its process stages kept clean and tidy throughout the observational period. For this reason, only six of the eleven process stages mapped on this site have been considered as "literal replication" of this heuristic approach.



Figure 5.39 - Literal Replication of *Maintenance of a Clean and Orderly Workplace* (Case Study 1)

However, site manager, foreman and bricklayers declared their satisfaction with the level of housekeeping observed on site. Maintenance of housekeeping in the workplaces was among the basic demands established by the contractor upon the subcontractor. Moreover, in their view the ample area available in the site reduced the problems of process visibility. Still, the site manager admitted that housekeeping would became a priority for the next stages of the project since there would then be a more intense presence of clients moving across the site.

b.2) Case Study 2

On this site, 87% of the observations showed a good level of housekeeping in the process stages, the highest level among the case studies. In other words, seven of the eight process stages were regularly kept clean and tidy every time the researcher visited this site. As Table 5.15 shows, this degree of housekeeping was remarkable taking in consideration that there were fewer labourers per bricklayer in comparison with the other case studies. One of the practices that enabled this condition was the good layout and workflow planning associated with the reduced size of delivery batches. The layout and workflow planning allowed smooth movement of workstations and personnel without significant disruptions in the flow of material. The reduced delivery batches, on the other hand, made easier the access and control to the storage compound.

b.3) Case Study 3

This site offered the largest number of evidence to confirm the theoretical effects of clutter and disorder in the workplace (theoretical replication). Only 35% of the observations of process stages revealed satisfactory housekeeping. The workstation that used to produce mortar, illustrated on Figure 5.27, offers a good example of the situation observed across this site. Workers positioned sand, cement, water and the mixer without care to distances and order. The poor housekeeping compromised speed, quality and transparency of the production of mortar. Collecting information on, for instance, how much sand or cement there was on stock was a time consuming activity.

The site manager declared that the activities relating to housekeeping would became more intensive at the end of the project when clients began to visit the site. In his opinion,, the inefficiencies caused by poor housekeeping would come against the

bricklayer themselves. Thus, it should be the bricklayers responsibility to keep their process organised and tidy.

b.4) Case Study 4

Bricklayer and labourers on this site were formally responsible for cleaning and keeping the order of the workplace before leaving it. The payment of productivity bonus depended on the degree of housekeeping of each bricklayer. The observations during the ten days of data collection in this revealed that 80% of the process stages were kept clean and tidy. In this relatively clean environment, it was easier to identify process problems as well as workplaces without housekeeping.

This foreman was clearly the most committed to achieving higher levels of housekeeping and a clear indication of this lie in the fact that he was proud in receiving visitors to his site. An example of his housekeeping actions was the establishment of an area for wastage disposal, shown on Figure 5.40 (according to the site manager it was not feasible economically to hire a metallic container). Every afternoon, at pre-defined times, labourers used to sent wheelbarrows containing the daily wastage to be unloaded in this space.



Figure 5.40 - Literal Replication of *Maintenance of a Clean and Orderly Workplace* (Case Study 4)

Certainly, the final objective of this construction company was not having waste at all. However, the designation of waste disposal area and regular housekeeping had a positive impact on process transparency and in the worker's motivation towards waste reduction. Hence, waste produced in the workstations was visible to anyone and became a concern of everyone.

b.5) Case Study 5

During ten days of data collection on this site, the researcher had the opportunity of observing that only 72% of process stages presented a satisfactory housekeeping condition. The high process variability and excessive number of process stages made it difficult to keep the site tidy and clean (*see* Table 5.15). Variability in the dimension of blocks and concrete structure, for instance, generated large amount of wastage that needed to be constantly cleaned and moved away from the workstations. Extra storage and transport stages increased the amount of clutter distributed throughout the pathways. The lack of a suitable packing system for bricks, for instance, demanded further manual handling and, consequently, greater chance of breaking them on the way to the workstations.

b.6) Case Study 6

Despite of having one labourer per bricklayer, this site kept only 50% of the process stages in a satisfactory level of housekeeping (*see* Table 5.15). There were often pieces of blocks and equipment obstructing bricklayers around the workstation. The cleaning operations were too late and, usually, carried out at the end of a bricklaying cycle. Managers and bricklayers were clearly aware of this situation and recognised the effect of poor housekeeping on the efficiency of operations and workforce moral. However, contractual relationship based solely on price had limited the possibilities of involving bricklayers and labourers in the maintenance of site cleanliness and organisation.

5.5.5.6 DISCUSSION

The main lessons from the analysis of the approach 'maintaining a clean and orderly workplace' are:

i. Examples of best practice in systematic housekeeping described in the literature have not been found in the same degree across the construction case studies. Good housekeeping was still only seen as an activity required to give a better image, especially to visitors and clients, and not as an instrument to support problem solving activities;

ii. Good housekeeping is clearly a supporting approach and, therefore, it is more effective if applied alongside other approaches. Continuous improvement activities and a leadership that understands the importance of a transparent process seem to be fundamental requirements for effective implementation of this approach in the construction environment.

The lack of involvement of the workforce in continuous improvement activities gave housekeeping a distorted image among the workforce. Housekeeping was seen as an activity carried out only to please management and customer. Indeed, there were no actions investigating the problems that resulted in the need for housekeeping in the first place. Bricklaying kept producing piles of wastage throughout the site and, in the best sites, the only orientation from management was to move these piles to a wastage disposal area. In such environment, it was no surprise to find out that housekeeping was sensed to give little contribution to increasing the performance of bricklaying.

The reduction of batch sizes had helped the maintenance of good levels of housekeeping in the best case studies (Case Study 2 and 4). There was less material moving across these sites and it was easier to keep visual control of locations, pathways and storage levels. It is possible to say that lean flows have driven these construction sites to maintain well-organised layouts since there was less tolerance for delays in the transportation of materials. Confirming Galsworth (1997) proposition, this practice created a reinforcing cycle since with cleaner site it became easier and faster to locate areas with poor housekeeping.

The idea of reducing or eliminating the activity of housekeeping, and still maintaining clean and tidy sites, was still alien to most manager and workers. They had a strong trade-off paradigm in their mind that reduced their creativity towards innovative housekeeping practices. According to their view, better housekeeping necessarily implied greater time spent cleaning and organising. Changing this paradigm is a major constraint for future developments of this topic.

5.5.5.7 CONCLUSION

The observations of construction practice confirm that maintaining a clean and orderly workplace is a viable approach to increasing transparency in construction sites.

Notwithstanding, the case studies revealed that good housekeeping still is not seen as a "process" in construction. Indeed, most of the daily observation revealed a contingent approach to housekeeping. Although contradicting common arguments, the continuous movement of workstations could be used as an advantage when applying the approach to the sector. Since workstations have to visit the workplace in different periods in time, this could be used as an advantage to drive an effective process for continuous housekeeping.

5.5.6 RENDERING INVISIBLE ATTRIBUTES VISIBLE THROUGH MEASUREMENTS

5.5.6.1 WORKING DEFINITION

This approach means to transform qualitative attributes of bricklaying into quantitative measures and present them throughout the production environment.

5.5.6.2 OBSERVATIONAL FOCUS

The observational focus here during data collection was on any activity relating to process measurement that had occurred in the bricklaying activity during or before the data collection on site. In particular, the researcher tried to identify the existence of information displays showing process measurements. From the first visit on site, managers were asked about the existence of any systematic measurement activity carried out in bricklaying in that particular project. In case of a positive answer, they were also questioned about the media used to present such information to the workforce. Subsequent conversations with the workforce and verification on archival records and documents available on site helped to confirm the accuracy of their answers.

5.5.6.3 KEY INDICATORS

The main indicators used in the pattern matching analysis were:

a) *Number of Performance Indicators Collected Regularly:* the amount of indicators measured regularly can reveal the commitment of managers towards better visibility of process performance. This information was initially gathered from an open-ended

interview with the site manager and, subsequently, verified against the opinion of the workforce, archival records and documents available on site.

b) *Number of Displays Showing Performance Indicators:* process measurements should be exposed to the workforce in a transparent environment. Therefore, the amount of information displayed should contain process indicators. This could be a direct indication of how transparent is the bricklaying process. Observations were carried out in the first day of data collection and then followed through every process stage.

5.5.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and respective boundaries for the chosen indicators were as follows:

a) *Number of Indicators Collected Regularly:* the minimum practical boundary for this indicator has been established as four. It is based on the four measurements criteria used in this thesis (*productivity, waste, average storage and flow efficiency*). Other indicators were considered as applicable and valuable for bricklaying and contributed to define "eight" as the maximum boundary (*gang composition, work-in-progress, variability of production rate and the size of transfer batches*). There is no suggestion in the literature regarding the correlation between the number of indicators collected regularly and performance. However, it seems reasonable to infer that the benefits of increasing further the number of indicators becomes gradually smaller.

b) *Number of Displays Showing Performance Indicators*: the practical boundary for this indicator has been established as a multiple of the shortest process encountered in practice (8) since the literature did not supply such a reference parameter. Like in the previous indicator, it seems reasonable to infer that increasing further the number of information displays offers reduced benefits.

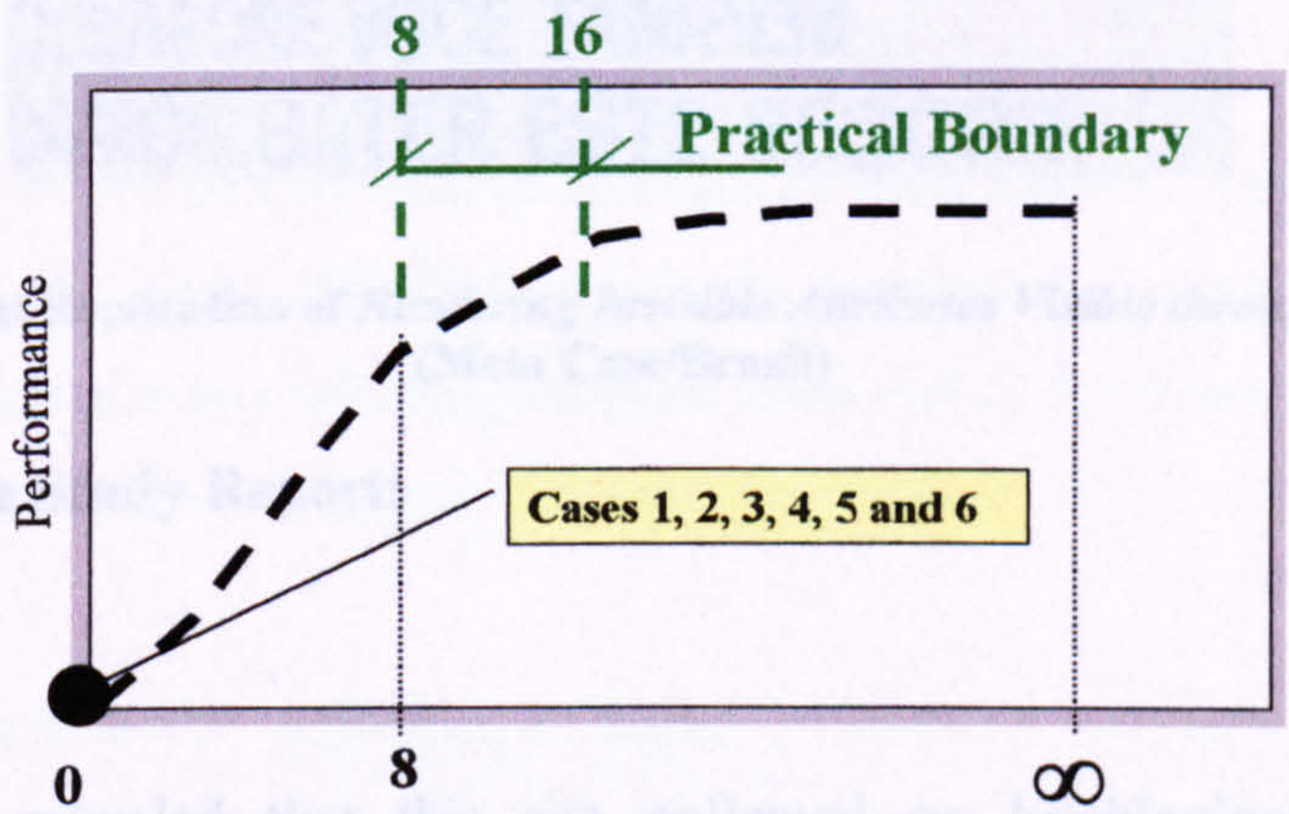
5.5.6.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

There was a generalised lack of process measurements across the case studies and absolutely no information displays presenting quantitative measurements of process attributes, as shown on Table 5.16. Poor workforce involvement in systematic process analysis was the main cause behind this situation. The lack of trust between managers and workforce reflected on the belief identified among most bricklayers that information displays showing performance could be used as another source of pressure on their daily activities.

Table 5.16 - Performance of Case Studies Regarding *Rendering Invisible Attributes Visible through Measurements*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	2	2	2	2	2	2
Number of Performance Indicators Collected Regularly	0	0	0	0	1	0
Number of Displays Showing Performance Indicators	0	0	0	0	0	0
Number of Process Stages	**11**	**8**	**8**	**8**	**12**	**12**
Number of Literal Replications	**0**	**0**	**0**	**0**	**1**	**0**



Rendering Invisible Attributes Visible Through Measurements

The managers in the host companies could not confirm with sufficient accuracy the achievement of expected levels of process and product performance. In general, managerial experience was the main criteria used to assess the conformity of brickwalls

o the technical characteristics set by the design. Nevertheless, brickwalls were rarely rejected by managers despite the high variability witnessed throughout the observations.

Despite the reduced number of literal replications among the case studies, evidence supplied by the meta-case confirms that this approach is already practised by some companies in the construction sector. The transformation of the invisible attribute of "safety efficacy" into a visible attribute is a clear example. Figure 5.41 shows the panel used by a Brazilian construction company to register the cumulative period without accidents (in this case, "51 days") and the corresponding site benchmark (in this case, "95 days"). Any person could see this panel right at the entrance of the construction site. This practice certainly affected the workforce commitment to achieving higher levels of safety performance since this was no longer an invisible attribute on the construction site.

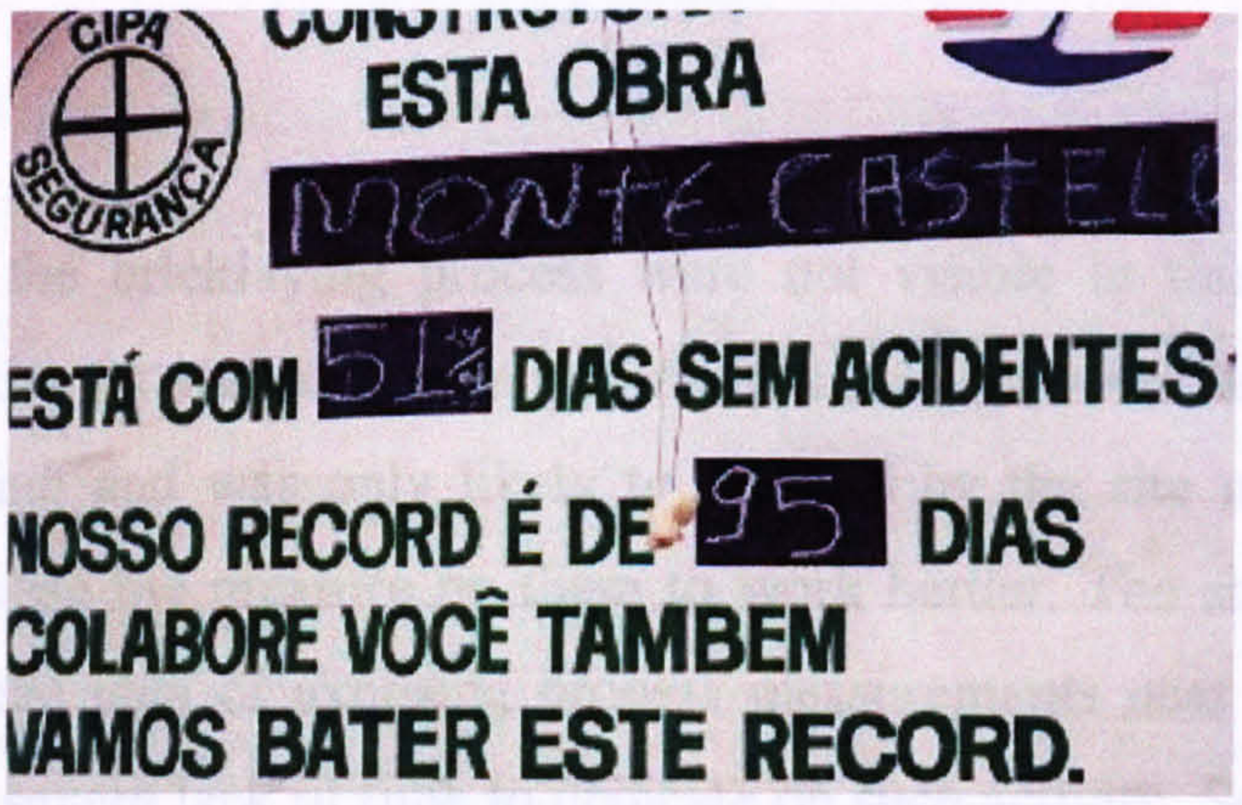


Figure 5.41 - Literal Replication of *Rendering Invisible Attributes Visible through Measurements* (Meta Case/Brazil)

b) Individual Case Study Reports

b.1) Case Study 1

The investigation revealed that this site collected no bricklaying indicators and, consequently, there were no information displays showing process measurements (*see* Table 5.16). The lack of systematic activities aimed at reducing process variability helped to explain this situation. In this environment, it was no surprise to find out that bricklayers did not know the status of their own performance, nor how it compared with the performance of other construction sites. Furthermore, the site manager declared his scepticism regarding the presentation of such quantitative measures in the workplace.

He argued that the subcontractor would misinterpret it as an attempt to tighting the control and pressure on schedule accomplishment even further.

b.2) Case Study 2

This site presented no activities of measurement and, therefore, none of the bricklayers knew exactly their performance (*see* Table 5.16). The assessment of the work was carried out visually, based on the practical experience of the subcontractor and foreman. The subcontract had worked with the same contractor in previous projects and there was a clear trust on the quality of the bricklaying product. The site manager argued that "*...variations in bricklaying are so small that it is not worth spending time measuring them*". Nevertheless, he acknowledged that daily visualisation of bricklaying performance could be a helpful tool for bringing attention of everyone to the actual process problems and increasing performance even further.

b.3) Case Study 3

The attributes of the bricklaying process were not visible in this construction site. Furthermore, bricklayers argued that an information display would have had little effect in their daily routine and was only likely to be used by the site manager as another instrument to increase the pressure on them to work harder. The site manager, on the other hand, liked the idea of exposing process measurements near the workplace but declared to have a severe lack of time to dedicate on such activity. Schedule and budget control were the only items that he was clearly interested in establishing measures despite the enormous quantity of flow problems observed by the researcher.

b.4) Case Study 4

There were no measurement activities or teams involved in problem solving activities on this site. The production manager told the researcher that he did maintain overall indicators for the project and that allowed him to report monthly to the board of directors. Nevertheless, the workforce and managers on this site were unaware of such measurements and could not precise their current performance or how that compared with their performance in previous projects.

b.5) Case Study 5

This case study presented the only example identified in this research of a company involved in process measurement. There, the sources of waste were under investigation and, consequently, many invisible process attributes could be transformed into visible attributes such as wastage level and average thickness of bricklaying courses. Even so, the initiative of these actions came from the local university and there were no information displays throughout the production system indicating the current level of waste. Therefore, when bricklayers were asked about the objectives of the measurement of waste they demonstrated total ignorance on this matter. In their understanding, this study was likely to be used by managers as way to blame bricklayers for the large quantities of waste present on site.

b.6) Case Study 6

This site presented various sources of process problems such as poor effectiveness of the standardisation process, large transfer batches and an excessive number of intermediary stores, as described earlier in this chapter. Yet, there were no process measurements of any kind, since there were no systematic process analysis and improvement (*see* Table 5.16). No personnel interviewed have accurate information of the quality of their product, or their performance throughout time. Bricklayers used their monthly productivity bonus as way to compare their efficiency month by month.

5.5.6.6 DISCUSSION

The main lessons from the analysis of this approach in the observed construction practice are:

i. In order to be successfully implemented, effective transformation of invisible attributes into visible measurements depends on the existence of continuous improvement activities;

ii. Lack of trust between managers and workforce can distort the perception of the actual aims of this approach in practice. Bricklayers can interpret it as another managerial mechanism to control their activities;

In many ways, "rendering invisible attributes through measurements" seems to overlapping with the approach "systematic measurement, identification and elimination of root causes of variations" analysed earlier in this chapter. However, although both require measurement, the focus in this heuristic is on the use of this information to enable everyone to understand the actual status of invisible attributes. Therefore, this approach necessarily requires displaying the information to anyone interested on it across the construction site.

None of the case studies observed could accurately trace the root cause of problems in their final products since they carried no systematic process verifications. Managers and workers argued that measurements were not practised in construction because it was a time consuming activity. Certainly, time-consuming measurement techniques are not compatible with a competitive environment that demands speed in production. Moreover, these measurements do not add value to the end customer and their need should be reduced or eliminated from the process. In this sense, the case studies revealed that alternative attributes could be used in construction, using the information already available in the contractor's existing information system, such as schedule controls, orders of materials and control of personnel.

Construction companies should direct more efforts towards integration and standardisation of administrative forms in order to enable the generation of useful performance indicators. Most of the construction companies observed have already some measures of production performance but these measures were not sufficiently standardised and systematic to allow their comparison with other projects or presentation in information displays.

5.5.6.7 CONCLUSION

This approach is valid in the construction environment according to the empirical evidence available. However, the best "literal replications" came from the meta-case and the six main case studies presented only one "literal replication". The researcher concluded that the main reason for this situation was an environment characterised by poor support for continuous improvement and lack of co-operation between managers and workforce.

5.5.7 CONCLUDING REMARKS

The case studies, together with the meta-case, supplied evidence that indicate the validity of the principle of transparency in the construction sector. Nevertheless, there was a generalised lack of integration among the "literal replications". Comparison of the case studies with the examples described in the literature reveals that construction applies the transparency principle in considerably less intensity than manufacturing.

The poor degree of transparency on the construction sites led production systems to operate well below their full potential. Workers frequently spent precious time searching, wandering, or waiting for tools, materials, and information instead of adding value to the final product. Often, piles of unneeded and sporadically used materials obstructed pathways and reduced direct process visibility. Conversation with the workforce revealed that workers did not know exactly what was expected from them or their current performance status. Indeed, the construction companies visited had few visual mechanisms to inspire or motivate workers to carry out their jobs more effectively and efficiently.

Finally, one important factor that negatively affected the transparency in the construction sites was the low level of participation of workers in improvement activities. Most of the managers of the host companies appeared to maintain a Taylorist approach to handle information and control production processes. Indeed, the control of information and knowledge was extremely centralised with the construction manager and foreman. This was a source of power for many managers, leading to some misconceptions about what and who is important and why, regarding the production system objectives.

5.6 BUILD CONTINUOUS IMPROVEMENT INTO THE PROCESS

5.6.1 SETTING STRETCH TARGETS

5.6.1.1 WORKING DEFINITION

This approach means the formal establishment of targets beyond original plans or normal practice.

5.6.1.2 OBSERVATIONAL FOCUS

The focus here was on the perception of bricklayers and managers regarding the existence of challenging targets during the observational period. The emphasis was also in understanding the effectiveness of these targets in generating actions to improve the bricklaying process. The researcher questioned site managers on these two aspects always in the first day of data collection. Daily conversations with the workforce and direct observations throughout the data collection enabled to check the accuracy of facts and, therefore, strengthen the validity of findings with respect to this heuristic.

5.6.1.3 KEY INDICATORS

The main indicator used to help the pattern matching analysis was the 'number of challenges relating to performance, design details or new technology', as perceived by the bricklayers. The inclusion of 'design details' and 'new technology' in this indicator occurred after the feedback from bricklayers on what they considered as challenging targets. In every visit to the site, the researcher asked directly their perception regarding the challenges they felt they were facing that day. More specifically, they were asked to describe the targets that they considered as above the normal practice in relation to their experience in previous projects.

5.6.1.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

Establishing "stretch targets", as they are called, should drive the introduction of improvements and innovative ideas in bricklaying. This approach is not just about the

amount of "stretch targets" placed upon bricklaying, but also the style and range of these targets in relation to previous projects. Because of the complexity of such an approach, it was not possible to infer practical boundaries or an expected behaviour in relation to performance. What seems clear Table 5.17 is that unrealistic targets can have a negative effect in the motivation of the workforce and their relationship with management.

5.6.1.5 SUMMARY OF RESULTS

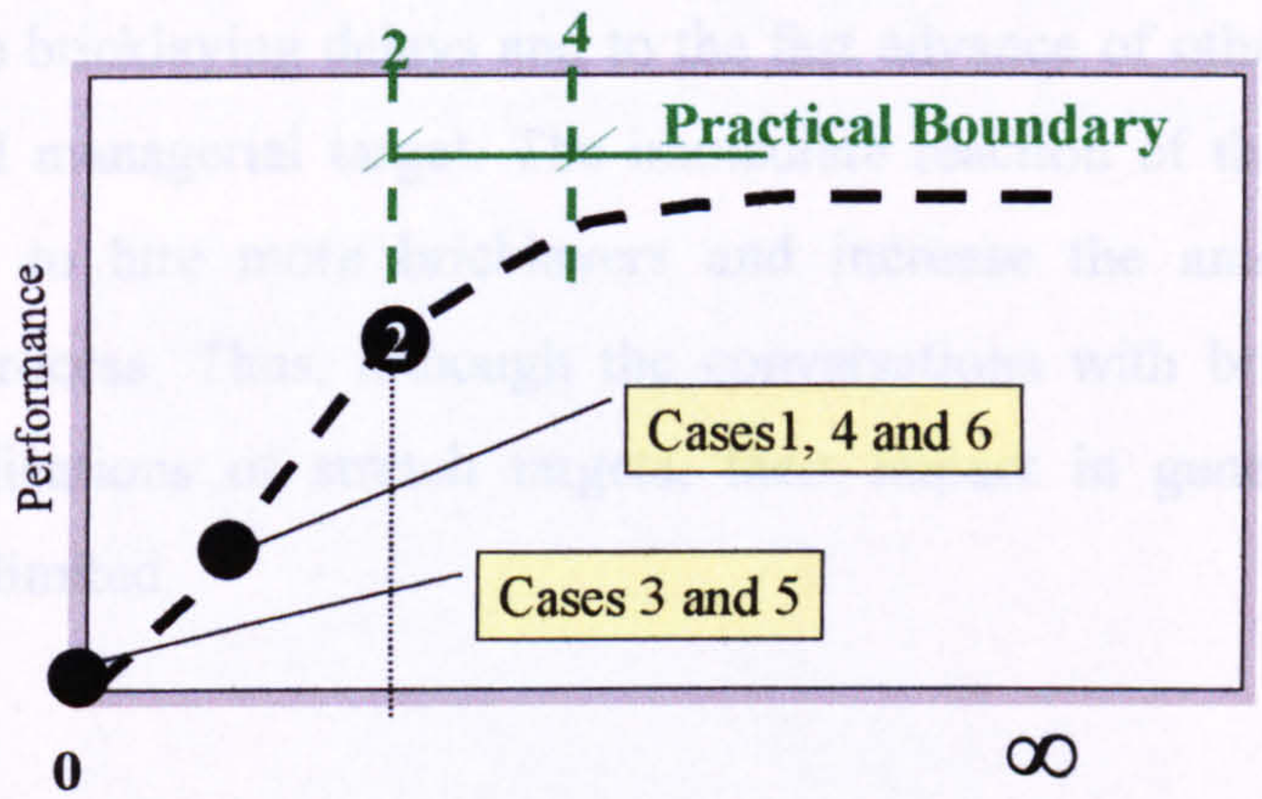
a) General Pattern Across All Cases

This research found various examples of "stretch targets", but they were not used by construction managers as a tool for driving continuous improvement in bricklaying (*see* Table 5.17). The "stretch targets" identified seemed to have happen more due to project constraints, delays in previous processes and client demands rather than some previously planned continuous improvement strategy. The challenging targets perceived by bricklayers were usually result of their own perception of poor performance, or due to the design complexities. Furthermore, few sites brought any other challenge to the workforce with the implementation or development of new technology.

Some managers even believed that challenging original objectives established at the original plans was a 'non-sense'. In their view, as long as the client was happy with the targets for the project, there was no need to elevate targets to difficult levels. Moreover, short-term relationships with the workforce generally restricted the establishment of an environment of trust between managers and workforce. "Stretch targets" demand a level of dialog with the workforce that was not existent in most construction sites analysed in this research. Clearly, one of the major barriers for improving this dialog was the lack of a clear definition of the criteria for sharing the benefits of achieving such "stretch targets".

Table 5.17 - Performance of Case Studies Regarding the *Setting of Stretch Targets*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Stretch Targets for the Entire Project	1	2	0	1	0	1
Number of Challenges Relating to Performance	15	12	15	5	8	22
Number of Challenges Relating to Design Details	0	5	0	2	0	3
Number of Challenges Relating to New Technology	0	0	0	2	0	2
Number of Workstations Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**15**	**17**	**15**	**9**	**8**	**27**



Additionally, in the opinion of many managers interviewed across the case studies, this approach could lead to an increase in the cost of production and greater conflicts within their organisation. In their view, demanding higher performance from bricklayers implies that more resources will be required and that more problems will occur. The trade-off paradigm in which was based their thoughts rejected the benefit that this approach brings in the promotion of learning and generation of new ideas for improving the process.

b) Individual Case Study Reports

b.1) Case Study 1

The client in this case wanted the building finished before December in order to benefit from the boom of shopping around Christmas. This challenge drove the development of many solutions of project management, design and supply chain management. An example of the solutions that derived from this challenge was the construction of part of

the steel columns before the foundations (*see* Figure 5.12). This practice contradicts traditional wisdom in construction that understands that foundations need to come before columns. This solution enabled the early start of bricklaying and other construction processes.

The pressure to compress cycle time originated all fifteen literal replications observed in the bricklaying workstations during the ten days of data collection (*see* Table 5.17). It is worth to emphasise that bricklayers began to describe pressures for increasing speed only after the first week of observations. Still, the challenging targets placed upon them occurred more due bricklaying delays and to the fast advance of other processes rather than a pre-planned managerial target. The immediate reaction of the subcontractor to this pressure was to hire more bricklayers and increase the amount of resources available in the process. Thus, although the conversations with bricklayers revealed fifteen literal replications of stretch targets, their impact in generating continuous improvement was limited.

b.2) Case Study 2

Like in the previous case study, the main drive that generated twelve of the seventeen literal replications observed in this case study come from the need of compressing time (*see* Table 5.17). The other sources of challenge for the workforce was the design since the brickwalls were part of an important corridor linking two hospital blocks and contain many complex details. Most bricklayers declared that it was rare to find this level of design complexity in such small space and this factor was considered as an actual challenge for their skills. The researcher also perceived a sense of pride among bricklayers for their involvement in the construction of a hospital.

b.3) Case Study 3

In this case study, only one third of the workstation revealed a clear stretch target placed upon bricklayers. However, this stretch target was not the direct result of a deliberate managerial decision aimed at promoting continuous improvement. Quite simply, bricklayers had been told about the arrival of carpenters too late. Their assessment revealed a need for reducing the period for concluding the first bricklaying stage. This fact provoke a frenzy of production and transport activities in fifteen of the workstations observed (*see* Table 5.17). However, contrary to bring continuous improvement, this

challenging objective brought even more disruptions and confusion in the construction site.

b.4) Case Study 4

The construction manager on this site used to register in a blackboard the status of the bricklaying activity in relation to monthly objectives, as illustrated on Figure 5.42. According to the interview, he accepted daily variations as long as bricklaying was on schedule and under budget at the end of each month. He had no information on the actual magnitude and cost of variations. The direct result of this practice was complacency with the current level of productivity and with the sources of variability.

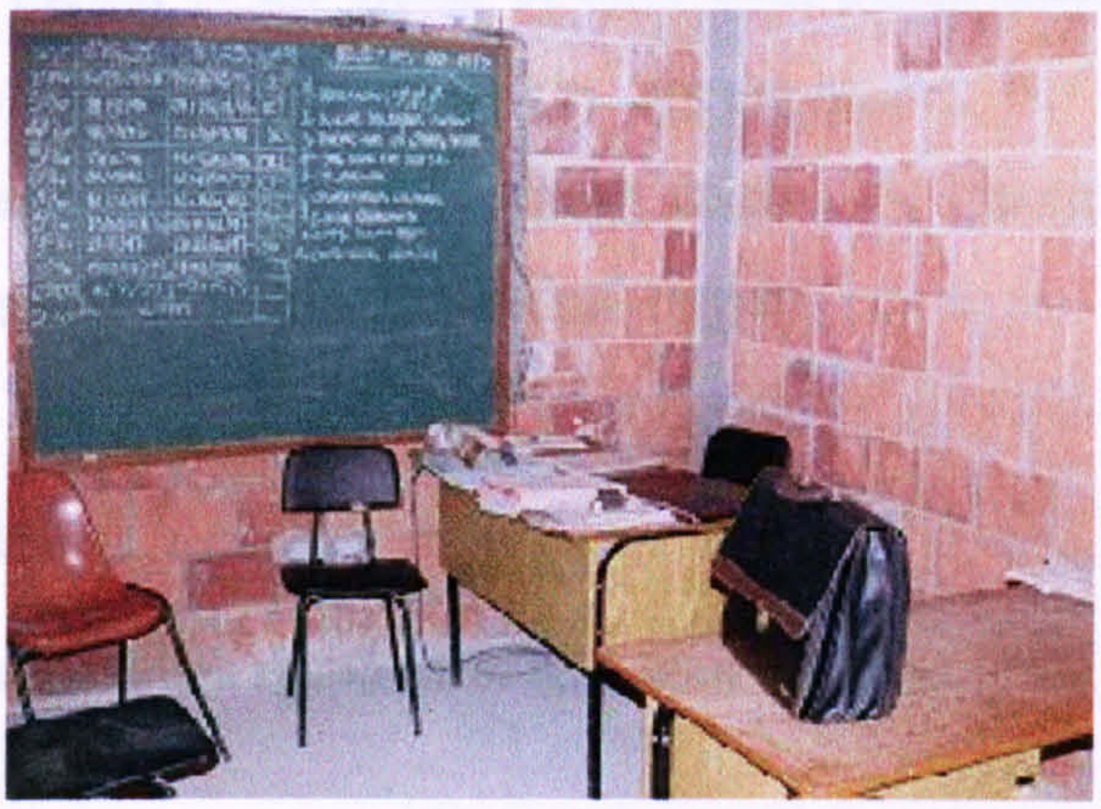


Figure 5.42 - Theoretical Replication of *Setting Stretch Targets* (Case Study 3)

Bricklayers declared to perceive a challenging target in only five of the sixty workstations observed in this construction site. However, the challenging targets described by the bricklayers did not result in the generation of improvements in the bricklaying process. Bricklayers felt a strong pressure for increasing speed due to the need to catch up with the other bricklayers and avoid to be seen as a slow bricklayer in relation to the rest of the group.

b.5) Case Study 5

Ten days of data collection on this site revealed no stretch targets set by management or any pressure from downstream processes (*see* Table 5.17). Bricklayers carried their work without clear knowledge of their deadlines or cost of their job. Daily control and communication between foreman and bricklayers were the only instrument used by the site manager to maintain the site according to plan.

b.6) Case Study 6

Bricklayers understood design details and the characteristics of the new masonry as challenges placed upon their skills in only five workstations. However, pressure for increasing productivity was present in twenty-two workstations analysed during the observational period (see Table 5.17). Further discussions with managers and workforce revealed that these "stretch targets" were the result of delays in the early stages of bricklaying. Managers blamed the decision for implementing a new technology, without adequate training for the workforce, as the main reason for these delays.

Bricklayers generally expressed that they did not have sufficient knowledge of the objectives set for the month or the status of their own performance levels. There was a clear preoccupation with the targets set for the current month, but only at the managerial level. Even so, managers did not place these targets on information displays where bricklayers could consult about their individual targets.

5.6.1.6 DISCUSSION

The analysis of the case studies resulted in two main lessons:

i. Performance measures such as productivity, waste or quality are the traditional "stretch targets" used in production. However, discussions with the construction workforce observed revealed that difficult design details and the implementation of a new technology can also be interpreted as a challenging target;

ii. Many literal replications were found at the project level but none of the construction companies analysed had used "stretch targets" as an instrument for promoting continuous improvement within bricklaying. Lack of involvement of bricklayers in problem solving activities and poor relationship between bricklayers and managers seemed to be the main reason for this situation;

iii. Presenting the "stretch target" information to the workforce is clearly needed in order to implement this approach. However, most construction sites presented no information displays with targets for bricklaying. Thus,

increasing the amount of formal and informal channels of communications needs to be carefully considered before implementing this approach.

Trade-off paradigms, and widespread complacency, were observed in all sites and reflected the attitude of managers towards the establishment of stretch targets. Surely, shortening deadlines, or attempting to use lesser resources than planned, are likely to generate production problems. However, managers committed to continuous improvement should see these problems as an opportunity for discovering new avenues for improvement. Hence, setting "stretch targets" is a necessary practice to increase the production capabilities, even if there is no need for them at the present. It is the long-term view of this approach that appears to be missing among construction managers. The focus of those observed was only on the present project and not on the long-term benefits of creating a highly performing production systems.

Delays in previous processes caused most of the performance challenges described by the workforce. In this context, "shielding" bricklayers from other processes, by creating a protective time buffer, as proposed by Howell & Ballard (1994) could offer a viable alternative to reduce poor perception of targets among bricklayers. The challenge for bricklayers should be to increase their reliability regarding weekly or monthly targets. Certainly, this would require more participation of the workforce in planning and decision making, but it would also be more likely that managerial targets would permeate through to the workforce if this were done.

Surprisingly, the targets considered by site managers, as most challenging did not always match with the challenging targets perceived by the workforce. Bricklayer's short time planning and limited responsibility on site meant that they often restricted their interpretations of a 'challenge target' to the immediate work at hand. Therefore, increasing their responsibility and involving them in decision making presents itself as an important factor for disseminating targets among the workforce.

5.6.1.7 CONCLUSION

The empirical evidence suggests that this approach is valid in the construction environment. Nevertheless, most production managers in the sites studied did not seem to understand and use this approach within a wider strategy for driving continuous

improvement in construction processes. "Stretch targets" were generally contingent to project constraints and were not supported by other complementary implementation approaches such as information displays or systematic monitoring activities.

5.6.2 SHARING THE RESPONSIBILITY FOR IMPROVEMENT WITH ALL EMPLOYEES

5.6.2.1 WORKING DEFINITION

This heuristic is defined as occurring when managers and bricklayers share the responsibility for identifying, developing, implementing and maintaining improvements within the bricklaying process.

5.6.2.2 OBSERVATIONAL FOCUS

The observational focus here was on the interactions between management and the workforce regarding improvements in bricklaying. The researcher gave special attention to the content of meetings and the level of involvement of the workforce in decision making. In the first visit to site, site managers presented their perception of the level of participation and responsibility given to the workforce. They were then asked to present evidence of their participation such as records of meetings, documents or images of the actual improvement resulted from their participation. After that, conversations with the workforce during a two-week period revealed the perception of bricklayers with respect their involvement in continuous improvement. They were then asked to describe the improvement developments that they have been involved, directly or indirectly, and the number of improvement suggestions they had given regularly.

5.6.2.3 KEY INDICATORS

This research used two indicators to support the pattern matching analysis of this approach, as follows:

a) *Number of Team Meetings Involving Managers and Workers/Month*: this indicator helped to demonstrate the actual involvement of bricklayers in decision making. Open-ended interviews and conversations with managers and workforce were the

main source of evidence for obtaining the values for this indicator. This indicator did not counted occasional conversations between managers and individual bricklayers.

b) *Number of Suggestions per Employee/year*: direct conversations with bricklayers at the beginning of the data collection supplied this information. A "suggestion for improvement" could be in any format and aim at any aspect of the construction site. The answers of the workforce were crosschecked with the perception of managers on the suggestions received in this case.

5.6.2.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

a) *Number of Team Meetings Involving Managers and Workers/Month*: team meetings are an important component of world-class companies. However, there is no suggestion in the literature on an ideal number of meetings. Most bricklayers and managers in the case studies agreed that one meeting each week or every two weeks would be adequate. In their view, a higher rate of meetings would result in excessive disruption in the workstation and, thus, negative effect on performance;

b) *Number of Suggestions per Employee/year*: in theory, there should be no limit in the number of suggestions for improvement generated from employees. However, the practical boundary for both indicators has been established as ranging from twelve to twenty four, based on a conservative rate suggested by managers in the case studies. It is worth to emphasise that this number is far below the benchmark of 47.7 suggestions per employee/year found at Toyota, back in 1986 (Monden, 1998)

5.6.2.5 SUMMARY OF RESULTS

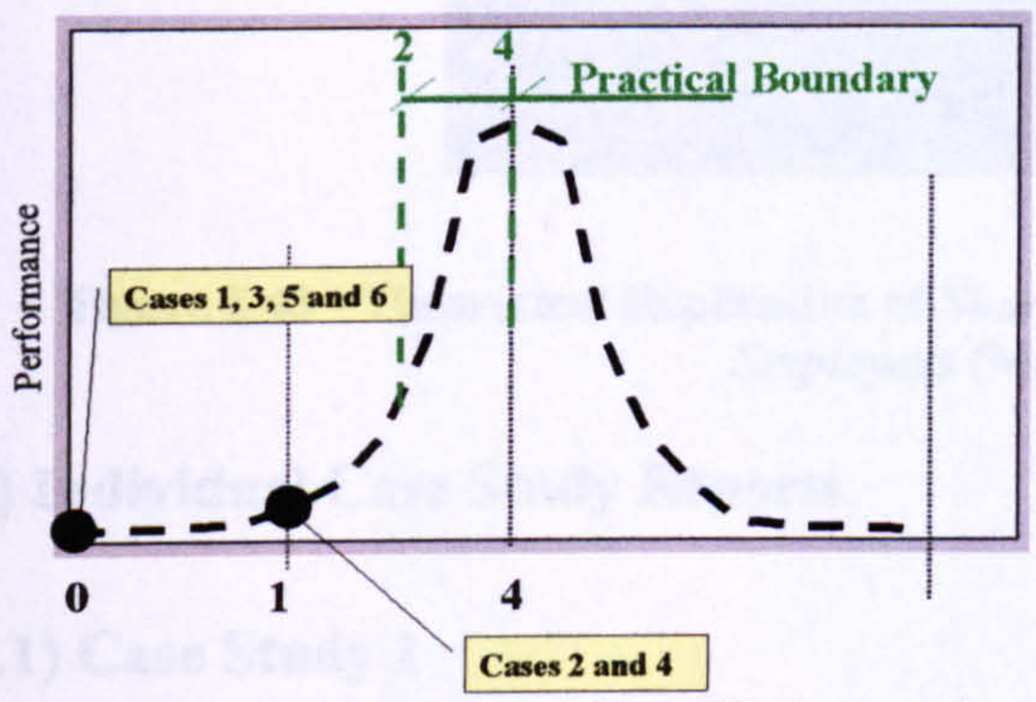
a) General Pattern Across All Cases

There was a generalised lack of participation of the workforce on improvement activities in all case studies. This deficiency is central in explaining the poor commitment of the workforce towards process improvement and application of other approaches investigated in this thesis. The situation was even more critical in the companies employing subcontractors and without long term relationships. Conversations and open-ended interviews with the workforce and managers revealed

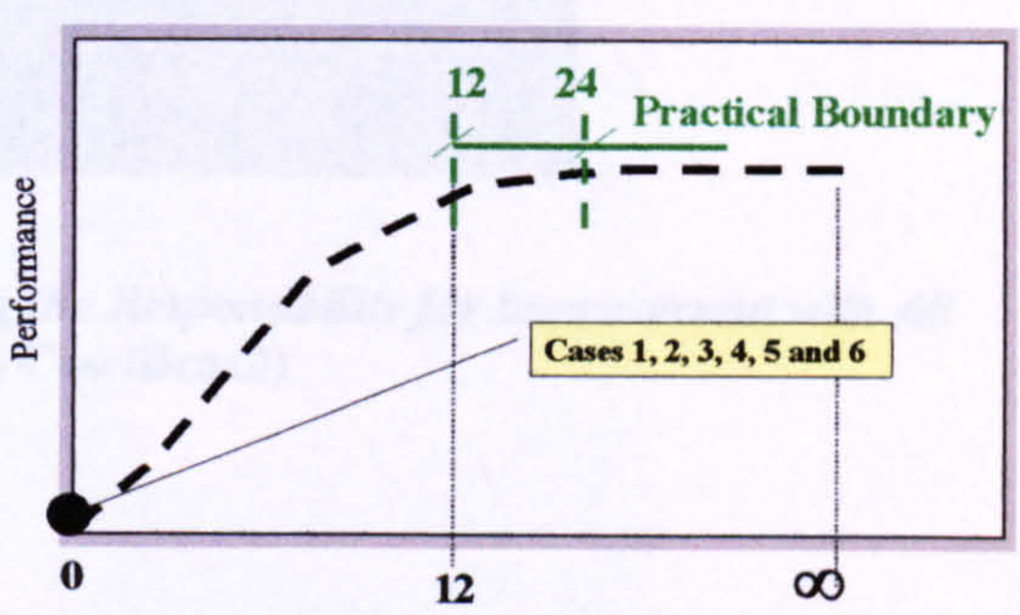
that there was no suggestion schemes or any kind of systematic instrument to gather the worker's opinions on the issue of process improvement. Consequently, there had been no suggestions for improvement in any of the six construction sites analysed, as demonstrated on Table 5.18.

Table 5.18 - Performance of Case Studies Regarding *Sharing the Responsibility for Improvement with All Employees*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Bricklayers Observed	6	6	2	4	3	8
Number of Suggestions per Employee/Year	0	0	0	0	0	0
Number of Meetings Involving Workers and Managers/Month	0	1	0	1	0	0
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications	**0**	**1**	**0**	**1**	**0**	**0**



Number of Meetings Involving Workers and Managers/Month



Number of Suggestions per Employee/Year

Additionally, none of the case studies revealed examples where managers shared responsibility or involve the workforce in planning activities. There was little participation of bricklayers even in short term planning. With little workforce commitment in the establishment of bricklaying targets and generalised lack of openness to discuss daily operational problems, the root causes of production problems remained untouched.

In the best case studies, the involvement of bricklayers was limited to the implementation of solutions developed by designers and construction managers. However, the observations revealed that managers tended to overlook important operational aspects that are crucial to successful implementation of improvements. The

development of a pre-fabricated window frame[7] presented on Figure 5.43, for instance, did not involve the workforce. The structural engineers responsible for that design had not considered the huge operational problem of transporting and adjusting such a heavy component on site. The consequence was a process that was even more expensive and time consuming than the corresponding traditional method (in Brazil) of producing this component *in loco*.



Figure 5.43 - Theoretical Replication of *Sharing the Responsibility for Improvement with All Employees* (Meta Case/Brazil)

b) Individual Case Study Reports

b.1) Case Study 1

Managers on this site claimed to be responsible for promoting continuous improvement in the bricklaying process. Despite this claim, daily observations revealed not a single example of process improvement carried out during the project. The researcher came to understand that the site manager viewed solutions for daily flow problems as examples of continuous improvement activities. However, all solutions observed during the ten days of data collection were specific to this particular site and did not improve the actual bricklaying process.

The subcontractor had weekly meetings with the project manager who was responsible for making sure that bricklaying followed the specified schedule. The problems discussed in these meetings usually relating to requests for materials, co-ordination of

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[7] **Window frame** a structure made up of concrete and used to hang windows (Dictionary of Building, 1995)

flows among processes and general information on the overall project plan. There was no suggestion from conversations the researcher had with the subcontractor that actual process improvements were a topic in the agenda of these meetings.

b.2) Case Study 2

The researcher witnessed clear evidence that the project manager on this site tried to share the responsibility for improving safety standards with the workforce. He regularly explained, in some detail, the site safety plan to the workforce through seminar/training sessions (see Figure 5.44. In these sessions, he presented and discussed with the workforce topics such as future workflow, layout plans, facilities and good safety practices. In the words of the site manager: "*...the objective of these meetings is to get the commitment from bricklayers and labourers to maintain and improve the good safety record of this site*"[8].



Figure 5.44 - Literal Replication of *Sharing the Responsibility for Improvement with All Employees* (Case Study 2)

The bricklayers revealed a great commitment to maintaining the good level of safety on this site. However, throughout the entire observational period, there was no attempt to gather the opinion of these workers on improvements in the bricklaying process itself. The subcontractor declared that his bricklayers worked with the best equipment, materials and tools available in the market. Therefore, in his view, making good use of the technology available was already sufficient to satisfy the needs of the project.

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[8] The control of who had already attended these sessions was carried out through coloured stamps fixed on the hardhats.

b.3) Case Study 3

Fifteen days of observations on this site showed an absolute lack of involvement of the workforce in the development of solutions for their own process (*see* Table 5.18). Bricklayers expressed, on various occasions, their scepticism about getting the support from the site manager on any aspect of process improvement. The site manager himself revealed no motivation to promote continuous improvement in bricklaying, since the bricklayers were not his employees.

b.4) Case Study 4

Most of the workforce on this site was directly employed by the contractor and there was a good level of trust and dialog between managers and bricklayers. However, only once during the entire observational period had the researcher been able to recognise a formal initiative from the foreman to bring the workers to participate and take responsibility for an improvement (*see* Table 5.18). This happened during the launch of a "5S" program that aimed to organise the housekeeping operations into a systematic program. Apart from that, all other improvement activities witnessed by the researcher came as isolated initiatives from the foreman or site manager. They hold the responsibility for developing those solutions and it was up to the workforce to implement them.

b.5) Case Study 5

The few improvement initiatives witnessed on this site all came from the production manager or designer (e.g. development of rotational filter for sand). The workforce reported they had not been involved in improvement activities and neither had been invited to participate with suggestions for process improvement. Consequently, implementation problems in the improvements developed by management were often motive of "jokes" during conversation with the workforce. When the researcher exposed this implementation problems to the site manager, his immediate answer was: "...*I know that there is a need for adjustments in these improvements, but it will have to wait because I have other more important things to do as a site manager*". Thus, his refusal in sharing the responsibility for developing process improvements with the workforce was a result of his narrow understanding about the role of a site manager.

b.6) Case Study 6

Managers on this site presented no examples of responsibilities for improvement being shared with the workforce. Bricklayers saw themselves as cheap workforce and did not have expectations of working with the same company in the next project. Their contract was solely based on price and the only responsibility they clearly acknowledged was to produce walls according to specifications and within schedule. The site manager recognised the need for more involvement of the workforce, but had not done so due to pressures in following the schedule.

5.6.2.6 DISCUSSION

The main lessons from the case studies are:

i. The generalised lack of involvement of the workforce in continuous improvement activities, across most construction sites, was the main barrier for full implementation of all other heuristic approaches investigated in this research;

ii. Inadequate leadership from construction managers was one of the main reasons for the poor workforce involvement in continuous improvement activities.

The managers of case studies analysed in this research did not share the responsibility for improvement with the workforce in the same level as reported in other industries. From the discussions with managers and bricklayers, it become clear that "promoting teamwork" needs to be treated almost as a separate matter from "sharing the responsibility". The trust between managers and workforce needs to be gained before they can willingly take more responsibility for continuous improvement. In this way, "promoting teamwork" could be addressed as another heuristic implementation approach for building continuous improvement.

The low level of analytical skills found among the workforce needs to be addressed in order to implement this approach in the construction industry. Indeed, if any of the six companies had decided to involve bricklayers in process analysis it is likely that the results would be limited. It is not to say that the bricklayers would not be able to

recognise problems in their own process. On the contrary, they generally revealed sufficient understanding on the key problems of bricklaying. The critical issue here is the lack of principles, tools and techniques that could guide their observations into the most critical aspects of the process. For instance, bricklayers generally gave priority to improvements in operations rather than on the process. When bricklayers were asked about their views on solutions for the problems identified in the process, invariably they mentioned a more intensive use of machines.

The researcher found that the lack of managerial attention to mechanisms aimed at sharing the benefits of improvements to be another barrier for implementing this approach. Without a clear commitment of managers for sharing these benefits, it is hard to expect that the workforce will be willing to share the risks of investing in the long-term effort of continuous improvement. This issue is particularly important for those companies employing subcontractors where the sub-contractor only get involved with the organisation as a result of the low cost of bidding.

Investment in the improvement of bricklaying practices is often seen as too risky by construction managers since there is no guarantee that the subcontractor will remain with the company. Furthermore, construction companies not always have another project enabling the continuity of the bricklaying process. However, two alternative strategies for reducing the problem of continuity remained unused in all six companies investigated in this research. The first strategy is increasing the flexibility of bricklayers in order to be able of maintaining them working within the same company even when there are no bricklaying activities. The second strategy (and perhaps the most complex) is to share information on the workload of bricklayers across different companies that use the same type of masonry technology. Continuous improvement could then be maintained since bricklayers would have more confidence on the replication of the ideas in other projects. Obviously, companies involved in such a strategy would have to avoid infringements of 'cartel' laws.

5.6.2.7 CONCLUSION

The approach "sharing the responsibility of improvement with all employees" was rare in all case studies in this research, despite its central role in the implementation of all other heuristic approaches. Open-ended interviews with managers and workforce

revealed that short-term relationships were one of the fundamental problems hindering the full application of this approach in practice. Even so, the reduced number of empirical evidence matching this approach suggests the validity of this approach in the construction sector.

5.6.3 USING STANDARDS AS HYPOTHESES OF BEST PRACTICE

5.6.3.1 WORKING DEFINITION

This approach appears when managers are shown to use standards as an instrument for assessing, training or controlling the bricklaying practice.

5.6.3.2 OBSERVATIONAL FOCUS

The procedure for identifying this approach in practice followed similar pattern as the one used for identifying practices of "standardisation". The first three days of observations on site were seen as being sufficient to detect any empirical evidence of managers "using standards as hypotheses of best practice". Open-ended interviews with the workforce and managers helped to confirm, or otherwise, the actual use of standard documents as instruments for guiding the bricklaying process. During these interviews, the researcher tried to understand how managers involved the workforce in the development and revision of standard procedures. Random questions about characteristics of the process to bricklayers and subsequent comparison with the company's own written standards contributed to reveal the effectiveness of standards. Another key focus of observation was the number of information displays presenting standard procedures relating to bricklaying.

5.6.3.3 KEY INDICATORS

This approach used the following indicators to support the pattern matching analysis:

a) *% of Bricklayers that Knew the Written Standard:* bricklayers should be able to describe the content of the written standards relating to their own processes. In order to assess that, bricklayers were asked random questions about their bricklaying practice. Subsequently, their answers were checked against the company's own standards;

b) *Number of Revisions of Standards per Year*: bricklayers and managers reported, at the beginning of the research, how many times it has been revised their standards in the previous twelve months. Their answers were checked against archival records and the information contained in the standards themselves. This indicator helped to show the actual commitment of the organisation towards the maintenance and improvement of standards;

c) *Number of Information Displays*: standard procedures need to be disseminated throughout the construction site in order to enhance understanding and avoid forgetfulness. Thus, the number of information displays showing standard procedures is a direct measure of the extent in which the workforce is exposed to, and challenged with, standards procedures.

5.6.3.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The items below describe the expected behaviour and practical boundaries of the chosen indicators:

a) *% of Bricklayers that Know the Written Standard:* the opinion of practitioners have lead the researcher to establish eight percent as the minimum value for this indicator. According to them, twenty percent of new personnel was reported by some the site managers as a normal situation in bricklaying. Ideally, all bricklayers should know the content of the contractor own standards relating to bricklaying. However, the constant movement of bricklayers across construction companies would demand a regular training activity that is not always observed in the sector;

b) *Number of Revisions of Standards per Year*: the practical boundary (2 to 4 revisions/year) for this indicator has been established using the opinion of specialists and academics involved in the implementation of improvement programs.

c) *Number of Information Displays*: the literature does not discuss any criteria for establishing the adequate level of information that should be present in the production environment. Inferences from Greif's (1989) and Galsworth's (1997) writing suggest that every process stage should have, at least, one information display. For analytical purposes, this research admits the minimum quantity of information displays as equal to the shortest number of bricklaying process stages

identified among the case studies (eight). After discussions with site managers, the maximum amount of information displays has been admitted as double of this value.

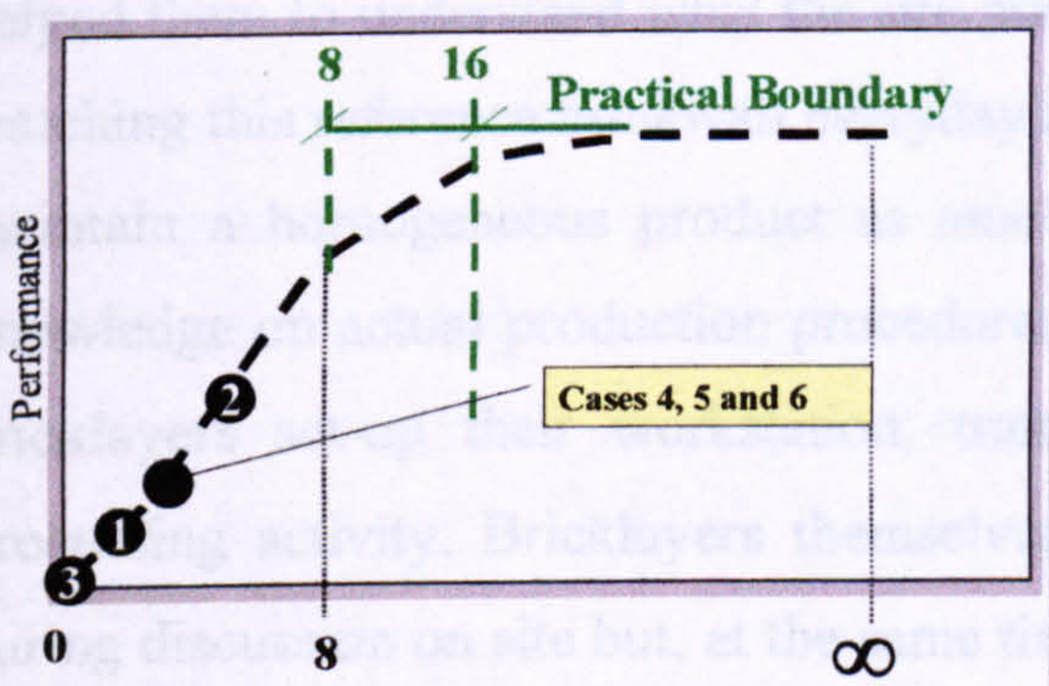
5.6.3.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

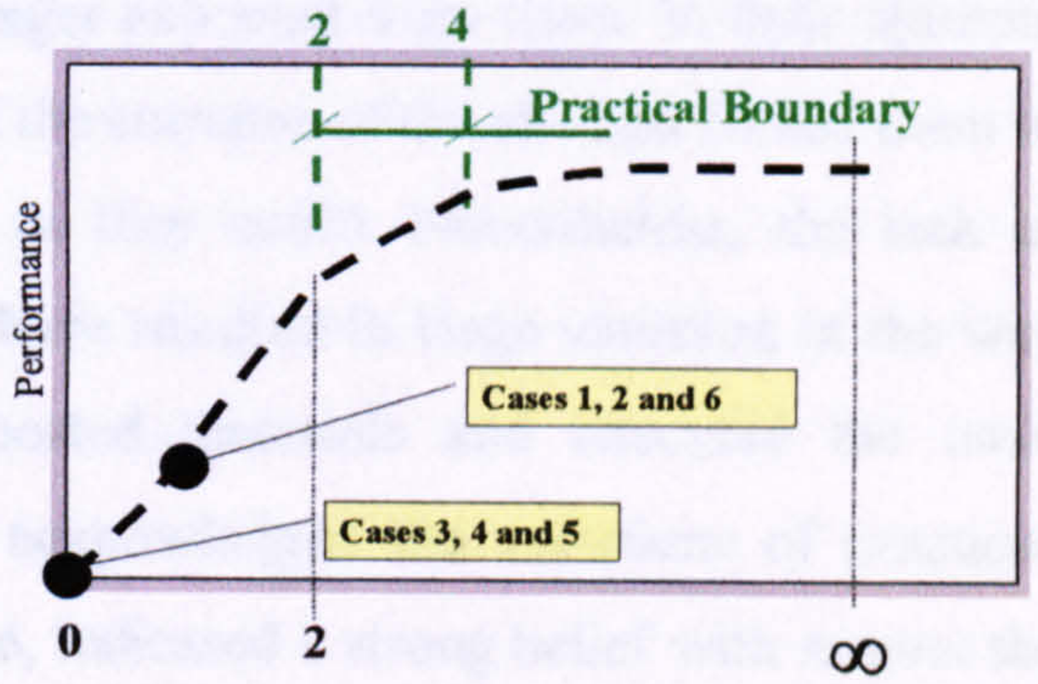
There was not an effective standardisation process in any of the construction sites analysed in this research, although in three of them there were documented standards. Consequently, the use of standards as an instrument to drive best practice was almost non-existent, as presented in Table 5.19.

Table 5.19 - Performance of Case Studies Regarding the *Use of Standards as Hypothesis of Best Practice to be Challenged*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Bricklayers Observed	6	6	2	4	3	8
Number of Boards Displaying Process Information	1	4	0	2	2	2
Number of Products Displaying Process Information	0	0	0	0	0	0
Number of Revision in Standards per Year	1	1	-	-	-	1
% of Operatives Knowing the Written Standards	0	0	-	-	-	0
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications*	**1**	**2**	**0**	**0**	**0**	**0**



Number of Information Display Areas



Number of Revision in Standards Per Year

Lack of involvement of the workforce in problem solving activities was the main barrier for using standards as a driver of continuous improvement in the case studies. None of the bricklayers interviewed had participated in the revision of written standards in the

previous twelve months. They never mentioned standards as a basic platform for searching better bricklaying practices. Moreover, there were no suggestions schemes or a clear strategy to involve workers in future revisions of standards. In this environment, it was no surprise to find out that most workers in the six case studies did not know the content of the written standards relating to their own process (*see* Table 5.19).

Few information displays presented standard procedures despite the high variability of practices observed among bricklayers. Furthermore, the information displays in use did not follow the move of workstation around the site. Hence, bricklayers had no direct access to process information throughout most of the working day. Access to information on standard procedures was remote, held in the site office, and usually needed the help of managers. Thus, any consultation to standards would take time that bricklayers were not prepared to spare.

b) Individual Case Study Reports

b.1) Case Study 1

The only clear challenge to the bricklayer's practice, witnessed during the data collection on this site, was a sample of brickwall built at the entrance of the site. This brickwall was a visual reference that communicated to bricklayers what was expected from their process. Bricklayers declared that having this visual reference have actually helped them to understand what the site manager expected from them. In their opinion, watching this reference brickwall everyday at the entrance of the site had forced them to maintain a homogeneous product as much as they could. Nevertheless, the lack of knowledge on actual production procedures have resulted in large variation in the way bricklayers set-up their workstation, transported materials and executed the main processing activity. Bricklayers themselves acknowledged the variations of practices during discussion on site but, at the same time, indicated a strong belief with respect the positive merits of their own individual practices.

b.2) Case Study 2

This site revealed only two situations where there was a clear use of standards to promote the improvement of bricklaying practice. In both situations, information displays asking the workforce to comply with safety standards have been displayed in

circulation areas. Law enforcement would impose heavy penalties on the contractor for any safety infringements. This factor, according to managers, was the main reason for the emphasis on the maintenance of safety standards. Figure 5.25 has illustrated a situation where the project manager explained the company safety standards for new workers arriving on site. In this environment, the bricklaying subcontractor had to maintain and promote the safety standards if he wanted to continue to have contracts with this company.

b.3) Case Study 3

This site presented no standardisation process and, consequently, bricklayers were not challenged to do better against standard practices. Furthermore, there was no involvement of the workforce in continuous improvement activities and the communication between bricklayers. The site manager limited any discussion with them to administrative matters. The consequence of this environment was easily seen on the great variation of practices found among bricklayers. Like in previous case studies, bricklayers have accepted that there were excessive variations but, they still expressed the view that their individual practices were as good as they could to.

b.4) Case Study 4

There were no written standards to guide and challenge the practice of the bricklayers on this site. They relied heavily on the initiatives of process improvements generated by the designers, technologists and site manager. No evidence has been found of their involvement in problem solving activities, or suggestions schemes for improvement. Bricklayers argued that, usually, there was no time available to discuss their procedures because of the tight schedule imposed upon their work.

b.5) Case Study 5

The variability of blocks, mortar and the concrete structure had serious effects in the quality of the bricklaying output and level of bricklaying practice on this site. There was a generalised lack of standards among the bricklayers themselves during the entire observational period. The very basic technological state of this process on this site was a strong influence in the way the workforce and managers saw the possibility of developing standard procedures. Indeed, during open-ended interviews both asserted

that the bricklaying process was too simple and straightforward to deserve standardisation efforts.

b.6) Case Study 6

Case Study 6 displayed a well-designed "book of standards" (*see* Figure 5.45) but did not use it to challenge the highly variable practice observed among bricklayers. The actual practice observed on this site was different from the company's own written standards. This mismatch between the standard procedures and the actual practice on site increased even further the scepticism of the workforce regarding the usefulness of such an exercise.

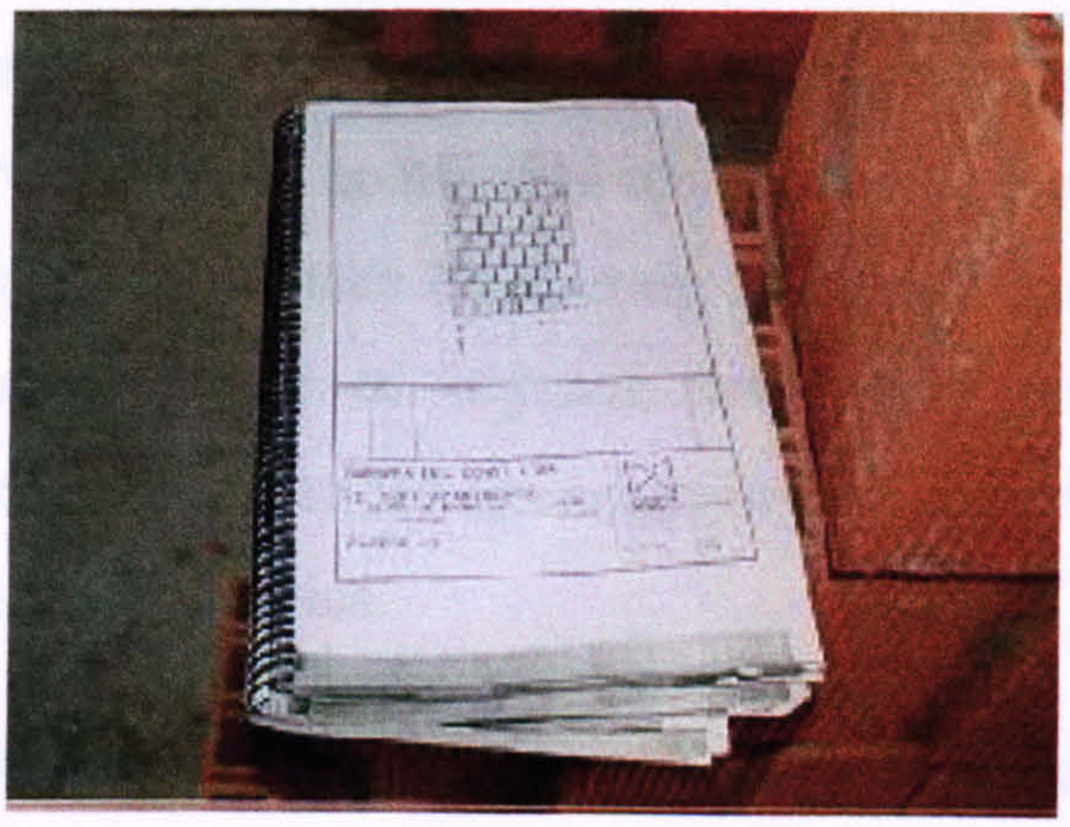


Figure 5.45 – Theoretical Replication of *Use of Standards as Hypotheses of Best Practice to be Challenged* (Case Study 6)

As in the previous case studies, the main reason for the widespread lack of standards in the bricklaying process was the lack of instruments to involve and motivate the workforce in the revision of the standard procedures. Managers blamed the short-term relationships imposed by a contractual relationship, based solely on cost, as the root cause of the poor involvement of bricklayers in improvement activities.

5.6.3.6 DISCUSSION

The main lessons learned from the analysis of this approach in the construction practice are as follows:

i. Sharing the responsibility for improvement with the workforce and building teamwork is a pre-requisite in implementing this approach in construction practice;

ii. The procedures for updating, revising standard procedures was not adapted to the needs of bricklayers. The process of standard revision was often too bureaucratic and slow, thus, reducing the motivation of managers to use standards as tool for promoting process improvements.

The lack of other complementary approaches severely affected the application of this approach on the construction sites analysed in this research. The lack of involvement of the workforce in problem solving activity was clearly the main obstacle here. Without a team atmosphere, it is difficult to imagine that challenging the bricklayer's practice could have any positive effect on continuous improvement. The discussions with the bricklayers suggest that this approach could even cause an opposite effect. They had little support from management to improve bricklaying practices and working environment. Furthermore, they also felt managers had no authority and justification in controlling or criticising their practice.

The dissemination of standards throughout the construction sites observed was poor and used no information displays in sufficient intensity. Bricklayers had no access to process information when, and where, they needed it. In this respect, sub-products moving across the sites could have given a significant contribution in disseminating information on standard procedures. The challenge on bricklaying practice could then be permanent, wherever the workstation was to operate. This channel of communication also offers the potential of fastening the process of revision and update of standards.

5.6.3.7 CONCLUSION

The use of 'standards as hypothesis of best practice to be challenged' was scarcely identified among the case studies, as well as in the meta-case. The reduced number of evidence identified had focused mainly on the safety aspects of production. The main reasons for this situation was the lack of an effective process for standardisation, reduced use of information displays and poor teamwork on site.

5.6.4 MEASURING AND MONITORING IMPROVEMENTS

5.6.4.1 WORKING DEFINITION

The manifestation of this approach in practice is confirmed when the company regularly measures, evaluates and keep records of improvement developments in bricklaying.

5.6.4.2 OBSERVATIONAL FOCUS

The focus during data collection here was on any measurement activity or documents that presented a clear relationship with improvement activities in the bricklaying process. Site managers were asked in the first visit if there were regular measurements or documents relating to improvement activities. Their answers were crosschecked with subsequent analysis of archival records and documents available on site. Improvement reports and the agenda of meetings were the kind of documents that could contribute to certify the presence of this approach in practice. Daily discussions with the workforce revealed their perception on the use and effectiveness of measurement and monitoring activities for implementing and adjusting improvements in bricklaying.

5.6.4.3 KEY INDICATORS

Some of the instrumental indicators used in the previous approaches were also applied to identify practices matching this approach. The *Number of Indicators Collected Regularly*, in particular, can be a direct indication of managers' intents in investigating the root cause of problems in the implementation of improvements. Open-ended interviews with managers were the main instrument used to gather this information. The analysis also uses the *Number of Improvements in Bricklaying during the Project Based on Data* and the *Number of Displays Showing Performance Indicators* as complementary indicators since they are also directly relating to the practice of measuring and monitoring.

5.6.4.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The minimum practical boundary for the *Number of Performance Indicators Collected Regularly* has been established as four. It is based on the four basic measurements used in this thesis (productivity, waste, average storage and flow efficiency). Other indicators

were considered as applicable and valuable for bricklaying and contributed to define "eight" as the maximum boundary (gang composition, work-in-progress, variability of production rate and the size of transfer batches). There is no suggestion in the literature regarding the correlation between the number of indicators collected regularly and performance. However, it seems reasonable to infer that the benefits of increasing further the number of indicators in bricklaying becomes gradually smaller since there are a limited number of important process variables.

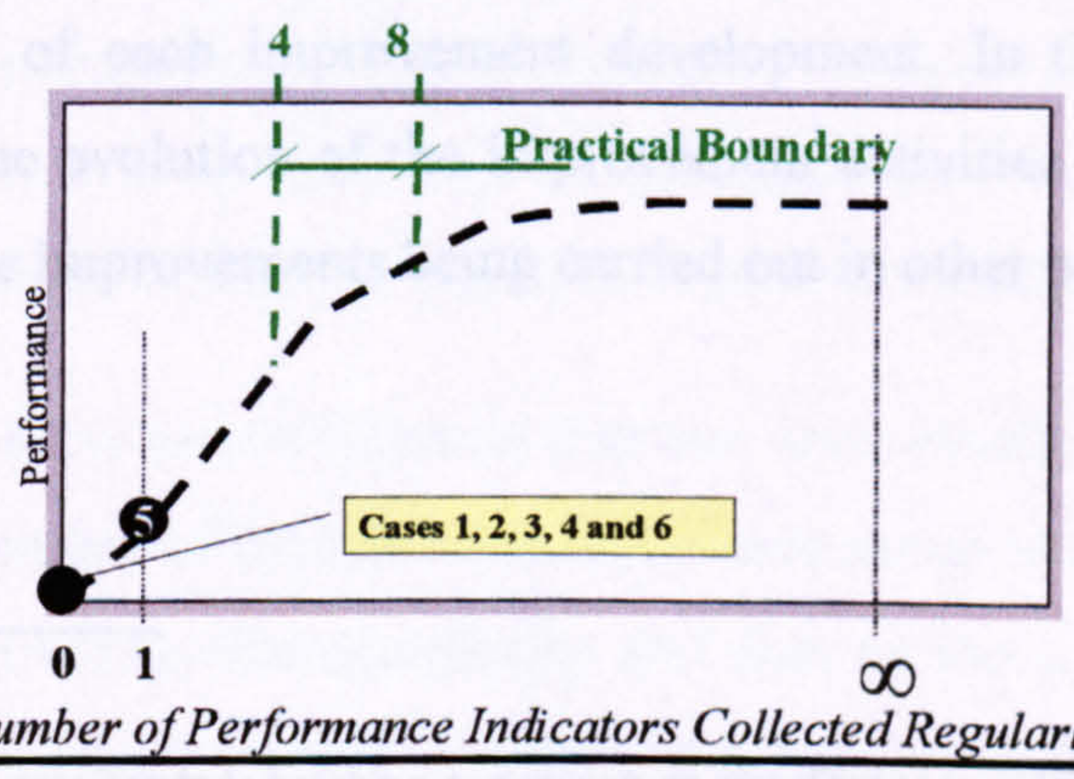
5.6.4.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

The case studies revealed only one piece of evidence of monitoring activity following the implementation of improvements in production (see Table 5.20). Managers in the majority of case studies seemed to implement improvements and innovations under the assumption that they would be fail-proof, hence, not requiring further adjustments.

Table 5.20 - Performance of Case Studies Regarding to *Measuring and Monitoring Improvements*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Improvements in Bricklaying during the Project	0	0	0	1	1	3
Number of Improvements in Bricklaying during the Project Based on Data	0	0	0	0	0	0
Number of Performance Indicators Collected Regularly	0	0	0	0	1	0
Number of Displays Showing Performance Indicators	0	0	0	0	0	0
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications	**0**	**0**	**0**	**0**	**2**	**0**



Many authors, including Imai (1997), have emphasised that successful implementation of any improvement depends on the incremental adjustments using regular measurements and monitoring. Figure 5.46, extracted from the meta-case, is a good illustration of the practical implications of not applying this approach in practice. The worker on this site did not use the equipment installed to improve the precision of volumes of sand during the production of mortar (equipment above the cement mixer[9]). The improvement was not very successful since there were no adjustment and corrections in the implementation stage. The worker had never been involved or consulted during the development and implementation stages in this site. Furthermore, the new equipment did not offer adequate ergonomic conditions to the worker and hampered his productivity.



Figure 5.46 – Theoretical Replication of *Measuring and Monitoring Improvements* (Meta Case)

The applicability of this approach in the construction sector has been clearly substantiated by evidence supplied by the meta-case. Figure 5.47 shows a panel used by a 'kaizen' team, working in a Brazilian construction company, to present the status of improvement activities. This board has different colours representing different implementation stages of each improvement development. In this way, all workers could easily monitor the evolution of the improvement activities relating to their own processes, as well as the improvements being carried out in other processes.

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[9] **Cement mixer**: machine that does mortar's batching and mixing on site (Dictionary of Building, 1995).



Figure 5.47 - Literal Replication of *Measuring and Monitoring Improvements* (Meta Case/Brazil)

b) Individual Case Study Reports

b.1) Case Study 1

No improvement activities in the bricklaying process were observed during the observational period on this site. There were also no measurement activities with the objective of detecting the root cause of problems. The conversion paradigm was heavily used in this site as a result since managers failed to give sufficient attention to bricklaying flows. They paid attention mostly to things such as deadlines, number of bricklayers on site, amount of material and equipment available. Interviews with the site manager and foreman made it clear that the development of improvements in the bricklaying process was subcontractor's responsibility and not his. Therefore, there was no managerial support for such activity and no direct benefit for the workforce.

b.2) Case Study 2

Despite the active participation of managers in workflow planning and the relative low level of batch sizes, this site presented no permanent improvement in the bricklaying process itself. Comparison with other sites revealed a large number of improvement opportunities in the production of mortar, transport equipment, visual controls and information displays. However, there was no guarantee that the relative smooth and synchronised flow observed in this site would be repeated in another site.

Monitoring activities of any action taken on this site were usually *ad-hoc* and relied on the experience and attention of the subcontractor, foreman or site manager. According to the open-ended interviews, the complexity and size of the project pressured daily activities of all workers in such a way that they had little time to document their actions.

Consequently, many successful experiences were never shared with the rest of the company, or available for consultation in future projects.

b.3) Case Study 3

Fifteen days of observations on this site revealed no activities relating to measurement and monitoring of improvements. In fact, there was no improvements carried out in the bricklaying process during the entire project (*see* Table 5.20). The poor leadership and commitment of the site manager towards continuous improvement was the root cause of the low level of motivation of the workforce towards developing better solutions for their own process. Bricklayers resented the lack of attention given by the site manager to their daily difficulties and problems with the process flow such as the long transportation distances, poor quality of accesses and lack of information.

b.4) Case Study 4

There has been one improvement development in bricklaying during this project, but there was no systematic activity aimed at monitoring its operation. This improvement consisted of a poka-yoke device installed on the elevator, as described earlier in this chapter. There had been some operational problems with this device during the observational period, such as the slow maintenance, lack of training for operatives and the lack of protection against rain. Notwithstanding this, both site managers and foreman paid no attention to such issues once the equipment was installed on site.

Here again, the lack of participation of the operatives in developing continuous improvement activities was a major obstacle to further adjustments in existing improvements. Managers considered the lack of formal education and training among bricklayers to be the largest barrier for involving them in systematic process analysis. Yet, those bricklayers had a good understanding of the main sources of variability.

b.5) Case Study 5

The researcher witnessed measurement activities in two of the ten visits carried out on this site. These measurements aimed at identify the root causes of waste and, at the same time, contributed in assessing the company director's decision in adopting a new type of brick. There was no adequate preparation of the design and production for the

implementation of this new brick. In reality, this decision amplified the combined negative effects of poor design modularization and high variability in the bricklaying and concrete structure. The foreman and site managers were fully aware of the problem caused by the new brick. In their opinion, measurements would give them a full assessment of the damage caused by the director's decision. Hence, they intended to use this information to put forward suggestions for improvements that were urgently required in the construction site.

b.6) Case Study 6

The three improvements witnessed by the researcher on this site had no systematic monitoring or measuring activities following their implementation: a) placing electrical and bricklaying operations in parallel; b) implementation of a poka-yoke device in the elevator and; c) use of metallic device to guide the position of brickcourses. The main reason for this situation was the lack of workforce participation in continuous improvement activities. None of the bricklayers showed motivation to participate in such activities since there was no trust in the fairness of managers in sharing the benefits of improvement. Again, as reported before, the bricklayers had no guarantee of continuing with the same company and same technology in the near future.

5.6.4.6 DISCUSSION

The main lessons from the comparison between the descriptions found in the literature and the construction practice in this respect are:

i. Most construction companies observed have developed improvements in production without the participation of the workforce. Managers carried out the monitoring activities in an *ad-hoc* basis and, often, failed in developing further adjustments during the implementation stage;

ii. There was a lack of knowledge among managers and workers regarding the techniques available to investigate the bricklaying process. Generally, companies relied on external advice when they had problems in implementing a particular improvement.

Managers seemed to focus on each project in isolation, without long-term perspective in terms of process improvement. This certainly influenced their reluctance in monitoring, documenting and measuring bricklaying practices and improvements. Managers usually saw adjustments in improvements as not worthy the effort and time demanded for identifying them. Their short-term thinking in terms of the benefits of monitoring and adjusting improvements, led them to forget the great benefit for the organisation that is developing the workforce capability for carrying production improvement.

The poor involvement of the workforce in measuring and monitoring activities was further hampered by their lack of knowledge of the techniques, principles and concepts described in this thesis. Since they had no opportunity and incentive in getting involved with continuous improvement activities, they could not develop their analytical skills and improve their understanding of such knowledge. Hence, this created a vicious cycle, where improvements were usually performed below their optimal level because the people that implemented them had little say in how to adopt them.

5.6.4.7 CONCLUSION

The habit of measurement and monitoring the progress of an improvement still is rare in construction. This factor led the innovations and improvements in the case studies to operate well below their potential performance. Indeed, all six case studies supplied reduced number of evidence to support the applicability of this approach in the construction sector. However, evidence available from the meta-case clearly confirmed this approach to be valid and it is already used by many construction companies.

5.6.5 LINKING IMPROVEMENTS TO PRORITIES SET BY THE CONTROL ACTIVITIES

5.6.5.1 WORKING DEFINITION

This approach occurs in practice in when the empirical evidence shows the company developing improvements for bricklaying based on the priorities set by the control activities.

5.6.5.2 OBSERVATIONAL FOCUS

The focus during data collection for this principle was on any improvement activity observed to be under development within the bricklaying activity and on the dynamics of decision-making that led to the choice of that particular improvement. In the first visit, site managers were asked to list the improvement priorities set for bricklaying and, subsequently, the source of information that led to that prioritisation. In the subsequent days of data collection, their answers were cross-checked with subsequent analysis of archival records and documents available on site. A "literal replication" occurred when there was unequivocal evidence that an improvement has been formulated using hard information from control activities.

5.6.5.3 KEY INDICATORS

The pattern matching approach used three indicators already used in the analysis of previous heuristics, as follows:

c) *Number of Performance Indicators Collected Regularly:* regular control procedures can generate performance indicators and, thus, enable the development of benchmarking between different sites and the establishment of tolerance limits;

d) *Number of Improvements in Bricklaying carried out during the Project:* there should be examples of improvements developed under a systematic inquire if the company practice this approach. This information was gathered directly from conversations with the site manager and workforce and cross-checked with archival records and documents;

e) *Number of Information Displays Showing Performance Indicators*: Greif (1989) shows that the information from process controls have to be exposed to the workforce in order to be effective within continuous improvement activities. .

5.6.5.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The expected behaviour and respective boundaries for the chosen indicators are, as follows:

a) *Number of Performance Indicators Collected Regularly:* the minimum practical boundary for this indicator has been established as four. It is based on the four measurements used in this thesis (productivity, waste, average storage and flow efficiency). Other indicators were considered as applicable and valuable for bricklaying and contributed to define "eight" as the maximum boundary (gang composition, work-in-progress, variability of production rate and the size of transfer batches). There is no suggestion in the literature regarding the relationship between the number of indicators collected regularly and performance. However, it seems reasonable to infer that the benefits of increasing further the number of indicators becomes gradually smaller, since there are limited number of significant sources of process variations.

b) *Number of Improvements in Bricklaying carried out during the Project:* not all improvement decision can be based upon hard data and insisting in doing so can have reduced benefits in terms of enhancement of production performance. The literature review has not shown references for this indicator. Still, feedback from the personnel interviewed indicated that it should be possible to develop between two and four improvements per month in current construction practices;

c) *Number of Displays Showing Performance Indicators*: the practical boundary for this indicator has been established as a multiple of the shortest process encountered in practice (8) since the literature did not supply a reference parameter. Like in the previous indicator, it seems reasonable to infer that increasing further the number of information displays offers gradually smaller benefits since the workers may find themselves overloaded with information.

5.6.5.5 SUMMARY OF RESULTS

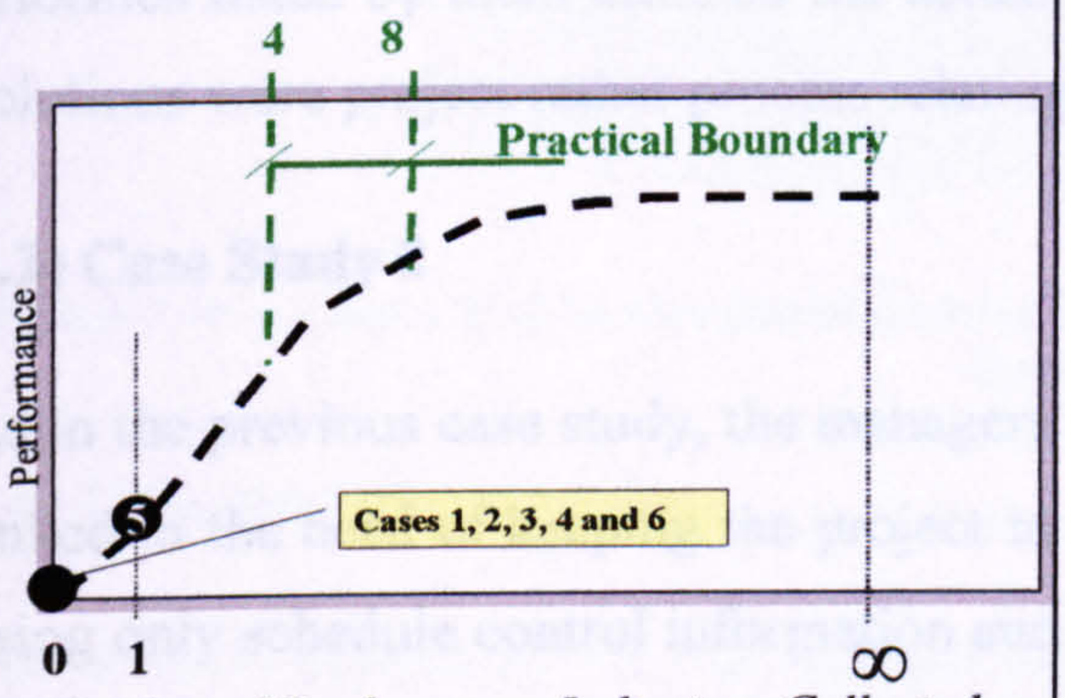
a) General Pattern Across All Cases

Direct observations and open-ended interviews revealed that construction managers used "trial and error" and cost evaluations associated with their previous experience to decide the improvement priorities. The majority of case studies had no systematic measurement of process indicators and none of the process improvements observed used hard information in their development, as Table 5.21 shows. The applicability of

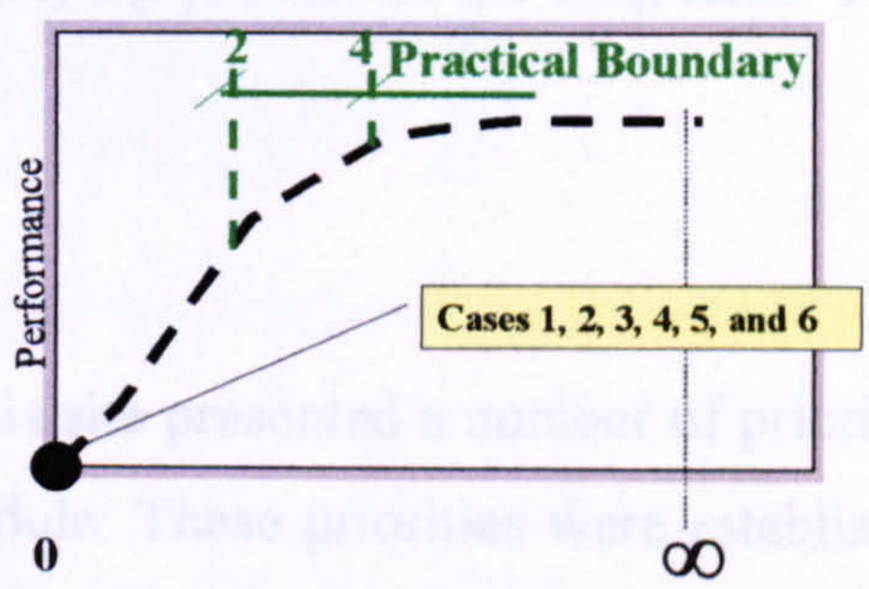
this approach in construction can only be supported using the empirical evidence assembled from the meta-case. One clear "literal replication" comes from a Brazilian company that used information from the geometrical control of formwork (*see* Figure 5.48) and structure to prioritise improvements in the sources of deviations. With this practice in place, it was able to promptly formulate better solutions in formwork design and workflow. This company used control information to establish performance indicators that informed structural engineers and production managers about the strength and weaknesses of the formwork process.

Table 5.21 - Performance of Case Studies Regarding *Linking Improvement to Priorities Set by the Control Activities*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Improvements in Brickl. during the Project	0	0	0	1	1	3
Number of Improvements in Bricklaying during the Project Based on Data	0	0	0	0	0	0
Number of Performance Indicators Collected Regularly	0	0	0	0	1	0
Number of Days Observed	**10**	**10**	**15**	**10**	**10**	**6**
Number of Literal Replications	**0**	**0**	**0**	**0**	**0**	**0**



Number of Performance Indicators Collected Regularly



Number of Improvements in Bricklaying during the Project Based on Data

Outside the bricklaying scope, the most common controls that were observed across all case studies was the quality control applied to concrete. Concrete producers use such data to prioritise improvements in their product and processes. The correlation between the distances for transportation and concrete consistency, for instance, helped them to establish the best possible concrete mixture with the lowest possible cost. Discussions with one of the concrete suppliers showed that the detection of these sources of variations drove improvements in the factory itself such as the installation of poka-yoke devices and better visual controls.



Figure 5.48 - Literal Replication of *Linking Improvement to Priorities Set by the Control* (Meta Case/Brazil)

b) Individual Case Study Reports

b.1) Case Study 1

Ten days of observations on this site revealed no formal process control. Open-ended interviews with the managers indicated that what they considered as improvement priorities were, in reality, short-term solutions to problems with deadlines. They based their decisions relating to production solely on the delays in relation to schedule and, therefore, used time as the only criteria for decision making. However, none of the priorities listed by them affected the actual bricklaying process in the long term. Their solutions were project rather process relating.

b.2) Case Study 2

As in the previous case study, the managers on this site presented a number of priorities linked to the need of keeping the project to schedule. These priorities were established using only schedule control information and included decisions such as the introduction of more bricklayers, or renting more scaffolding. None of these decisions affected the actual production processes, since the bricklaying practices had remained the same throughout the entire observational period. The delivery batches were relatively small in comparison with other case studies, but the site manager mentioned no strategy for promoting further reductions in their size.

b.3) Case Study 3

Case Study 3 had no process control and the site manager had no priorities for improvements in the bricklaying process. In fact, the site managers seemed to be

unaware of the large amount of waste caused by inefficient flows on site. For instance, the management decisions were heavily oriented towards large production batches as well as large delivery batches. The assumption of the site manager here was that large batches would contribute to the elimination of stopping times due to lack of materials and, thus, enable him to work to full production capacity. However, the consequence was quite the reverse since this was more waste of material and excessive time spent on transportation. The decision for constructing the two houses illustrated on Figure 5.49, for instance, resulted in excessive distances between the four bricklayers available on site. The same Figure also shows the large quantity of material and the great distance between them and the workstations.



Figure 5.49 – Theoretical Replication of *Linking Improvement to Priorities Set by the Control* (Case Study 3)

b.4) Case Study 4

The controls applied by the site manager and foreman on this site were largely ad hoc. During open-ended interviews, they could not supply numerical data on the performance of bricklaying. Indeed, there has been only one improvement implemented in bricklaying during the project and this decision had been taken without consideration of the process main needs. The only improvement consisted of a poka-yoke device installed on the elevator, as described earlier in this chapter. The site manager revealed that the decision for implementing that improvement came in fact as a result of the expectation of law enforcement and the need to maintaining an innovative image in the market.

b.5) Case Study 5

This is the only site that presented empirical evidence of systematic measurement aimed at identifying problems and set prioritises for improvements. Yet, the only improvement in bricklaying described by the site manager failed to use process control information to aid its development. This improvement consisted of adopting a new type of brick that proved to be useful for installing plumbing and electrical services. The decision to use this brick did not tackle the main process problems and did not take into account the opinion of bricklayers and foreman. Hence, this had amplified the negative effects of poor design modularization and high variability in the bricklaying and concrete structure.

b.6) Case Study 6

All three bricklaying improvements developed during this project were the result of decisions taken by designers and site manager without previous process analysis. The need for greater transparency in this construction site, for instance, had not being contemplated in these improvements. All improvement priorities described by the site manager focused on operations rather than process. Furthermore, these priorities clearly ignore the urgent need for reductions in variability. The poor level of trust and dialog between managers and the workforce again limited the feedback from those that could actually implement the managerial decisions.

5.6.5.6 DISCUSSION

The main lessons from the case studies regarding to the establishment of a *link between improvement to the priorities set by control activities* are, as follows:

iii. Construction managers used "trial and error" experiments, cost evaluations and their individual previous experiences to decide the improvement priorities;

iv. Construction managers gave higher emphasis to improvements in operations, rather than the process. Their technical background helped them to explain their excessive emphasis on technological solutions and poor attention to recurrent problems in the process flow;

v. Sharing the responsibility for improvement with the workforce and building teamwork is a pre-requisite to implement this approach in construction practice but little was observed in this respect across the case studies;

Lack of time for adequate assessment of improvement priorities seems to be one of the route causes why this approach was not identified among the case studies. Managers had no time to carry out proper process control and did not delegate this activity to the workforce. This created a vicious cycle since poor decision-making led to more process problems and process problems resulted in less time available for better decision-making.

The misconception among site managers on what constitutes an improvement in the bricklaying process reflects the culture of fire fighting described in the literature. This misconception had transformed short-term solution for contingent problems into actual process improvements. Thus, the implementation of this approach definitely depends on the move of managers' mental set from a project-based view to a process-based view. As far as possible, bricklaying process improvements should be repeatable across different projects.

The technological emphasis given in construction relating courses may explain the emphasis given by site managers on equipment and innovative technologies. Whilst the researcher acknowledges the importance of these improvements, managers should also understand the need for considering process prior to operations. Hence, before comparing the qualities between two different machines, construction managers should question the actual need for machines if the operation could be eliminated from the process in the first place.

5.6.5.7 CONCLUSION

The situation observed in the case studies revealed that trial and error, financial assessments and previous experience are still driving daily decisions and improvement developments in the construction sector. The generalised absence of process controls and poor participation of the workforce in continuous improvement activities led managers to misinterpret the production process actual needs. Only examples extracted

from the meta-case allow the researcher to confirm the approach is valid in the construction environment.

5.6.6 CHANGING PUSH ORDERS TO PULL ORDERS

5.6.6.1 WORKING DEFINITION

This approach occurs in practice when downstream orders activate the bricklaying process or when bricklaying sends a production order to an upstream process. Both bricklaying and upstream processes have to restrict their production approximately to the quantities specified in their downstream orders.

5.6.6.2 OBSERVATIONAL FOCUS

The central focus during observations was on the communication and flow of orders within bricklaying and between bricklaying and other upstream/downstream processes, including suppliers of bricklaying components and material. A "literal replication" occurred when there was unambiguous evidence that a brickwall has been built, or a truckload has been delivered, against a clearly defined downstream order. The researcher's attention was on any formal and informal communication that occurred during the observational period. The average storage of materials or sub-products helped to confirm the actual use of "pull orders". Daily conversations with bricklayers were used to confirm the number of workstations actually operating against downstream orders..

5.6.6.3 KEY INDICATORS

The *Indicator of Flow Efficiency* used in the previous approaches seemed also to be suitable for analysing the effectiveness of using "pull production orders" to reduce inventory in the process. In addition, the researcher have chosen two other indicators, both tested in the pilot study, as a way to measure the performance of bricklaying regarding pull production, namely:

a) *Number of Materials/Brickwalls Requested by Pull Orders*: an order was considered as 'pull order' when it came from a downstream operation and production/delivery batches were restricted to the amount specified in that order. Most of the values for

this indicator were obtained by tracking the ordering process of each material in site archives, direct observations or through open-ended interviews;

b) *Number of Meetings Between Bricklaying and Upstream/Downstream Operations:* Monden (1998) shows that in a pull production system the process problems cannot be re-passed to downstream operations since the amount of inventory is considerably reduced. Thus, the practice of pull orders demands an increase of problem solving activities involving upstream and downstream processes in order to avoid disruptions in the process flow.

5.6.6.4 EXPECTED BEHAVIOUR AND BOUNDARIES OF INDICATORS

The following considerations defined the expected behaviour and practical boundary for the chosen indicators:

a) *Number of Materials/Brickwalls Requested by Pull Orders*: the Toyota Production System shows that the achievement of one hundred percent pull production can be a drive for improvement and innovations in the entire organisation. At the same time, Toyota's experience shows that striving for hundred percent pull orders offers important but increasingly smaller benefits in terms of production performance (Monden, 1998).

b) *Number of Meetings between Bricklaying and Upstream/Downstream Processes:* regular problem solving meetings between bricklayers and neighbour process owners is an important factor to enable pull production. Discussions with the workforce and managers led to the conclusion that these meetings could occur once a month or once a week, depending on the variability and type of process problems. They were also concerned that a greater number of formal meetings would bring increasingly smaller benefits on performance and could even generate further delays and disruptions in the process if carried out in excess.

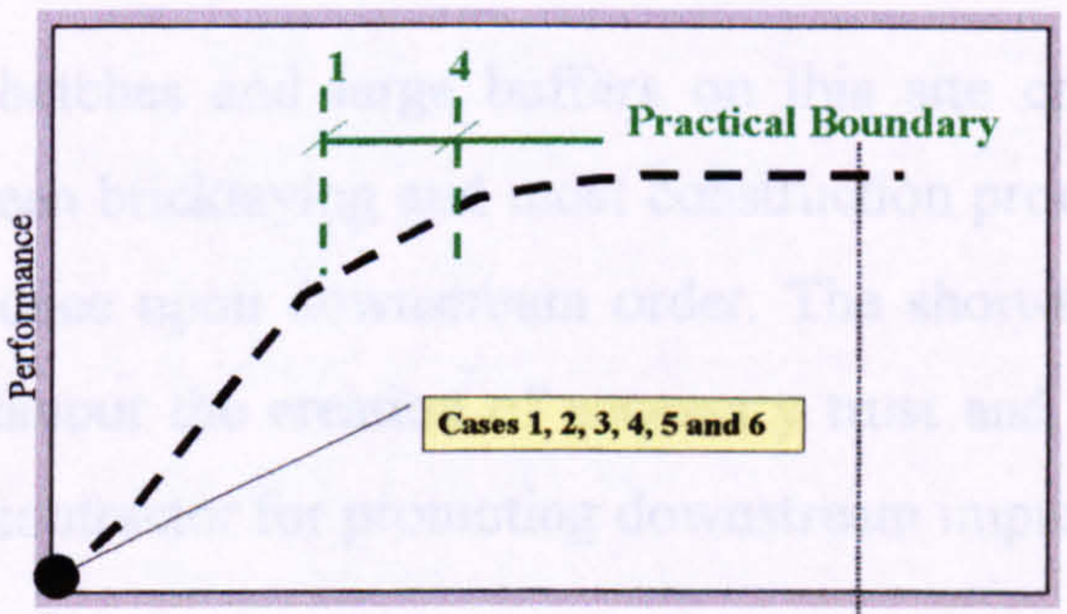
5.6.6.5 SUMMARY OF RESULTS

a) General Pattern Across All Cases

Most construction sites practised push orders when requesting material from suppliers and for constructing brickwalls. The most visible consequence of the generalised lack of pull orders be the long time brickwalls had to wait for the downstream processes. Table 5.22 shows that only nine of the thirty-seven deliveries observed followed exactly the bricklayers needs and, even so, most of these "literal replications" happened in just one case study. Furthermore, none of the bricklayers interviewed during this research had direct contact with downstream operations, concerning the establishment of when, how or which brickwalls should be constructed.

Table 5.22 - Performance of Case Studies Regarding *Change from Push Orders to Pull Orders*

INDICATOR	CASE STUDY					
	1	2	3	4	5	6
Number of Days Observed	10	10	15	10	10	6
N° of Meetings Between Bricklaying and Upstream/Downstream Operations	1	0	0	0	0	0
Flow Efficiency (A/B)	0,05	0,06	0,03	0,07	0,03	0,04
N° of Deliveries Requested by Pull Orders	0	8	0	1	0	0
N° of Deliveries during Observational Period	**7**	**10**	**7**	**6**	**4**	**3**
N° of Brickwalls Requested by Pull Orders	0	0	0	0	0	0
Number of Workstation Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications	**0**	**8**	**0**	**1**	**0**	**0**



Number of Meetings Between Bricklaying and Downstream/Upstream Operations/Month

Without direct interaction between upstream and downstream processes, there is no exchange of ideas on how to improve process interfaces or how to follow a better workflow. Indeed, avoidance of errors and problems in downstream processes was not a

main issue in the concerns of any bricklayers interviewed. Moreover, bricklayers never had the opportunity for discussing these matters with upstream/downstream processes and there were no instruments to motivate them to do so. Table 5.22 shows that none of the bricklayers had participated in meetings with upstream or downstream operations.

Empirical evidence resembling "literal replications" pull production processes have been identified in the production of mortar of some case studies. Even so, in these situations the workstation responsible for producing mortar very often did not have a formal order from bricklayers. In fact, in most situations labourers used to produce enough mortar for a half day of work based on the normal consumption occurred in the previous days. Small adjustments did in fact occurr at the end of the working day when labourers corrected any occasional shortage of mortar.

b) Individual Case Study Reports

b.1) Case Study 1

This site presented no literal replication of "pull orders" on the workstations or on the delivery of material on site. Even so, this is the only construction site where there was a clear attempt to bring different processes to discuss problems and improve the overall project. This site in fact had a container dedicated to promoting meetings between downstream and upstream processes. However, these meetings focused mainly on logistics and on the co-ordination of resources, rather than on promoting the practice of pull production.

The practice of large batches and large buffers on this site created a physical and temporal distance between bricklaying and most construction processes that diminished their motivation to produce upon downstream order. The short-term relationship with the contractor did not favour the creation of necessary trust and commitment between the subcontractors and contractor for promoting downstream improvements.

Although not included on Table 5.22, the activity of cutting blocks was the only activity that resembled a literal replication of pull production on this site. The upstream operation (cutting blocks) only processed blocks after receiving orders from downstream operations (bricklaying). This procedure resulted in almost no storage and avoided mass production of errors in case of changes in the dimensions required by

bricklayers (see Figure 5.50). However, in order to achieve this, the workflow had to be better planned in order to allow rapid access to the saw machine.



Figure 5.50 - Literal Replication of *Change Push Order to Pull Order* (Case Study 1)

b.2) Case Study 2

This case study presented the largest number of literal replications relating to the use of pull production orders, as demonstrated on Table 5.22. Eight deliveries of material witnessed during the ten days of observations had clearly followed a direct order from the subcontractor and in the exact quantity required by the bricklayers. Cement, bricks and sand orders arrived on site exactly in the moment the storage reached minimum levels and always in small quantities (*Flow Efficiency = 0.06*). Consequently, this site had lesser handling due excessive storage and much better visibility than the other construction sites.

Pull orders of frequent and smaller deliveries were only possible because the contractor had a long-term relationship with the major suppliers. There was not much spare material flowing across the site and there were no delays in deliveries. Hence, in order to enable pull orders the company had simplified the procurement system. The bricklaying subcontractor had direct access to the supplier and could order material without having to fill any document. The practice of pull orders had also driven many improvements in the workflow, layout and communication within the bricklaying process.

Many of the practices witnessed in the flow of materials within bricklaying still resembled a push production mode. Figure 5.51 shows an example: a pile of bricks that had been cut by labourers in advance to the actual request from bricklayers. In other

words, this production was against expected demand and not against direct orders from downstream operations. Waste of material would certainly occur if any of the bricklayers changed the dimensions of bricks required for carrying out their operations.



Figure 5.51 - Theoretical Replication of *Change Push Order to Pull Order* (Case Study 6)

b.3) Case Study 3

All production activities observed on this site operated under a push production mode. Large quantities of material had been delivered previously to the data collection on site and bricklayers have never received direct requests from downstream operations (*Flow Efficiency = 0.03*). In this context, bricklayers found themselves having to transport material from long distances and improvise pathways across the storage. They declared never having discussed process problems with downstream or upstream operations or to receive any incentives from the site manager to do so.

b.4) Case Study 4

Analysis of the schedule revealed that bricklaying and other processes had short time buffers on this site. This factor had driven many improvements in the design of building and logistics of the organisations. Short buffers meant that any delays would have serious effects in attempts to keep a smooth and stable production workload across different projects. Nevertheless, the entire production system worked in push production mode and, thus, upstream operations never received orders from, or shared ideas with, downstream operations.

Managers, designers and suppliers polarised the responsibility for generating innovative ideas and developing solutions for production problems. However, they often overlooked process problems on the interface between bricklaying and other processes.

Yet, there was no attempt in collecting suggestions and promoting the participation of the workforce that had daily contact with those problems.

The only literal replication identified on this site was a small delivery of bricks that had been clearly pulled by a order from bricklayers. According to the bricklayers, this was a rare occasion since it only happened because the foreman forgot to order material in the appropriate occasion. The storage reached a critical level and bricklayers had to order another delivery in order to avoid possible interruptions in the workflow.

b.5) Case Study 5

The practice of large batches associated with poor communication in this construction site and absolute no mutual co-operation between bricklayers and downstream processes resulted on the push transfer of process problems between processes. For instance, both bricklayers and electricians had financial bonus relating to their individual performance. Hence, there was little interest in cross-process improvements because benefits would not be shared.

It became clear that the implementation of pull production on this site would face enormous barriers. The poor level of education, commitment and trust found among the workforce would impose enormous difficulties in establishing problem solving activities in the process interfaces. Furthermore, parts of the building could not be delivered regularly to downstream processes due to design and technological constraints. Thus, the intensive use of large buffers and push production mode was the safest route for the site manager.

b.6) Case Study 6

Large buffers, transfer batches and delivery batches that were observed in this site reflected the strong push production paradigm found among the workforce and managers. All thirty-five workstations observed were operating against schedules established at the beginning of the project, and not against orders from downstream processes. Thus, bricklayers had never received feedback from downstream operations regarding the quality of their products. Most problems were at the interfaces of bricklaying with other processes. These problems would only be recognised when bricklayers had completely finished their operations and left the construction site. The

foreman could act as an internal client in this respect but daily observations showed that his focus was almost exclusively on the achievement of bricklaying deadlines and not on bricklaying efficiency.

5.6.6.6 DISCUSSION

The main lessons from these case studies regarding the practice of pull production are, as follows:

i. Bricklayers hardly contacted downstream operations due to temporal and physical distances in their process, caused by process variability and large buffers schedule. Moreover, their participation in continuous improvement was severely affected by the short term relationships with the contractor and the lack of transparency regarding the benefits of such participation;

ii. Reduction of buffer size in push production schedules resembles some of the effects of pull production in terms of continuous improvement. Small buffers require reliable processes, better design, and more attention of managers towards the synchronisation between processes.

Short-term and cost oriented contractual relationships did not help the motivation of subcontractors to participate in improvement activities with other professionals. Even in the case studies where bricklayers worked as employees, the situation was similar since the bonus systems only rewarded the performance of each process. Highly demarcated professional responsibilities resulted in disconnection and friction between upstream and downstream processes. Hence, higher performance in bricklaying occurred to the detriment of the performance on the overall production system.

In this context, the challenge in construction is to find ways for upstream workers to be involved and become more interested in helping downstream workers and vice-versa. The physical and temporal distances between professionals demands the development of alternative communication channels between downstream and upstream operations. Consistent leadership of managers and long-term views of process improvement is necessary to achieve these objectives. Construction managers should see bricklaying as a process crossing various projects and not as another input for accomplishing a particular project.

Monden (1998) and other have shown that pull production drives continuous improvement in production because it puts upstream and downstream operations much closer and, at the same time, restricts the amount of resources available. Critical analysis of the cases studied suggests that the achievement of reliable push production orders could be an alternative strategy for reaching pull production in construction. Reducing buffer sizes and the variability of processes, within a push production mode, could create the basic conditions for implementing pull orders.

5.6.6.7 CONCLUSION

The "literal replications" identified in the case studies suggests that this approach is applicable in the construction environment. Yet, driving improvements in production by promoting pull production orders is still an unknown approach in most of the construction sites analysed. Even the best case study in this matter did not present this practice as part of a planned attempt to expose the existing problems and drive actions on improvement possibilities. With little planning and synergy between process owners, the clear result was a great volume of improvisations and missed opportunity for improving production interfaces.

5.6.7 CONCLUDING REMARKS

The amount of continuous improvement practices observed in the case studies was considerably small in comparison with the cases reported in the literature, particularly in the manufacturing industry. More striking was the lack of participation of workers in problem solving activities and the little use of systematic data collection for identifying the root cause of problems. Because continuous improvement is a central principle to the successful implementation of all the other principles, this deficiency certainly had great impact in the achievement of overall better practices.

The *deliberate and progressive reduction of resources available* emerged from the analysis of the case studies and current literature as a general strategy for driving continuous improvement in production. When resources such as time, space, materials and components, workforce time and equipment are deliberately reduced from the production system and proper managerial support is given, people naturally find improvements to enable the progression of the work. Indeed, the restriction of resources

was the environment where the Toyota Production System initiated in Japan post-war and it is the environment where construction companies operate nowadays.

5.7 DISCUSSION

A large proportion of the practices observed in the case studies reflected the intense application of the "conversion model", as opposed to the "flow model". The management of production using the conversion model seemed to demand less effort from managers since they could focus solely on inputs and outputs. When construction is viewed as a flow, many more process problems, that were considered unimportant before, then became the focus for obtaining higher production performance. For instance, the great volume of information handled in the flow model demands more attention to simplification of procedures and development of visual devices.

Although some managers and workers seemed to understand the implications of the "flow model", their actions concentrated mainly on keeping the processing activities in pace with the project deadlines. The lack of information regarding the actual cost and time spent on moving and waiting activities certainly influenced their behaviour in this respect. Short-term and adversarial relationships between production stakeholders contributed to the persistence of wasteful practices. In such an environment, managers tried to use innovative solutions in technology as a short cut to improving production performance and avoiding recurrent problems. These factors need to be addressed if the flow model is to permeate in the construction sector.

Finally, the personnel interviewed did not seem to understand the clear distinction between process and operations as defined by Shingo (1988). Indeed, many of the decisions observed in the case studies revealed, for instance, that managers did not distinguish between improving transport and improving the means of transport. The focus of construction managers in operations, rather than in process, is reinforced by other studies of construction. The case studies analysed by Tatum & Nam (1992), for instance, presented more situations of *technology-guides-problem* than situations of *problem-leads-solution*. More research is required in order to understand how to change this paradigm in construction.

5.8 SUMMARY

This chapter presents an analysis of each individual heuristics presented in Chapter 3 according to the empirical evidence of the six case study and meta-case. The analysis followed through a standard structure that started with the presentation of a working definition, observational focus and key indicators used in the pattern-matching analysis. Subsequently, it summarised the main findings and showed the situation observed in each case study regarding each heuristics. The conclusions focused on the degree of similarity between the theoretical propositions and the empirical evidence.Time, particularly the avoidance of delays, was among the main preoccupation of construction managers in all case studies. However, the researcher observed very few literal replications of the heuristic implementation approaches. Observations revealed the conversion paradigm was heavily present on the managerial decisions since their main focus was on inputs and outputs. The principal aim of construction managers was to accomplish the design specifications, under the right budget and schedule specified rather than challenging them with ideas and questions for more efficient and faster practices.

The empirical evidence indicated that all three approaches aimed at reducing variability presented in this thesis are applicable in the construction environment. However, the six main case studies offered just a few literal replications and complementary evidence had to be used from the meta-case. The segmented division of responsibilities and bonus system resulted in a culture of cumulative re-pass of process variability from upstream operations to downstream operations. The case studies and meta-case supplied evidence that indicate the validity of the principle of transparency in the construction sector. Nevertheless, comparison of the case studies with the examples described in the literature reveals that construction applies the transparency principle in considerably less intensity than in manufacturing. Likewise, the amount of continuous improvement practices was considerably small in comparison with the cases reported in the literature, particularly in comparison with the best examples of the manufacturing industry. Because continuous improvement is a central principle to the successful implementation of all the other principles, this deficiency certainly had great impact in the achievement of overall better practices.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter 6

INTRA CASE STUDY ANALYSIS

We learn wisdom from failure much more than success.
Samuel Smile

6.1 OVERVIEW

Chapter 5 analysed each heuristic implementation approach individually against empirical evidence extracted from the six case studies and meta-case. The assessment of empirical evidence was carried out using a "pattern matching" approach and the support of quantitative criteria and key examples from practice. That analysis attempted to establish what Yin (1989) calls "*analytic generalisation*" instead of "statistical generalisation". This analytic generalisation used the previously developed theoretical framework as a template or benchmark against which empirical results were compared.

This chapter uses the same empirical evidence analysed in Chapter 5 but now focuses on the **inter-relationships** among the heuristic implementation approaches. Hence, it re-visits groups of inter-connected evidence in order to illuminate the discussion further by looking for integration as opposed to individual replication. It concludes by investigating the correlation between the overall case study performance and the corresponding level of integrated "literal replications". Hence, this chapter explores the second question stated on Chapter 1: *what is the extent to which construction integrates the production flow principles in practice?*

6.2 EXPECTED PATTERN OF INTER-RELATIONSHIPS

The comprehensive integration of the flow principles is an extremely important factor in achieving the full benefit of their implementation in practice. According to Monden's (1998) descriptions, the simultaneous and coherent application of the production management principles is a fundamental factor in explaining the high level of production performance at Toyota. Hence, the principles 'increase of transparency', 'reduction of variability', 'reduction of cycle time' and 'continuous improvement' must interact in construction practice to maximise performance. Ideally, applying one principle should automatically trigger the application of other principles and vice-versa, rather than this being seen as following a trade-off paradigm.

'*Reduction of variability*', for instance, is fundamental for enabling implementation of the heuristic approaches aimed at '*reducing cycle time*', such as the reduction of batch size and the reduction of work-in-progress. Production in small batches demands a high level of predictability from production processes, and any variations can bring the entire production system to a halt. On the other hand, the control over the sources of variations in the production processes is time consuming when there are no visual controls in place. Likewise, the effective implementation of visual controls and other heuristic approaches aimed at 'increasing transparency' depends on the existence *of* '*continuous improvement*' activity.

The construction case studies analysed in this research should therefore ideally portray systemic integration of all principles and corresponding heuristic implementation approaches in practice. Figure 6.1 shows the graphical representation of an ideal situation where there is total integration among the heuristic implementation approaches.

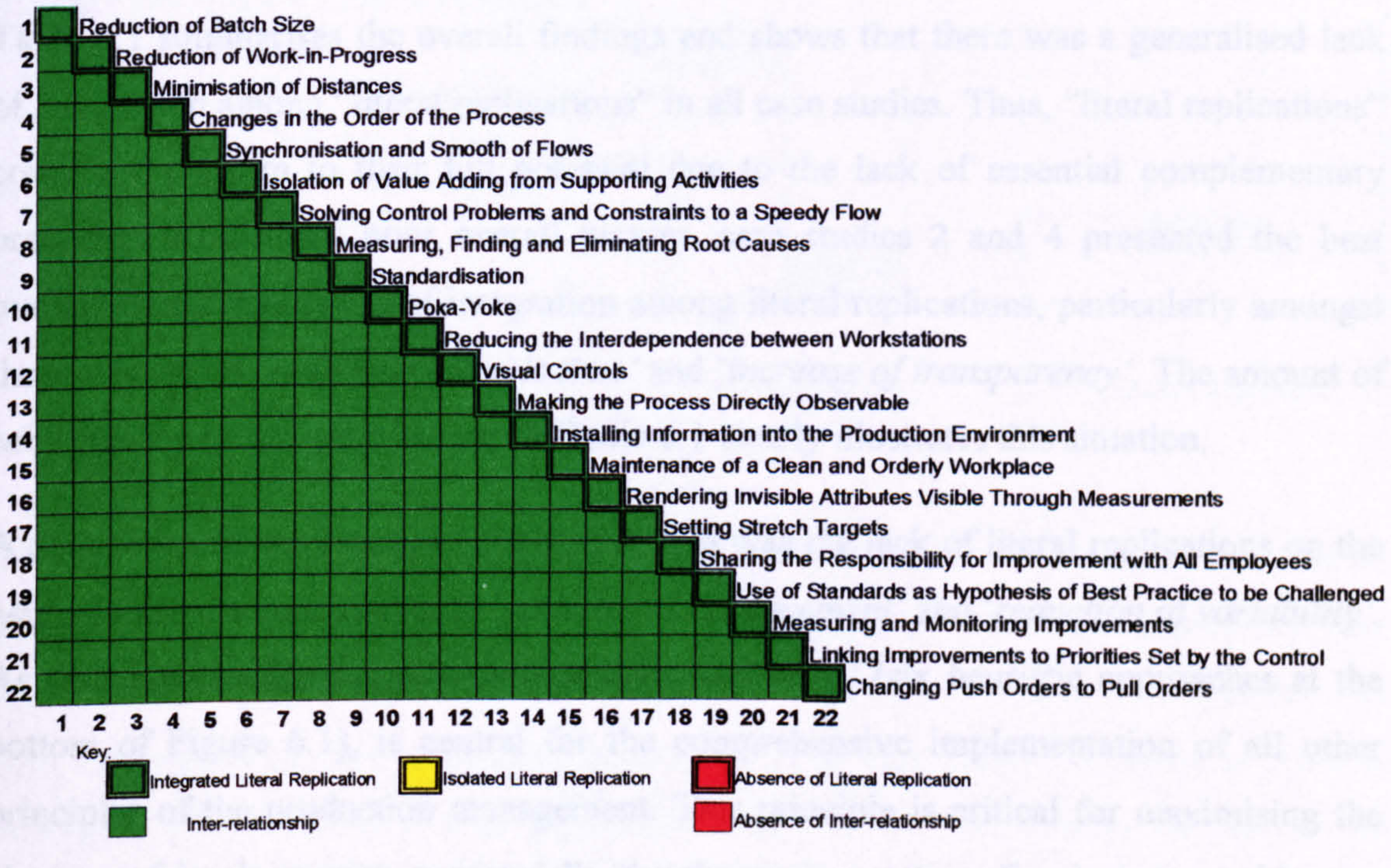


Figure 6.1 – Expected Inter-relationships among the Implementation Approaches

The green colour in Figure 6.1 represents individual "literal replications" which seen together in this way show diagrammatically the ideal level or integration among heuristic implementation approaches. The red colour represents a lack of literal

replication of a particular implementation approach, or the lack of integration among implementation approaches. A yellow cell represents an isolated literal replication (the conventions will be used in the following sections for representing the diagnosis of each case study regarding integration of heuristics).

The intra-case study analysis presented in the next section tries not repeating the same descriptions of empirical evidence presented in Chapter 5. Rather, it concentrates on the analysis itself. However, in order to illustrate the findings, it has to revisit groups of key inter-related facts that had significant effect on the bricklaying performance of each case study.

6.3 INTER-RELATIONSHIPS OBSERVED IN PRACTICE

6.3.1 SUMMARY OF FINDINGS

Table 6.1 summarises the overall findings and shows that there was a generalised lack of integration among "literal replications" in all case studies. Thus, "literal replications" could not perform to their full potential due to the lack of essential complementary practices. Within this poor overall picture, case studies 2 and 4 presented the best overall situation in terms of integration among literal replications, particularly amongst those relating to '*reduction of cycle time*' and '*increase of transparency*'. The amount of cells presenting the green colour on Table 6.1 clearly illustrates this situation.

A common problem across all six case studies was the lack of literal replications on the heuristic approaches relating to '*continuous improvement*' and '*reduction of variability*'. As discussed in Chapter 5, '*continuous improvement*' (six heuristic approaches at the bottom of Figure 6.1), is central for the comprehensive implementation of all other principles of the production management. This principle is critical for maximising the chances of implementing successfully the theory in practice. For instance, without a '*continuous improvement*' attitude it is difficult, if not impossible, to see the full implementation of the principle '*reduction of variability*'. Furthermore, standardisation and the systematic solution of process problems can only be operated successfully if there is full involvement of the workforce in its implementation.

Table 6.1 - Literal Replications identified across the Cases

INDICATOR	CASE 1	2	3	4	5	6
REDUCTION OF CYCLE TIME						
Reduction of Batch Size						
Reduction of Work-in-Progress						
Minimisation of Distances						
Change in the order of the process						
Synchronisation and Smooth of Flows						
Isolation of Value Add from Support Activities						
Solving Control and Constraint Problems						
REDUCTION OF VARIABILITY						
Measuring, Finding and Eliminating Problems						
Standardisation						
Poka-Yoke						
INCREASE OF TRANSPARENCY						
Reduction of Interdependence						
Number of Visual Controls						
Making the Process Directly Observed						
Installing Information into the Workplace						
Maintenance of Clean and Orderly Workplace						
Rendering Invisible Attributes into Visible						
BUILD CONTINUOUS IMPROVEMENT						
Setting Stretch Targets						
Sharing the Responsibility for Improvements						
Using Standards to Challenge Practices						
Measuring and Monitoring Improvements						
Linking Improvements to Control						
Change Push Orders to Pull Orders						

Key:

Integrated Literal Replication Isolated Literal Replication Theoretical Replication

Koskela (1993) alerts to the fact that a lack of attention to flow principles can lead to uncertain and complexity in processes, an expansion of non value-adding activities, and a reduction of output values for construction. It is possible to infer from this that the poor integration of flow principles observed in the case studies is likely to have a damaging effect on the overall production performance. This thesis did not set to directly measure such effect on performance, but it became clear to the researcher throughout this thesis that in nearly all cases performance was markedly affected by poor integration.

6.3.2 CASE STUDY 1

6.3.2.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

This case study revealed only a few "literal replications" and none of them had a satisfactory level of integration. The analysis presented in Chapter 5 showed that half of these literal replications did not interact with other basic complementary practices. Figure 6.2 illustrates the general assessment in a graphical form.

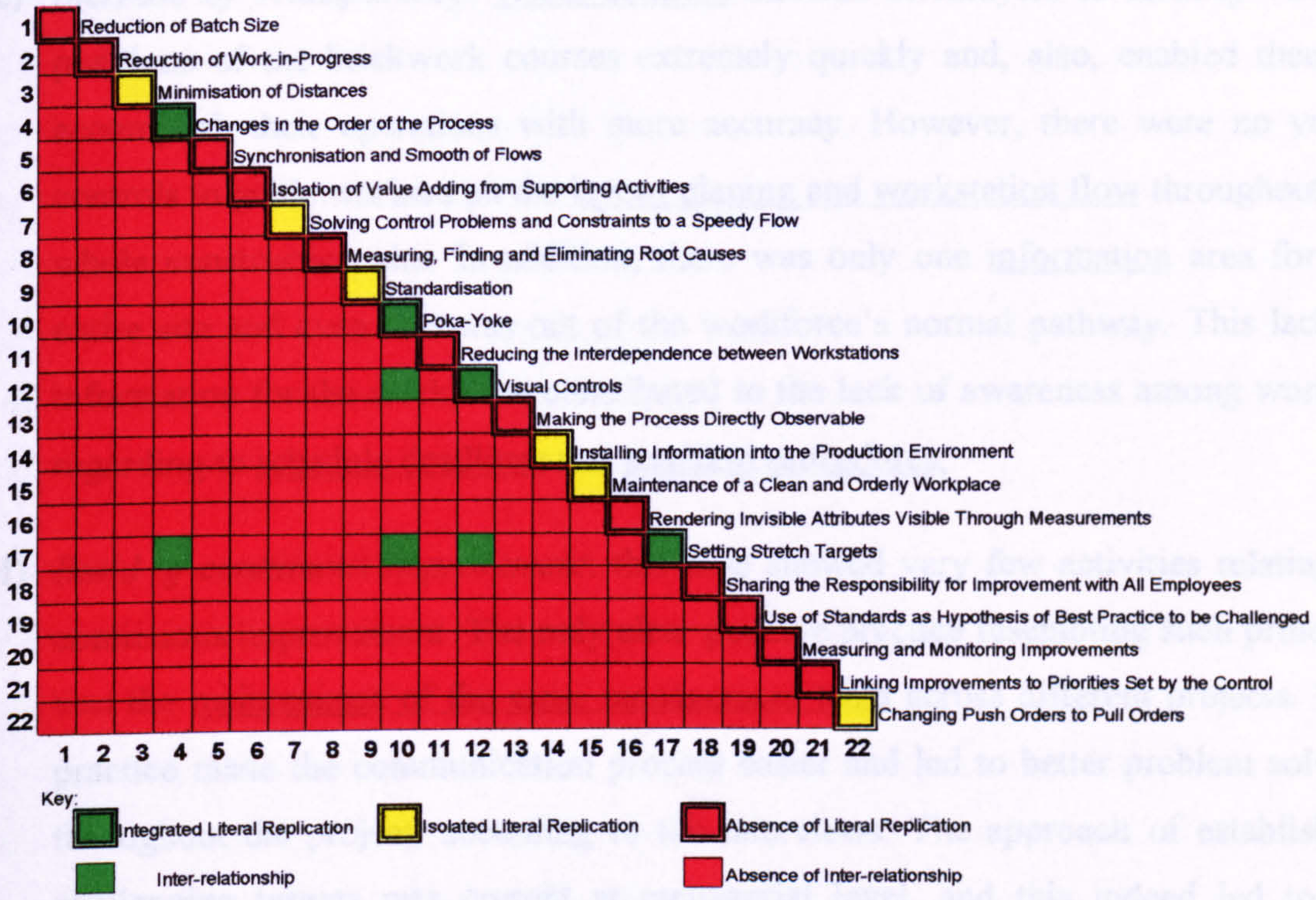


Figure 6.2 – Integration of Heuristic Implementation Approaches in Case Study 1

The following items illustrate the status of integration of practices observed in this case study:

a) *Reduction of Cycle Time*: the lack of planning and co-ordination of flow among workstations resulted in an increase in transportation distances. This was because there were too many fronts of work operating at the same time, and these were spread in a large area in comparison with the number of bricklayers available. The high volume of work-in-progress added further complexity, reducing synchronisation between suppliers and the workstations. This situation contributed to an increase in the amount of time spent on non-value adding activities.

b) *Reduction of Variability*: this company undertook no activity to find and eliminate the root cause of process problems during the period observed. The only poka-yoke device identified was a safety mechanism attached to transporting equipment. This safety mechanism produced a sound that alerted every time the equipment moved backwards. However, it had little impact on the actual reduction of variability since it had no direct effect on the main process problems and had been imposed from outside the site manager's control.

c) *Increase of Transparency*: visual controls allowed bricklayers to identify vertical positions of the brickwork courses extremely quickly and, also, enabled them to accomplish their operations with more accuracy. However, there were no visual controls to guide workers on the layout planing and workstation flow throughout the whole construction site. In addition, there was only one information area for the entire site and even that was out of the workforce's normal pathway. This lack of information for the workplace contributed to the lack of awareness among workers regarding to schedule deadlines and standard procedures;

d) *Build of continuous improvement*: this case showed very few activities relating to continuous improvement. The only clear positive practice resembling such principle was the maintenance of the same management team across different projects. This practice made the communication process easier and led to better problem solving throughout the project, according to the interviews. The approach of establishing challenging targets was present at managerial level, and this indeed led to the generation of various innovative ideas at the project level, such as the change in the order between foundations and the steel structure.

6.3.2.2 DISCUSSION

The poor level of integration in this case clearly also hampered the effectiveness of the literal replications in contributing to better production performance. In particular, the lack of continuous improvement activities seemed to be a central reason for explaining the deficient application of all other principles. Imai (1997) argues that *kaizen* activities are one of the fundamental practices for reducing *muda* (waste) from production. Hence, this was one of the main reasons for the sub-optimal performance of the bricklaying process.

During open-ended interviews and discussions with workers and managers, it became evident that they understood the negative implications of having a production system with poor integration of practices. However, it was not possible to identify if they were fully aware of such problem prior to the researcher's questions. Notwithstanding this, their views revealed a great tolerance to poor and ineffective levels of practice. They also all expressed a clear resentment to their own lack of personal power for dealing with wider structural and cultural problems that affected their daily life.

Everyday observations on the site also revealed that this company relied heavily on sophisticated design solutions and on the intensive use of modern equipment and materials as the means of guaranteeing their objectives with respect to cost, delivery, quality and flexibility. However, the actions of managers revealed little concern with the potential gain achievable through the elimination of non value-adding activities from production. In this respect, there was severe scepticism among the managers on this site with respect to the early involvement of subcontractors and their employees in continuous improvement activities.

The short-term basis of the relationship with subcontractors and the bonus system itself were also often pointed out as the major barrier for improving practices. Indeed, the contracting system itself did not favour the establishment of long term relationships between subcontractor and contractor, since low price was the main winning criteria in the bidding process. Thus, as long as the subcontractor finished the job on time, under the budget and to the specified quality, there were no efforts from the contractor to push the process performance toward even higher levels.

6.3.3 CASE STUDY 2

6.3.3.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

This case study presented the highest number of integrated literal replications among the case studies. In particular, the most significant amount of integrated literal replications occurred between the principles *"reduction of cycle time"* and *"increase of transparency"*, as Figure 6.3 shows. Partnership with suppliers, good dialog and co-operation between managers and bricklayers together with a constant attention to

workflow in this respect were the main features of this site that enabled the application of these principles.

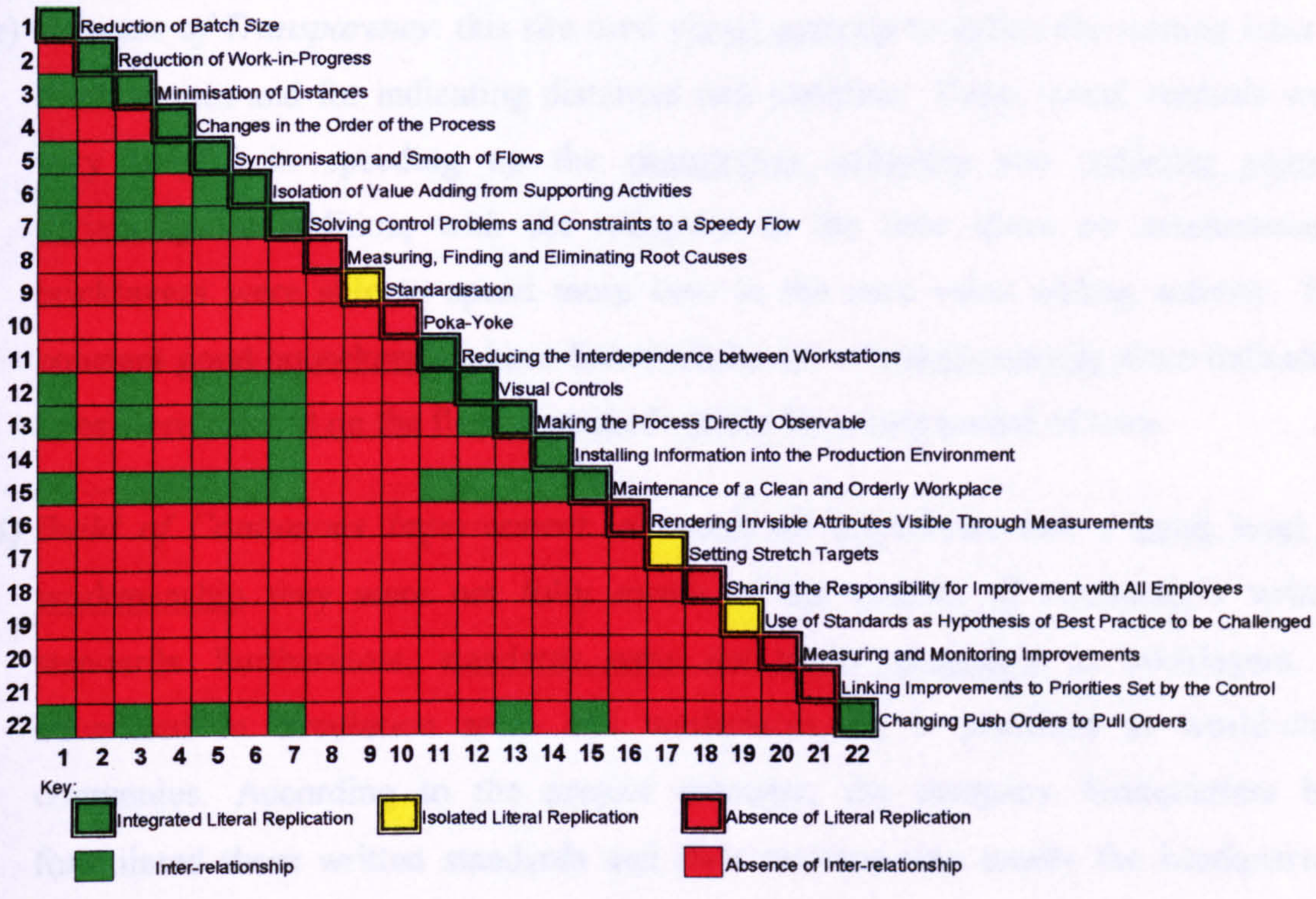


Figure 6.3 - Integration of Heuristic Implementation Approaches in Case Study 2

The following descriptions represent the most significant practices and characteristics observed in this construction site:

a) *Reduction of Cycle Time*: the restrictions of space imposed by the hospital administration on this site forced the reduction of delivery batches of all materials. This restriction also demanded more attention of subcontractors to their workflow and to the maintenance of clean and tidy storage area. As a result, transportation was more efficient and there was better visibility of the process status. The need for small batches drove better relationships between suppliers and contractors since adjustments to delivery orders had to be quickly operated;

b) *Reduction of Variability*: this site relied heavily on the supervisor's motivation and willingness to solve the flow problems. The workforce did not participate in the decision making with respect to process improvement and there were no systematic activities related to measurement, identification and elimination of process problems.

Consequently, although this site presented a good flow performance, there were no process improvement activities in bricklaying during the entire construction project;

c) *Increase of Transparency*: this site used visual controls to define the starting lines of brickcourses and for indicating distances and positions. These visual controls were very helpful in speeding up the changeover activities and reducing process variability. In addition, with the reduction in the time spent on measurements bricklayers were able to spend more time in the core value adding activity. The constant good housekeeping have favoured the use of visual controls since indicative lines were painted on the floor remained visible for a long period of time.

d) *Build of Continuous Improvement*: although all bricklayers had a good level of workmanship they were not fully aware of the content of contractor's written standards. Furthermore, standards were not easily accessible to bricklayers, or advertised in circulation areas and workplaces, as is practised in world-class companies. According to the project manager, the company headquarters had formulated these written standards and their revision was totally the headquarters responsibility.

6.3.3.2 DISCUSSION

This case study presented the largest number of practices matching the heuristic implementation approaches among the case studies. These "literal replications" were well integrated, particularly on the principle '*reduction of cycle time*' and '*increase of transparency*'. Transparency was clearly a supporting principle and played an important role in reducing the need for measurements and enabling rapid recognition of locations. Certainly, reduction of cycle time could occur without process transparency, but with the support of this principle it became much easier to see the operation of flows and processing activities.

However, there was great lack of integration among other complementary heuristics, particularly among those related to continuous improvement. There was no habit on the site of systematically measuring, identifying and eliminating the root causes of variability. Also, there were no instruments in place to motivate the workforce and managers to attempt changing this situation. The poor link between the reduction of

batch size and continuous improvement was a clear example in this respect. Shingo (1989) suggests that reducing batch sizes can promote continuous improvement activities. However, observations in this case study revealed that small batches were not producing that effect since the site manager was merely following the restrictions of space imposed by the hospital administration. Indeed, analysis of the archival records of this company revealed no deliberate attempts in reducing batch sizes even further in order to enhance performance improvements.

There were some characteristics of teamwork between bricklayers and supervisor but, again, teamwork was not used in any instance for contributing to actual process improvement. Like in Case Study 1, the contractual base of the relationship between the subcontractor and the contractor was the main barrier for promoting and sharing the benefits of continuous improvement. Also, open-ended interviews with managers revealed there were no instruments for sharing production experiences across the company. Thus, there was great waste of best practice "know-how" and little discussion of alternative bricklaying processes.

6.3.4 CASE STUDY 3

6.3.4.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

This case study presented a small amount of literal replications but almost no integration among them, as Figure 6.4 illustrates. It is worth noticing that this company used similar materials and equipment as those used in Case Study 2, but did not presented the same level of performance. The most significant absence of "literal replications" and integration happened between the principle *'reduction of cycle time'* and *'build of continuous improvement'*. Daily observations on site showed that the reduction of cycle time in the bricklaying process required solutions that failed to occur because there was no dialog and trust between management and workforce.

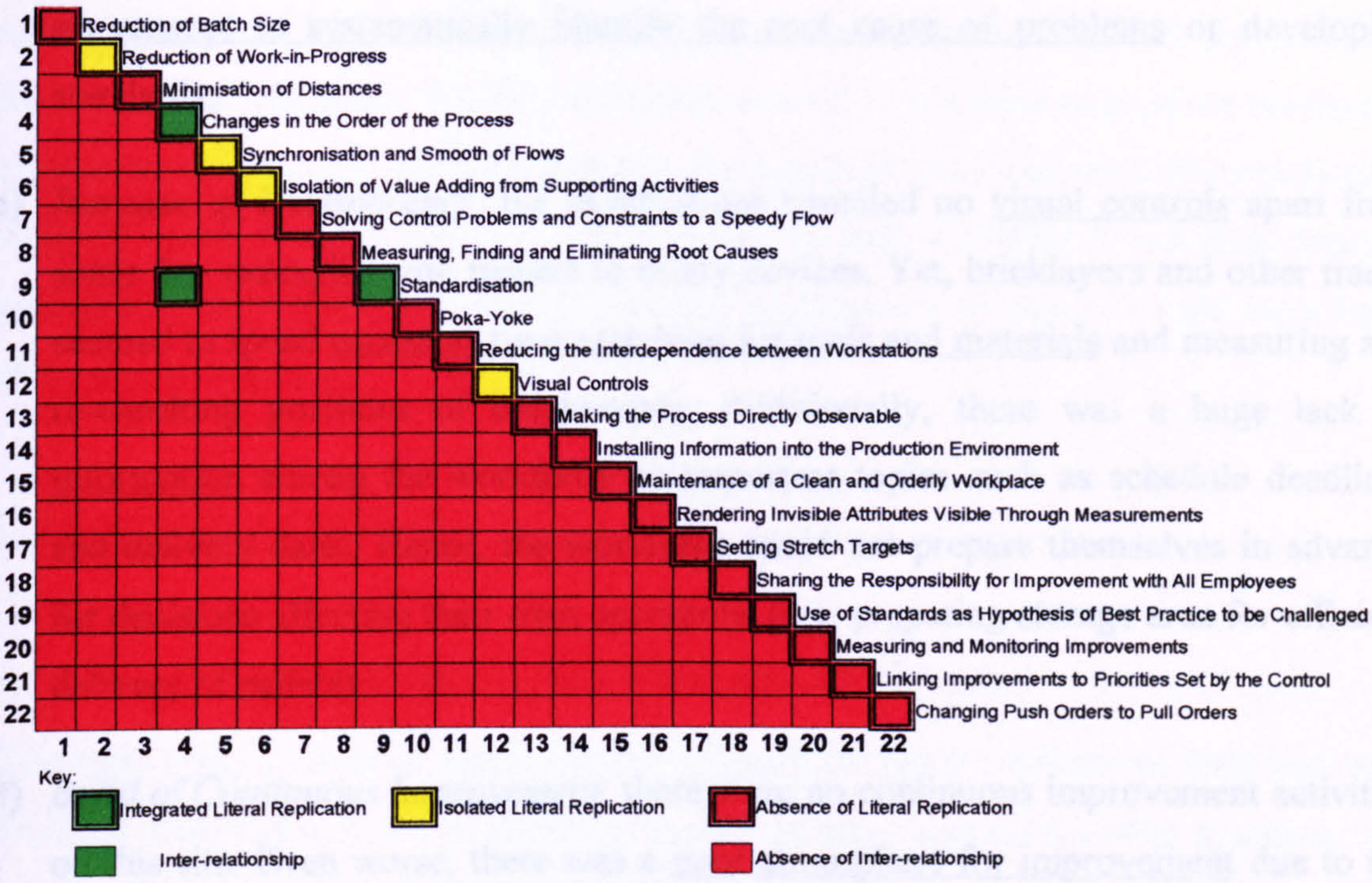


Figure 6.4 - Integration of Heuristic Implementation Approaches in Case Study 3

The following descriptions represent the most significant practices and characteristics observed in this construction site:

a) *Reduction of Cycle Time*: the practice of delivering large batches strongly affected the performance of transportation activities since it increased the need for a larger storage area. Large delivery batches made the process of ordering blocks much simpler but considerably increased the distances between storage and workplace. The poor state of pathways throughout this site caused by rain and circulation of heavy trucks, contributed to worsen transportation from storage to workplace. This situation was incompatible with the large volume of work-in-progress observed during the data collection;

b) *Reduction of Variability*: despite the high quality of materials delivered onto this site there was a high level of process variability caused by poor workflow planning. Large batches of materials delivered to site and large transfer batches were the main sources of process variation. This produced extremely negative effects on the productivity of bricklayers. Excessive transportation distances reduced the level of support the labourer could give to bricklayers. Despite of this situation, there were

no attempt to systematically identify the root cause of problems or developing standards;

c) *Increase of Transparency*: the observations revealed no visual controls apart from some few examples with respect to safety devices. Yet, bricklayers and other trades seemed to spend excessive time searching for tools and materials and measuring and re-checking positions of components. Additionally, there was a huge lack of information among the workforce on important topics such as schedule deadlines and delivery dates. Hence, the workforce could not prepare themselves in advance for decisions affecting their own operations (e.g. preparing storage area for efficient delivery of pallets).

d) *Build of Continuous Improvement*: there were no continuous improvement activities on this site. Even worse, there was a poor atmosphere for improvement due to the bad relationship between the construction manager and the workforce. According to the bricklayers and the researcher's own findings, as long as they finished the job on time and to budget, the contractor would not be concerned with investigating alternatives for reducing waste. In this environment of mistrust, and poor dialogue, it was no surprising to find no problem solving activities.

6.3.4.2 DISCUSSION

This case study presented empirical evidence matching few of the heuristics under investigation and almost no inter-relationships among them. This lack of integration among "literal replications" resulted in a production system operating under sub-optimal levels of performance, according to various indicators such as waste, productivity and work sampling. Theoretical replications such as large volume of work-in-progress, associated with large delivery batches, affected the running of the entire production system. Indeed, the construction of two building simultaneously resulted in constant crossing of flows from different directions, usually involving long transportation distances.

The decision to start two buildings at the same time came as a result of early availability of financial resources, rather than the desire for efficient production. This over reliance on commercial and financial gains, and the lack of awareness on the cost of non-value

adding activities, was a fundamental barrier for changing managerial practices and thinking in this company. The data collected showed no attempts to promote continuous improvement activities whatsoever on the site and there were also very few practices of trying to make existing flows more transparent. In such a context it was clear that any attempts to apply other important production management principles would have had a slim chance of success.

6.3.5 CASE STUDY 4

6.3.5.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

This case study presented a much larger quantity of literal replications than had been found in case studies 1 and 3. However, there was less integration among practices than witnessed in Case Study 2. Figure 6.5 illustrates that the main focus on this case study was clearly on the approaches aimed at *reducing cycle time*.

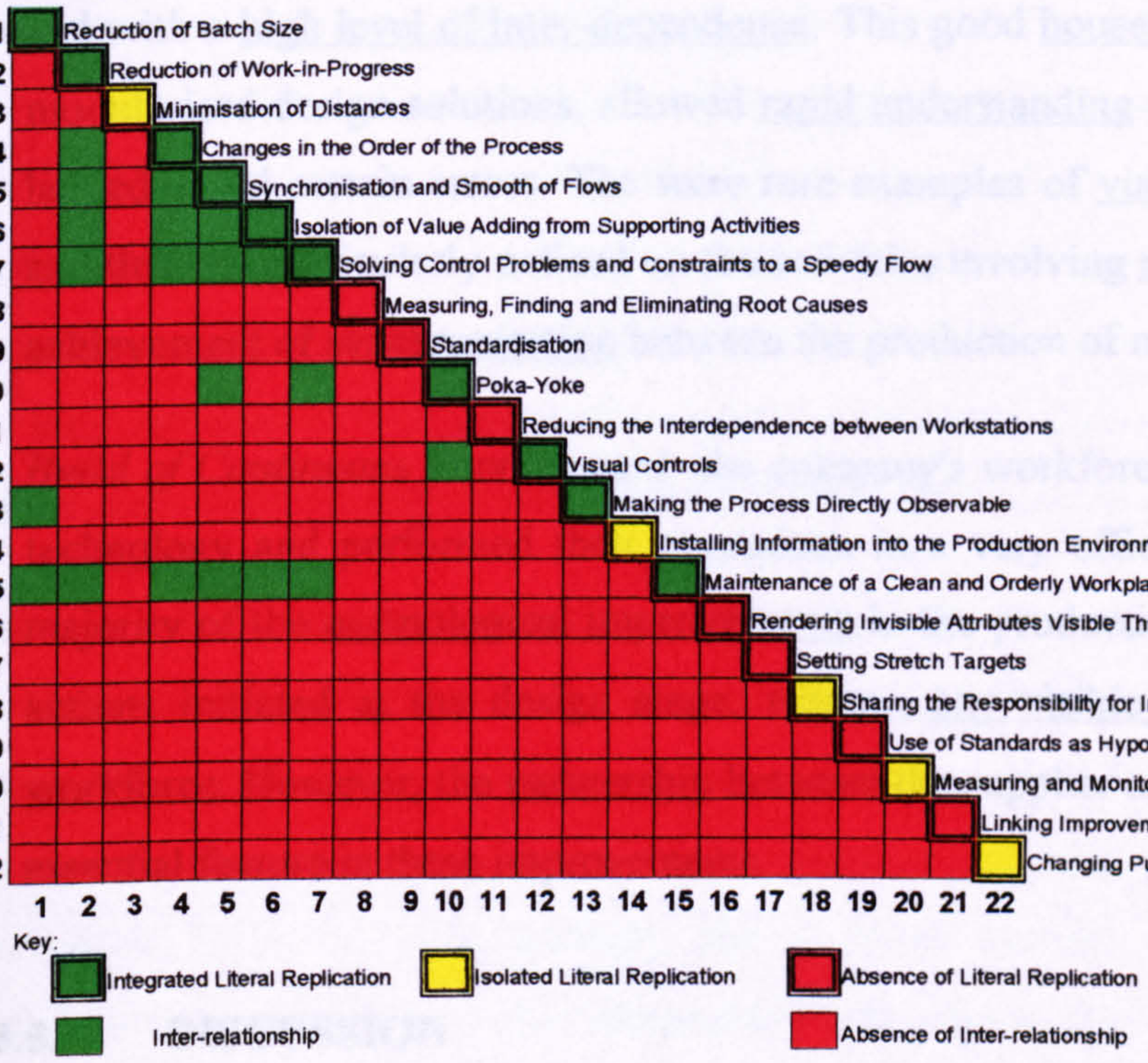


Figure 6.5 - Integration of Heuristic Implementation Approaches in Case Study 4

The following descriptions represent the most significant practices and characteristics observed in this construction site:

a) *Reduction of Cycle Time*: the bricklaying activity was carried out in parallel with the electrical fittings. This practice reduced future rework and increased the value added by the bricklayer himself. Bricklaying and electrical operations had to be absolutely synchronised and smooth, otherwise the productivity of both trades would have been low and, consequently, their salary;

a) *Reduction of Variability*: this case study showed a fairly standard practice among bricklayers, although there were no written standards available. The workforce had mastered the technology mainly because of the repeatability of design details. Indeed, the bricklayers were very skilful at avoiding unnecessary cuttings of blocks. However, they carried out no activities related to measuring, finding and eliminating root causes of problems. Neither did they got involved in a process for developing standard procedures;

a) *Increase of Transparency*: most workplaces on this site were kept clean and tidy although both electrical and bricklaying activities were carried out simultaneously and with a high level of inter-dependence. This good housekeeping, associated with modularised design solutions, allowed rapid understanding of production status and helped avoid certain errors. The were rare examples of visual controls on this site and this was particularly noticed on the activities involving measurement, and on the achievement of synchronisation between the production of mortar and bricklaying;

a) *Build of Continuous Improvement*: the company's workforce had mastered the new technology and performed their operations in a very efficient way. However the majority of the technological improvements in the production system resulted from actions initiated at the design stage, without any visible contributions from the workforce. However, the partnership between the supplier and the contractor was an essential feature in these improvements.

6.3.5.2 DISCUSSION

This site presented a better level of practice in comparison to most other cases studied. However, the observations of practices revealed that the production process still had large potential for achieving even higher levels of practice. Despite sub-optimal

operation of the bricklaying process this company was able to remain competitive, and even receive awards for its technical excellence.

The observation of their site suggests that the implementation of a few, but well focused set of heuristic implementation approaches were enough to guarantee competitive advantage over competitors. It supports Skinner's (1992) proposition that a company should focus their production strategy in one or two competitive criteria. In this particular case, key practices were standardisation and simplified design details that resulted in low variability in the bricklaying process. Reduction of variability is important because reliability of delivery and cost become the main competitive focus of this company. Notwithstanding this, the researcher believes that the careful inclusion of other heuristic implementation approaches in the practice of this company would expand their competitiveness even further since they reinforce each other.

Despite the lack of workforce participation in continuous improvement activities, it became clear, throughout the data collection, that there was a significant flow of ideas and improvements derived from decisions taken outside the construction site. This flow of ideas and actions came mostly from the middle and top management levels but also involved a growing number of partnerships with suppliers and designers. The brick supplier, for instance, had an essential, and active, role in the development of the new masonry system and its subsequent implementation. Nevertheless, as in Case Study 1, the total reliance on technological and design solutions ignored the potential for even higher gains in performance coming from small improvements in production flows.

The data collection and the resulting analysis of practices in this case study showed that the detection of process problems in a relatively stable construction process could be extremely complex. Indeed, many of the problems identified in this case study would remain invisible without a systematic data collection and subsequent discussion with the workforce. However, it is unlikely that a direct implementation of a systematic monitoring would work in this construction site, since the workers did not have a sufficient formal education to understand the logic of statistical inquiry. In addition, there was no organisational structure and support for implementing, and maintaining, a continuous improvement activity. The full implementation of the theory in this case would only be possible with major changes in these two aspects.

6.3.6 CASE STUDY 5

6.3.6.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

Like Case Study 3, this case study presented few literal replications and almost no integration among them. Figure 6.6 shows that there was some concentration on the heuristics relating to the principle of '*increasing transparency*'. However, most the "literal replications" on transparency directed to safety had little influence on the actual process performance.

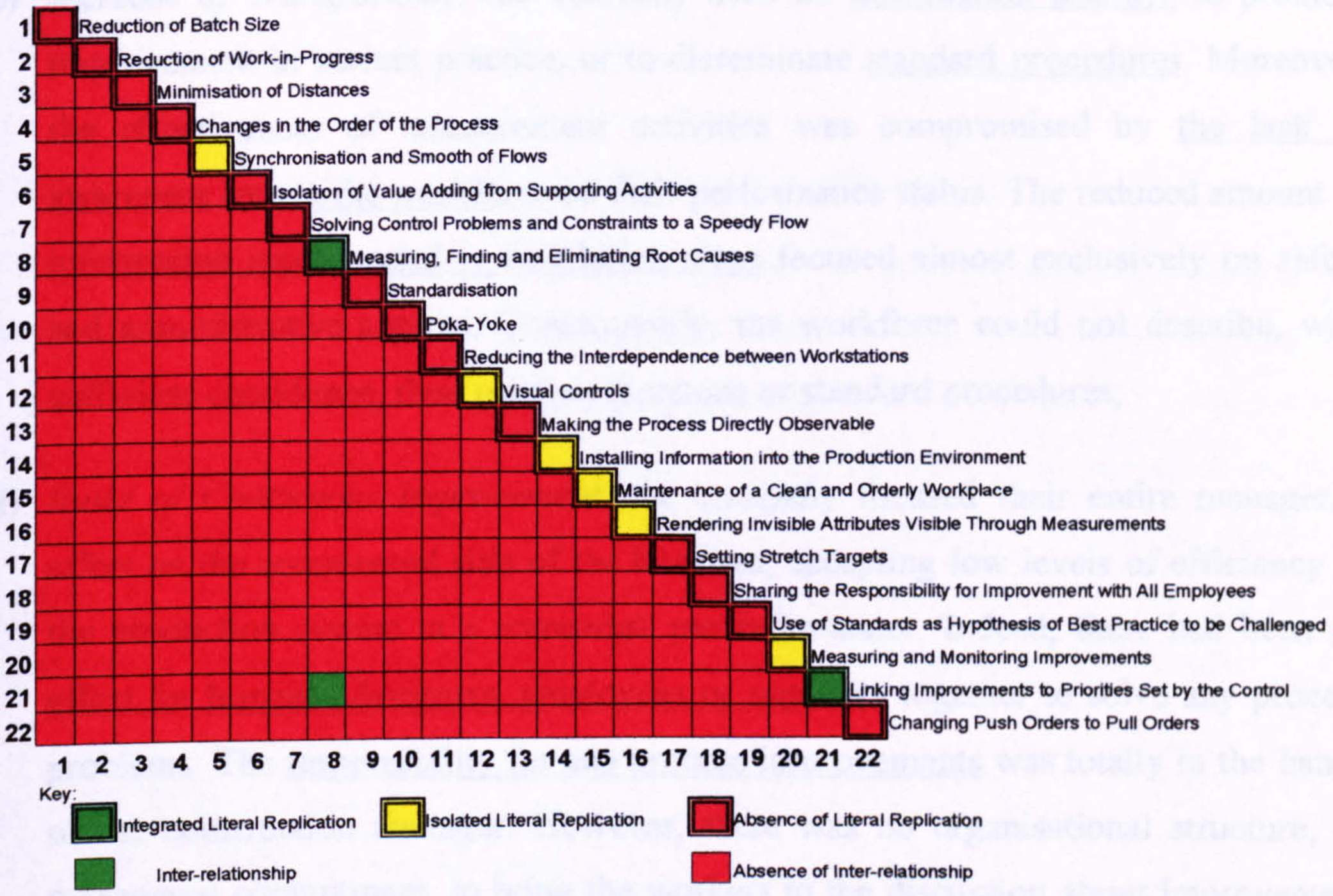


Figure 6.6 - Integration of Implementation Approaches in Case Study 5

The following descriptions represent the most significant practices and characteristics observed in this construction site:

a) *Reduction of Cycle Time*: bricklaying had an excessive number of process stages due to the poor compatibility between the transportation equipment and the packing system. The delivery of materials in large batches also led to an increase in the number of transportation stages. The use of large piles of bricks compromised site safety and often affected the efficiency of other construction flows;

b) *Reduction of Variability*: the practice of waste measurement witnessed on this site could lead to the identification and quantification of the principal roots of process problems. Nevertheless, the daily actions and decisions observed on this site were often only contingent, and based solely on 'practical experience', rather than factual evidence. The decision of managers to change the brick specification, during the construction project, for instance, was taken without proper assessment of the consequences in terms of waste and workflow. This amplified the negative effects of high variability present in the work on the concrete structure, mortar and bricks;

c) *Increase of Transparency*: the company used no information displays to promote improvement in current practice, or to disseminate standard procedures. Moreover, the effectiveness of measurement activities was compromised by the lack of awareness among the workforce on their performance status. The reduced amount of information incorporated in circulation areas focused almost exclusively on safety and administrative aspects. Consequently, the workforce could not describe, with sufficient confidence, their own performance or standard procedures;

d) *Build of Continuous Improvement*: the company focused their entire managerial effort on the commercial side of the business, accepting low levels of efficiency in the production system in a somewhat passive manner. Indeed, there had been no effort for bringing designers, employees or suppliers together to solve any process problems. The responsibility for any process improvements was totally in the hands of the construction manager. However, there was no organisational structure, or managerial commitment, to bring the workers in the discussion about improvement priorities.

6.3.6.2 DISCUSSION

This site presented a generalised lack of replication in the majority of heuristic approaches and inter-relationships investigated in this thesis. The prospect of improving practices was likely to be difficult since there was no desire to involve of the workforce in any aspect of continuous improvement. Moreover, poor literacy records of site operators made it even harder to expect their involvement in formal data collection and analytical techniques. Improvements in the performance of production in this company would necessarily involve efforts in the basic education of the workforce.

There was clearly a lack of knowledge among managers and workforce regarding the principles in this study or alternative practices within bricklaying. Daily conversations on site revealed that the theory of production management and the examples from practice worked better when presented concomitantly. The presentation of examples of the principles using illustrations from real construction sites helped site operators by convincing them on the applicability of the theory. It is possible to speculate that once people understand the abstract meanings of the principles described in this thesis, they would be able of transcend their interpretations to other settings.

6.3.7 CASE STUDY 6

6.3.7.1 SUMMARY OF MAIN INTER-RELATIONSHIPS

This construction site presented the same pattern of poor integration among literal replications identified in Case Study 1, 3, and 5. However, it is worth emphasising that the design and technology on this site were quite similar to Case Study 4. There was a fairly distribution of the "literal replications" among the principles 'reduction of cycle time', 'reduction of variability' and 'increase of transparency'. However, there was almost no "literal replication" on continuous improvement and that was one of the fundamental reasons for the sub-optimal operation of the technology on this site.

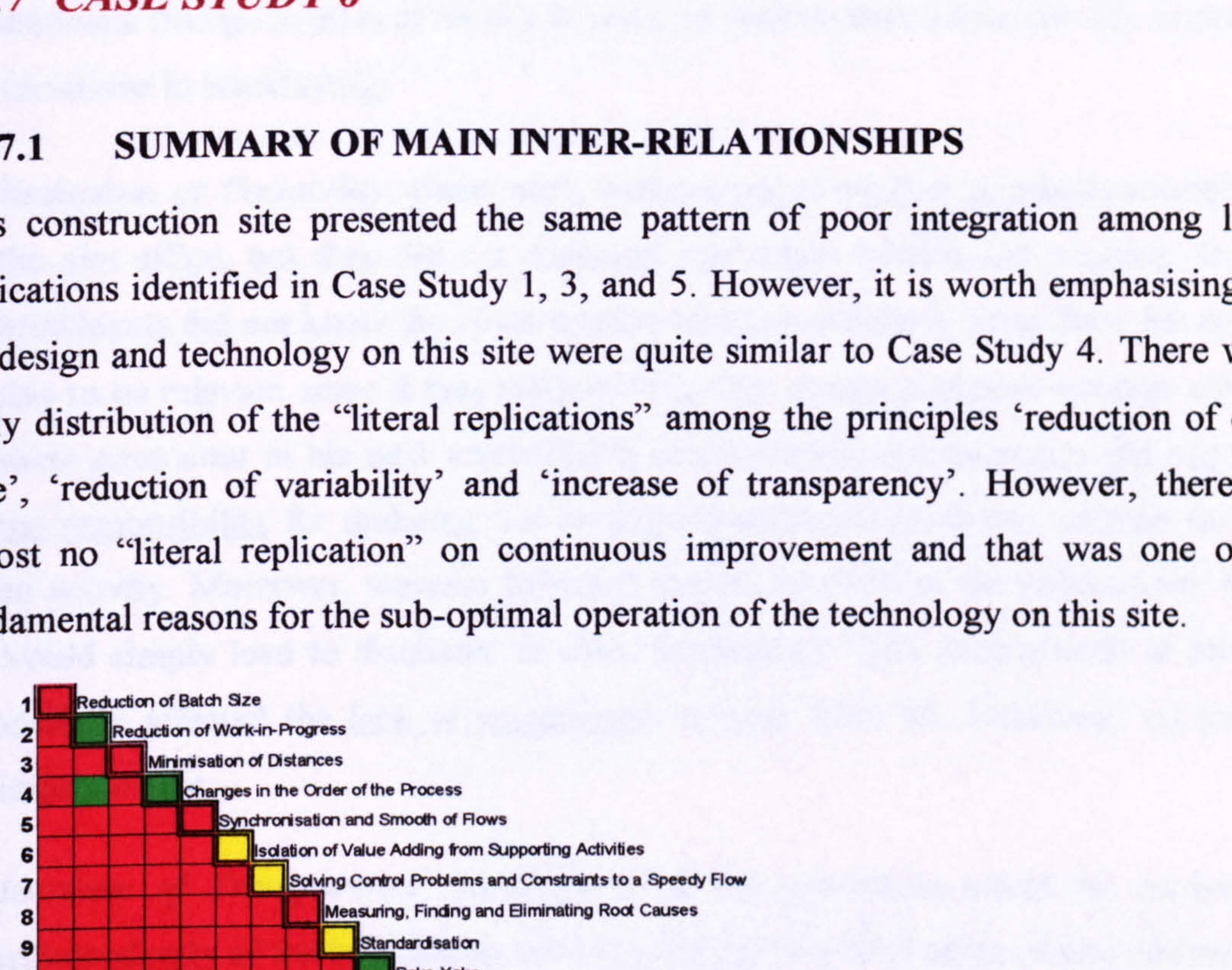


Figure 6.7 - Integration of Implementation Approaches in Case Study 6

The following descriptions represent the most significant practices and characteristics observed in this construction site:

a) *Reduction of Cycle Time*: electricians installed part of the electrical fittings in parallel to the bricklaying activity. This practice contributed to a reduction in the amount of work-in-progress. Yet, in order to give its full potential contribution to the achievement of higher performance, both processes should have presented a better degree of synchronisation. Large transfer batches, large delivery batches and the slow set-up of workstations increased the problems of synchronisation between electricians and bricklayers. Hence, the researcher observed electricians assembling electrical fittings in piles of blocks in order to prepare themselves for any occasional variations in bricklaying;

b) *Reduction of Variability*: there were well-presented written standards available in the site office, but they did not represent the actual bricklaying practice. In fact, bricklayers did not know the exact content of these standards since they did not feel this to be relevant since it was unlikely that they would continue working with the same contractor in his next construction site. Construction managers did not share the responsibility for updating the writing standards and dedicate no time for such an activity. Moreover, workers believed that an increase in the productivity levels would simply lead to dismissal of other bricklayers. This environment of mistrust strongly affected the lack of suggestions coming from the workforce on process improvement;

c) *Increase of Transparency*: small parts of the operations could be carried out independently of the bricklaying activity, such as pre-fabrication of components, the installation of electrical fittings in blocks and the production of shafts in toilets. In theory, such parallel practices could help reducing the amount of disturbances and clutter in the workplace. However, lack of synchronisation and the high degree of dimensional variability of blocks and concrete structure resulted in the generation of great quantities of wastage in the workplaces. Furthermore, since there was no systematic problem solving activities in this site, there was no identification of the root causes of wastage;

d) *Build of Continuous Improvement*: there were a great number of managers in this site, but none of them dedicate efforts for promoting systematic improvement activities. However, they concentrated all the responsibility in developing and promoting improvements. It seems that the lack of an appropriate systematic process control contributed to their lack of attention to "flow activities". Indeed, managers were not sufficiently aware of the time and cost wasted with non-value adding activities.

6.3.7.2 DISCUSSION

Similar technological solutions that had been adopted with relative success in Case Study 4 had not the same impact in this case study. The high variability of materials and large production batches associated with poor workflow planning led to the lower level of performance of the new technology in this context. Design solutions that originally aimed at increasing productivity ended up producing an opposite outcome since the new masonry system was less flexible.

The lack of integration among the heuristics affected considerably the effectiveness of the entire production system. However, the holistic application of the entire set of approaches investigated in this thesis would certainly demand profound strategic and cultural changes in this company. Long-term relationships with suppliers and subcontractors and the active involvement of the workforce in decision making would certainly require a different managerial attitude towards production improvement.

6.4 INVESTIGATING THE LINK BETWEEN PROCESS PERFORMANCE AND INTEGRATION OF HEURISTICS

This section explores the link between the degree of integration of "literal replications" in each case study and process performance. The analysis aims to generate insights for future research through the identification of general patterns observed in the case studies.

6.4.1 THE COMPLEXITIES IN ESTABLISHING THIS LINK

The link between the application of the flow principles presented and good performance is intuitive for many of the practitioners interviewed in this research. Womack, Jones & Roos (1996), in a five year's study, showed that this correlation is valid in the car industry. However, from an academic point of view the search for scientific proof of this correlation in the construction industry presents a considerable challenge. Firstly, because empirical evidence matching a theoretical proposition has different impacts on performance depending on the interactions with other complementary practices. Secondly, the assessment of entire production systems will always depend on a certain level of individual interpretation and experience.

Certainly, studies using only objective measures of practice are more likely to enable rigorous statistical correlation between pattern matching and process performance. However, the great variety of independent factors that can influence process performance is a major constraint for establishing such correlation. For instance, Thomas et al. (1989) used twenty-five factors to enable the comparison of bricklaying performance between seven countries. Even with such a large number of factors, their study could only be applied within a limited set of technologies and still depended on certain degree of subjectivity.

The present research used sufficiently contrasting case studies to investigate the general pattern of an effective production process. The main analytical criterion used to evaluate each case study will be the number of literal replications and corresponding degree of interactions against key quantitative indicators. The objective here was only to obtain better understanding of the phenomena and establish hypotheses for future research.

6.4.2 ANALYSIS OF EVIDENCES

This section draws key inferences based upon the correlation between literal replication of each case study and the corresponding performance. Time is the criterion used to evaluate this correlation.

6.4.2.1 Case Study 2: *Good Performer*

Case Study 2 presented the largest number of "literal replications" from the theoretical propositions in study. The assessment portrayed diagrammatically on Figure 6.2 also reveals that this case study presented the best integration of related practices among the case studies. It shows that the literal replications in this study concentrated on the combined approaches for 'reducing cycle time' and 'increasing transparency'. Indeed, suppliers of this site delivered all basic materials for bricklaying in small batches and at the latest time possible, thus reducing storage on site. In addition, this site presented the greatest number of visual controls (6) and information displays (4) in relation to the number of process stages (8). Yet, even in this good site there was little empirical evidence of the heuristic approaches aimed at 'building continuous improvement' and 'reducing variability'.

The list below presents some of the most visible effects of these practices on process performance:

⇨ Best gang composition: this case study presented the best gang composition, with three bricklayers per labourer (3:1) while other cases had two bricklayers (Case Study 1, 3 and 4) or even only one bricklayer per labourer (Case Study 6). This criterion is a direct indication of how well organised the flows were in this construction site;

⇨ Best transport practices: this case study achieved the highest mark among the case studies regarding transport practices: 69% of the 'applicable' items of the check-list of practices;

⇨ Best facilities: this case study achieved 100% of the total number of applicable practices present in the 'process maturity' checklist on the issue of facilities;

⇨ Lesser storage: the average storage on Case Study 02 was significantly small than most of case studies. The practice of 'pull orders' from the supplier and small delivery batches was the main reason behind this good performance;

⇨ Efficient material flow: although this case study still presented a fairly modest level of productivity, this was compensated by an efficient flow of material. The flow

efficiency in this case study (0.06) was only a fraction behind the best flow efficiency among all case studies (Case Study 4 = 0.07);

⇨ Fastest time between visits to the workplace: the average time between visits to the workplace was only 48 hours, whilst in the worst case study it was 120 hours;

⇨ Fastest changeover time: the bricklayers on this site took only twenty minutes from finishing one brickwall and start the production activity in other workplace. This was possible because in most workplaces labourer and supervisor had set up the workstation in advance of the bricklayer;

⇨ Reduced waste of material: the measurements revealed 7% of waste of blocks which is quite near of the 5% benchmark (Skoyles & Skoyles, 1988).

6.4.2.2 Case Study 4: *Good Performer*

This case study revealed nearly the same literal replications that had been identified in Case Study 2. These literal replications also presented a fair degree of effectiveness when considering the various indicators of performance. However, the assessment of this case study revealed lesser integration than what had been found on Case Study 2 (*see* Figure 6.5). The list below shows some indications of the impact of good production practice on process performance:

⇨ Lowest storage: this case study presented the smallest value for the "average storage", 2,62 m3/hour/bricklayer;

⇨ Most efficient material flow: although this case study presented only a modest level of productivity this was compensated for the most efficient flow of material among the case studies (*Flow Efficiency = 0,07*);

⇨ Reduced waste of blocks: bricks presented 3% level of waste and this was better than the benchmark of 5% identified in the literature (Skoyles & Skoyles, 1988);

⇨ Reduced time between visits to the workplace: the average time between visits was 72 hours, whilst the worst case study presented an average of 120 hours;

⇨ Reduced changeover time: this construction site was just behind Case Study 2 in terms of the time between finishing processing activities in one workplace and starting them again in another workplace (30 minutes).

6.4.2.3 Case Studies 6: *Modest Performer*

Case Study 6 presented nearly the same number of literal replications identified in Case Study 4, however, without the same level of integration of practices (*see Table 6.1*). The following facts contribute for classifying this case study as a 'modest performer':

⇨ Worst gang composition (1:1): the use of one bricklayer to each labourer reflected the poor state of the flow of materials and flow of workstations on this site;

⇨ High level of storage: the average storage on this site (6,34 m^3/bricklayer/hour) was almost twice of what had been found on Case Study 4 (2,62 m^3/bricklayer/hour);

⇨ Poor flow performance: the flow of materials was very inefficient due to the high levels of storage (*flow efficiency indicator = 0,04*).

6.4.2.4 Case Studies 1: *Modest Performer*

Bricklayers were only able to have a high level of production in Case Study 1 due to the characteristic simplicity of brickwalls of a warehouse (0,33 m^3/hour). Thus, this productivity level cannot be considered as resulting from better practices in design or production. Likewise, this site presented the lowest level of waste (1%) but this was more due to the simplicity of the job rather than better practices. Deficiency in flows practically cancelled out the benefits of this performance, as it shown below:

⇨ high level of storage: the average storage on this site (6,12 m^3/bricklayer/hour) was almost twice of what have been found on Case Study 4 (2,62 m^3/bricklayer/hour);

⇨ poor flow performance: although this site presented the highest productivity, the flow of materials was very inefficient due to the high levels of storage (*flow efficiency indicator = 0,05*);

- ⇨ highest amount of time between visits to the workplace: bricklayers spent an average of 120 hours between the visits to the workplace whilst in Case Study 2 they spent only 48 hours;

- ⇨ slowest changeover time: bricklayers spent excessive time to re-start the processing activity in other workplace (60 minutes).

6.4.2.5 Case Studies 5: *Poor Performer*

This case study also presented a reduced number of literal replications and almost no visible interactions among them. The poor performance on the indicators presented below reflect the consequences of this situation:

- ⇨ highest average storage (10,38 m^3/bricklayer/hour) this site had almost three times the amount of storage measured in Case Study 4 (2,62 m^3/bricklayer/hour);

- ⇨ poor flow performance: although this site presented a fair level of productivity in comparison to other case studies, the flow of materials was very inefficient due to the high levels of storage (*flow efficiency indicator = 0,03*);

- ⇨ High level of waste: it has not been possible to measure waste on this site due to changes in material specification during the construction. However, the waste before, during and after the bricklaying activity had been documented on filming and photographs and was found to be high;

- ⇨ highest amount of time between visits to the workplace: bricklayers spent an average of 120 hours between the necessary visits to finish their operations, whilst Case Study 2 required only 48 hours;

- ⇨ Best safety practices: according to the checklist of process maturity, this site presented the highest level of safety with 66% of the total number of applicable practices. However, it seems as though this attention to safety was not matched with considerations to the flow of material.

6.4.2.6 Case Studies 3: *Poor Performer*

This case study presented a reduced number of "literal replications" and almost no visible interactions among them. The poor performance on the indicators presented below reflect the effect of this situation:

- ⇨ worst productivity: the need for involvement of bricklayers in transporting and set-up activities, the large production batch and the interruptions due to rigid inter-dependence with other processes led to a poor level of productivity (0,18 m^3/bricklayer/day) on this site;

- ⇨ highest level of waste of bricks (14%): a significant source of waste on this site was the long transportation distances and the excessive improvisation in storage;

- ⇨ highest rate of unproductive time (34%): the root causes for this situation lay on the large production batch and on the poor layout and poor workflow planning;

- ⇨ worst facilities, transport and safety practices: the check list of process maturity revealed the lowest level of practices (28%, 18% and 17% of the 'applicable' items, respectively);

- ⇨ slowest changeover time: bricklayers spent too much time to move the workstation from one place to another (60 minutes).

6.4.3 CONCLUSION

None of the production systems in the six case studied presented the entire set of heuristic implementation approaches investigated in this research. Furthermore, all case studies have presented a fairly poor level of integration among "literal replications". Analysis of the overall patterns of practice clearly indicates that there is a correlation between the amount of integrated "literal replications" and production performance.

6.5 DISCUSSION

The intra-case study analyses revealed a common problem across all case studies: the lack of integration of the various practices described in the theoretical framework.

Open-ended interviews with workers and managers revealed that the main reasons for this lack of systemic integration was twofold. Firstly, there was an actual gap in the knowledge of practitioners on all sites analysed concerning the heuristics for effective lean production systems. In this sense, there is considerable scope for research into the analysis of strategies for explaining theory to site operatives in such a way as to help to become more effective. Secondly, most case studies did not have an adequate structure and supportive management to enable and motivate the workforce in the application of the heuristic approaches investigated in this research.

The empirical observations showed that the construction sites analysed had a mix of the two problems described above. There was an excessive emphasis on the control of process inputs/outputs that deprived managers from the experience of improving flows (*conversion model*). Therefore, important knowledge may have not been developed and consolidated in the mental model of construction workers and managers. At the same time, the open-ended interviews revealed that certain individuals understood and agreed with the heuristic approaches but faced difficulties to implement them in practice. Most of these difficulties related to short term relationships and the low level of education and training of the workforce. The analysis revealed that production processes with best performance presented the greater amount of empirical evidence matching the theory and theoretical inter-relationships in practice. Foremost, the best performers showed a small core of literal replications closely supporting each other, as illustrated on Figure 6.8.

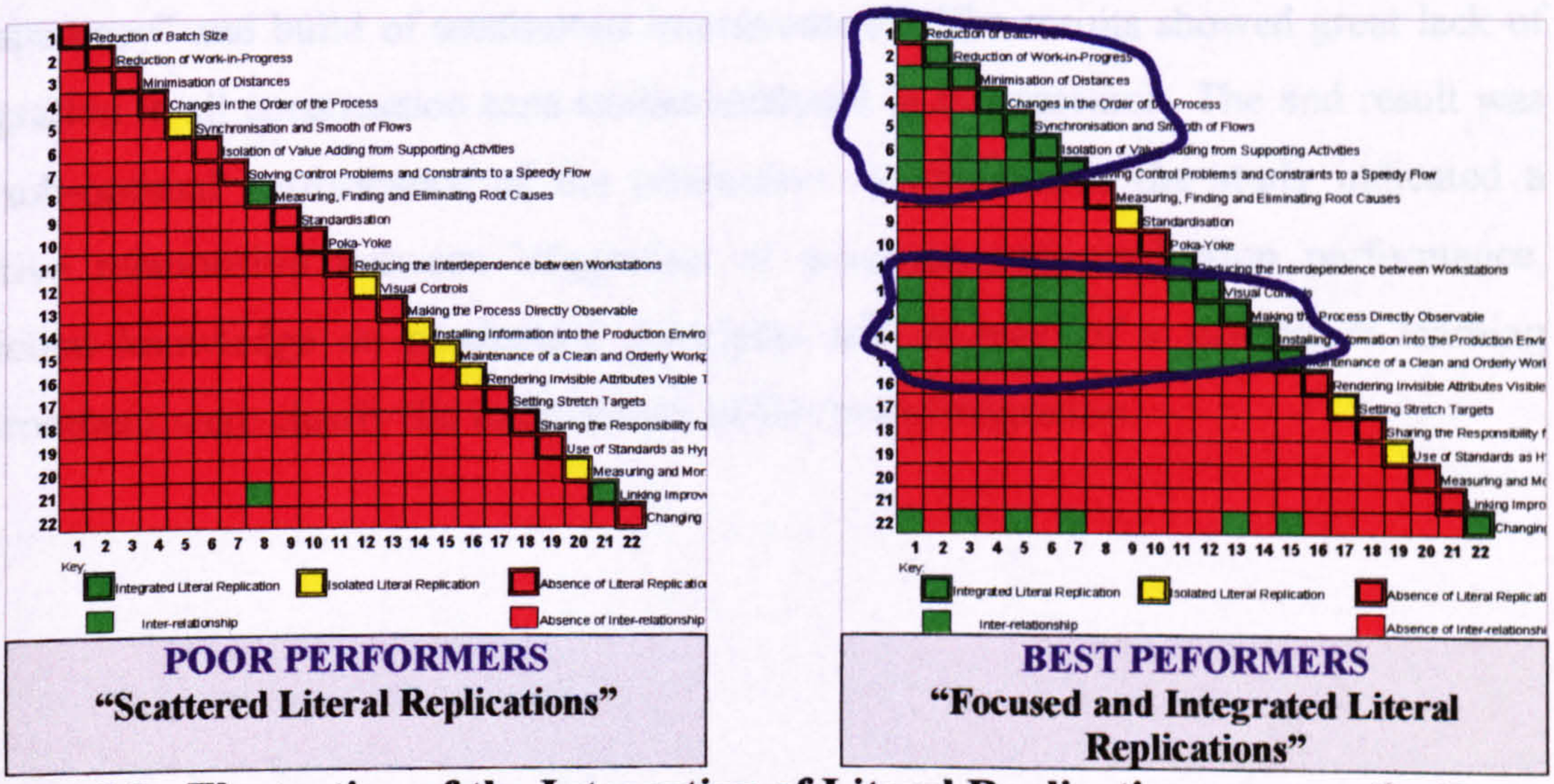


Figure 6.8 - Illustration of the Integration of Literal Replications among the Best Case Studies

Mastering a set of well-focused and well-connected heuristic implementation approaches appears to be a common factor linked to high process performance. This focus allows people to learn consistently and gradually develop their own individual solutions. Hence, focusing in a set of well-connected heuristic implementation approaches seems to be a creditable strategy to progress in the implementation of production management theory.

Unfortunately, it was not possible to identify a common focus among the case studies since this depends on the enormous number of variables within the company and on the complex interactions with the surrounding environment. Hence, a construction company may decide to reduce batch size as a way to drive improvements whilst, in parallel, building teamwork within the workforce in order to promote problem-solving activities. Another company may decide for increasing transparency in the flow activities and, at the same time, standardising processing activities.

6.6 SU7MMARY

The flow principles investigated in this thesis must be seen as part of an inter-connected whole when it comes to implementations in practice. Hence, the systemic and coherent application of these principles is fundamental to achieving higher level of performance in construction practice. This chapter investigated this degree of integration among the principles "reduction of cycle time", "reduction of variability", "increase of transparency" and build of continuous improvement". The results showed great lack of integration in all construction case studies analysed in this research. The end result was the sub-optimal performance of the production systems since the study indicated a positive relationship between integration of practices and production performance. Deficient knowledge on production principles and absence of a supportive learning environment were clearly the main causes of this poor integration.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter 7

EXPLORATORY STUDY ON THE CREATION OF A "LEARNING MOOD"

Q: 'How many psychotherapists does it take to change a light bulb?'
A: 'Only one. But the light bulb really has to want to change'
Gower (1995)

7.1 OVERVIEW

The Theoretical Framework (Chapter 3) has been analysed against the practice in different countries through six case studies and a "meta-case" in the previous chapters. Hence, Chapter 6 presented the cross-case study and Chapter 5 the intra-case study analysis. The association of the Theoretical Framework with the analysis of case studies is part of, what is now called in this thesis, a 'Learning Bank'. Thus, until this stage the thesis had covered aspects of 'observation', 'conceptualisation' and 'reflection' of theory development.

This Chapter intends to explore the use of the 'Learning Bank' and the 'Theoretical Framework' for changing practices in the construction industry. Firstly, it presents various approaches used by those in change management. Secondly, it discusses two opposite approaches for promoting learning in organisations: "push and pull learning". The subsequent sections then present a case study where the researcher attempted to change practices using both push and pull learning approaches. Finally, a model for better learning in construction is suggested. Hence, this chapter explores the third research question stated on Chapter 1: *how can we create a "learning mood" in construction companies in order to effectively transfer modern production management axioms into construction practice?*

7.2 THE NEED FOR CHANGE IN CONSTRUCTION

Recent government and academic reports have repeatedly emphasised the need for fundamental cultural and technical change in the UK construction industry. These reports come as a result of under achievements within the construction industry, both in terms of its own need for more efficiency as well as the needs of its clients for more effectiveness (DTI, 1994; Latham, 1994; Egan, 1998). As discussed in Chapter 1, low

productivity and high levels of waste in construction result damages the image of the industry and severely affects its ability to attract new investments and talented people.

The effective and efficient use of construction resources demands changes in the relationship between research and practice. Construction companies increasingly require research that supports solution of short-term problems, whilst leaving open the opportunity for long-term innovative ideas to develop. In this respect, one of the *Office of Science & Technology Expert Mission* – OSTEM - key conclusions from the comparison between Japanese and UK style of doing research was the need to promote cultural changes in the UK construction industry, especially regarding continuous improvement (DTI, 1994).

The OSTEM report also shows that UK construction research has been so far ineffective in transferring innovations into practice due to deficient communication between academia and industry. Furthermore, according to CIB (1996), construction research in the UK places greater emphasis on innovations, when the real problem is that the industry itself suffers from lack of support in developing incremental and small-scale solutions to recurring daily problems. In the future, construction companies need to learn how to manage the complex network of processes and relationships that constitute the entire supply chain.

Among other fundamental problems in the sector, and one of particular interest for this exploratory study, is the excessive attention of construction people give to finished products or sub-products, rather than to the flow and value of production. Indeed, a conceptual shift among construction personnel from the "conversion" model of production towards the "flow" and "value" model is seen as a key factor in changing practices in the construction sector (Koskela, 1992). Chapter 3 presented the meaning of these concepts and describes in more detail some of the core principles of the flow model.

The focus in this exploratory study is on how small and medium sized contractors could learn in sufficient depth about the "flow model" of construction such that they could make their processes in this respect more efficient. This is not to say that the "flow model" has precedence over the "value model" during practical implementations. In fact, simultaneous consideration of flow and value seem to be a normal practice in

highly competitive companies in other industrial sectors. Nevertheless, bearing in mind the large volume of waste attributed to construction, the researcher was led to believe that construction now urgently needs to reduce the proportion of non-value adding activities present in flows before any value considerations are taken into account.

The move of emphasis among construction managers from the "conversion" to the "flow model" is likely to have direct implications on the way they look at construction processes and their theories about how production systems should be managed. "Lean production" and "world-class" literature has shown that changes towards the adoption of the "flow model" can trigger the development of innovative technological and organisational practices (Schonberger, 1985; Smeds, 1994; Womack & Jones, 1996).

The lack of attention to flow activities due to the emphasis on "conversion model" is pointed out in the literature as one of the root causes of the great volume of rework, delays and waste in the construction sector (Koskela, 1992). This conversion paradigm clearly shapes the way construction people traditionally understand, reflect, communicate and formulate solutions to problems in that sector. In this way, the performance of construction has been below its potential not because people cannot solve flow problems, but because they cannot see the flow problems in their processes. This condition follows Revan's (1978) postulate, which reads, "*managers who cannot change their own perception of their problems cannot change the conditions that create those problems*".

Moreover, history already teaches that the shift of conceptual paradigms can shape changes in reality in a more profound and lasting way than any other approach, as the next example illustrates.

> *"When Copernicus suggested that the earth was not at the centre of the universe he was, though he knew it not, a paradigm revolutionary. But it was the minds of men that changed, not the motions of the planets, and the way in which they now viewed that same universe had a profound effect on their beliefs, values and behaviour"* (Handy, 1986:389).

However, the literature review for the present study showed that the process of change towards a new way of thinking is a highly complex topic, difficult to understand, and

because of its non-linear nature, almost impossible to deal with systematically. Understanding and practising new conceptual models takes a long time, involves a great quantity of resources and its effectiveness is difficult to evaluate in quantitative terms. Sjoholt (1998) supports the notion, for instance, that the effective transformation of TQM ideas into practice in construction companies takes an average of five years.

The shift of emphasis from the "conversion model" towards the "flow model" depends on many complex variables such as company's values, its management structures and the age of the workforce. Changing strategies for implementing new ways of working may vary from adaptation or improvement of existing practices to more radical strategies where the aim could be to abandon, or even remove, existing practices. The sections summarise the most relevant ideas related to change management, learning and cultural change.

7.3 MANAGING CHANGE

7.3.2 FROM INDIVIDUAL CHANGE TO SYSTEMIC CHANGE

Three schools of thought form the central concepts on which change management theory stands: the *Individual Perspective* school, the *Group Dynamics* school and the *Open Systems* school.

7.3.2.1 INDIVIDUAL CHANGE

The supporters of the *Individual Perspective* School are split into two groups: the *Behaviourist* and the *Gestalt-Field* psychologists. The *Behaviourist* psychologists see behaviour modification as the manipulation of *stimuli* so as to reward a desired activity. Their aim is to reward immediately all instances presenting the desired behaviour, but to ignore all instances presenting an undesired behaviour (Burnes, 1996). The Behaviourist view mirrors in many respects the mechanicist approach of Human Resource Management adopted in the Classical School, as described in Chapter 2.

Gestalt-Field psychologists, on the other hand, understand that individual behaviour is not just a product of external stimuli. Individual behaviour arises from how the

individual uses reason to interpret the stimuli. Consequently, *Gestalt-Field* proponents seek to help people change their understanding of themselves and any situation in question, which, in turn should lead to changes in behaviour (Burnes, 1996). The approaches of both groups have proved to be valuable in the management of change and some writers advocate using these approaches in tandem.

7.3.2.2 GROUP CHANGE

The *Groups Dynamics* school advocates that, because people in organisation work within groups, individual behaviour must be seen, modified or changed according to a group most prevailing practices and norms. The group changes the individual and the individual changes the group in a continuous process of mutual adaptation. Therefore, according to the supporters of this school it is useless to concentrate on changing the behaviour of individuals. The focus of change should be on the group level and concentrate on the its norms, roles and values (Burnes, 1996).

7.3.2.3 SYSTEMIC CHANGE

The *Open Systems* school sees organisations as composed of a number of inter-connected sub-systems. The central idea here is that any change to one part of the system will have an impact on other parts of the system, and, in turn, on its overall performance. Their approach for change is based on a method of describing and evaluating sub-systems in a meaningful way for any individual, in order to determine the best pathway to conduct the change so as to improve the overall performance of the organisation (Broome, 1990; Burnes, 1996; Vollmann, 1996).

7.3.3 FROM PLANNED CHANGE TO EMERGENT CHANGE

7.3.3.1 PLANNED CHANGE

The planned approach views change as essentially a process of moving from one fixed state to another through a series of predictable and pre-planned steps. There are a number of models and techniques for planned management that have been developed within the Organisational Development field. However, the most well known planned

change processes emerged from the pioneering work of Kurt Lewin (Lewin, 1958 apud Burnes, 1996) and includes:

- The Action Research model: it usually comprises a senior manager, people from the area where the change is to take place, and a change agent (e.g. consultant). Diagnosis and redefinition of the situation and of the problem under consideration is carried out interactively by a team after careful consideration of the entire system. The role of the change agent in this team will vary from being the generator of a crisis, in order to drive change, to simply helping fine-tuning existing changes (Burnes, 1996; Vollmann, 1996). It maybe necessary to build multiple scenarios when establishing the desired changes of any situation, especially when coping with a dynamic context such as construction;

- The Three-Step model: this method provides a general framework for understanding the process of change. Other writers have expanded the number of steps or phases in this model, but the essence remains the same (Leonard-Barton, 1992; Senge, 1990:150; Argyris, 1993; Smeds, 1994). In general terms, it involves the following steps (Burnes, 1996):

  - *Unfreezing the present level*: this usually involves reducing those forces that maintain the present organisational behaviour (e.g. confrontation meeting). The essence of this step is to enable those concerned to become convinced of the need for change;

  - *Moving to the new level*: having analysed the present situation, identified alternatives and selected the most appropriate, action is then necessary to achieve the desirable state;

  - *Re-freezing the new level*: this phase seeks to stabilise the organisation at a new state of equilibrium in order to ensure that the new ways of working are relatively safe from regression. Supporting mechanisms that positively reinforce the new ways of working are the usual ways for achieving objectives.

7.3.3.2 EMERGENT CHANGE

In contrast to the planned approach, the emergent approach sees change as a continuous, open-ended and unpredictable process of aligning and realigning an organisation to its changing environment. Advocates of emergent change tend to adopt a contingency perspective. For them, it is the environment's uncertainty that makes planned change inappropriate and emergent change more pertinent. Environmental change is so rapid and complex that the initiation and implementation of change in the emergent approach tends to be "bottom-up" rather than "top-down". The role of senior managers becomes one of ensuring that the structures, resources and the necessary skills and motivation are in place to carry out changes (Burnes, 1996).

Supporters of the emergent approach stress four features of organisations that either promote or obstruct change:

- Organisational structure: this can be an important lever for achieving change, but its effectiveness will depend upon the recognition of its informal, as well as its formal, aspects (Burnes, 1996);

- Organisational culture: it is important to understand the culture of any organisation that is to be changed in order to avoid contradictions and to plan the build up of change (Burnes, 1996);

- Organisational learning: involving people in change management decisions has the effect of enabling them to challenge existing norms and question established practices that result in commitment towards the change themselves. Organisational learning can be precipitated by making impending crises real to everyone in the organisation or encouraging dissatisfaction with the current systems and procedures (Leonard-Barton, 1992; Senge, 1990:150; Argyris, 1993);

- Managerial behaviour: managers are expected to operate as facilitators and coaches that bring together and motivate teams and groups to identify the need for change, and the implementation of change. It is necessary to create a shared vision about the future (Broome, 1990; Burnes, 1996).

7.3.4 APPROACH FOR CHANGE ADOPTED IN THIS RESEARCH

The change strategy used in this exploratory study integrates ideas from the various change strategies presented before. Nevertheless, the emphasis will be seen to be on group change and the researcher's actions will initially follow a planned approach. A protocol similar to the one applied in the previous projects will set the steps of change for the first half of the exercise. These steps include a thorough analysis of a construction process and subsequent presentation of a report and action plan to the company.

In the second half of the study the researcher experimented with the emergent approach. At that stage, the staff of the company involved in the study took over the process of change and defined what they wanted to learn, how and when to learn. Hence, the role of the researcher changed from "solution provider" to "knowledge provider". The content of the change could be influenced by the researcher's opinions but only on those matters that the group thought to be worth of analysis and action.

7.3.5 DISCUSSION

Despite the large body of literature devoted to the topic of change management, there is considerable disagreement regarding the most appropriate approach. The decision for the most suitable approach appears to be conditional on the objective and context of the change. Most of the production management literature appears to adopt a contingency approach to define the change strategy. Moreover, there is no general pattern among the descriptions of organisations involved in changing production practices. Smeds (1994) argues that organisational and technological change towards the "lean" enterprise resembles the emergent approach. Sjoholt (1998), on the other hand, shows that the implementation of TQM principles can follow pre-determined stages that resemble a planned approach.

Change in the construction sector is bound to be complex because of the constant flow of people across projects, and across organisations, does not facilitate the long-term assessment, or even the simple stabilisation, of change. Nevertheless, construction researchers and practitioners need to be aware of the various possibilities within change management in order to make more appropriate decisions and be more effective in their

actions. Change management considerations are still a rare topic of research in construction literature.

7.4 CREATING A "LEARNING MOOD" TO NEW IDEAS

The principal aim of this piece of work is to understand how to create the motivation in any organisation such that it effectively learns the production principles in study. The author came to believe that that change should not be seen as a one-time event but as part of an ongoing learning process. Hence, this section reviews the relevant aspects of learning for this study.

7.4.1 PRODUCTION AS A LEARNING LABORATORY

Everyone working within an organisation is already taking part in a learning phenomenon simply by being in that organisation. Nevertheless, if learning is treated in a casual manner, its positive contribution to the organisation's competitiveness is, usually, uncertain and unpredictable. In order to change that situation, activities within an organisation should be organised and planned in order to focus the learning activities on the company strategic needs.

The literature shows that learning relies on the creation of an adequate "mood" among members of the organisation in order to drive effective learning. "Learning mood" is defined here as a state of openness to receive and experiment with new knowledge. Broome (1990) calls this state "readiness to change". An individual's range of skills and personal confidence, as well as his/her ability to tolerate ambiguity and change, and his/her motivation has implications for the "learning mood". Likewise, the general climate of the organisation affects the creation of a "learning mood". Organisational ability to tolerate ambiguity and uncertainty is also essential if change and learning are to happen (Broome, 1990).

The theories describing how learning operates among individuals, groups or organisations have been the subject of intense research among psychologists and anthropologists, especially since the 1920's. Opinions vary radically from empiricists who regard learning as the "bit-by-bit" accumulation of thoughts to cognitive

psychologists that understand learning as a self-regulating system between the individual and the environment (Hallpike, 1979). Nowadays much knowledge exists about how people learn and incorporates new approaches to learning that range from treating the human being as a physiological/neuro-biological entity to one of treating the human being as a free, rational and self-determining whole (Gower, 1995).

Recent literature argues that in today's competitive and dynamic environment, companies should continuously promote learning activities in order to become a truly "learning organisation" (Pedler, 1997). Argyris (1993) argues that a "learning organisation" is characterised by being vigilant about detecting and correcting errors, dedicated to producing innovations, and ready to change to meet the demands of the environment. The workforce in these organisations should be prepared and motivated to receive, apply and develop new knowledge in practice. An extract from Senge's (1990) book – *The Fifth Discipline* - synthesises the vision of a learning organisation:

> *"While traditional organisations require management systems that control people's behaviour, learning organisations invest in improving the quality of thinking, the capacity for reflection and team learning, and the ability to develop shared visions and shared understandings of complex business issues. It is these capabilities that will allow learning organisations to be both more locally controlled and better co-ordinated than their hierarchical predecessors"* (Senge, 1990: 289).

The core ideas of the learning organisation literature have gradually been introduced within the production management field. Nowadays, the most competitive companies search for ways to develop the capacity within the production system to learn consciously, continuously and quickly. In this respect, Leonard-Barton (1992) suggests that production should be run as a learning laboratory - a place of active experimentation. This learning laboratory should help the company develop the capacity of the production system to maintain or improve performance, based on experience (Leonard-Barton, 1992).

The literature lists many different approaches for transforming production into an environment that promotes and enables learning. However, this thesis focuses on one central aspect of these approaches that is the creation of a "learning mood" in the

adoption of new ideas. More specifically, it investigates two opposite strategies of creating this "learning mood": "push learning" and "pull learning".

7.4.2 "PUSH LEARNING"

"Push learning" happens when learners have no power in defining the problem, action or knowledge that is required to improve their own process performance. Individual learners are in charge of their actions, while an external change agent (e.g. consultant) is in charge of observing and reflecting on the consequences of the actions. The change agent is also responsible for planning further actions to influence the learning and the situation based on newly formed or reformed understanding. The expert skills of the change agent and his/her clear guidance may provoke a "learning mood" among production personnel. However, in such a situation the change agent is the sole "*solution provider*" and retains most of the intellectual part of the learning process, as illustrated in Figure 7.1

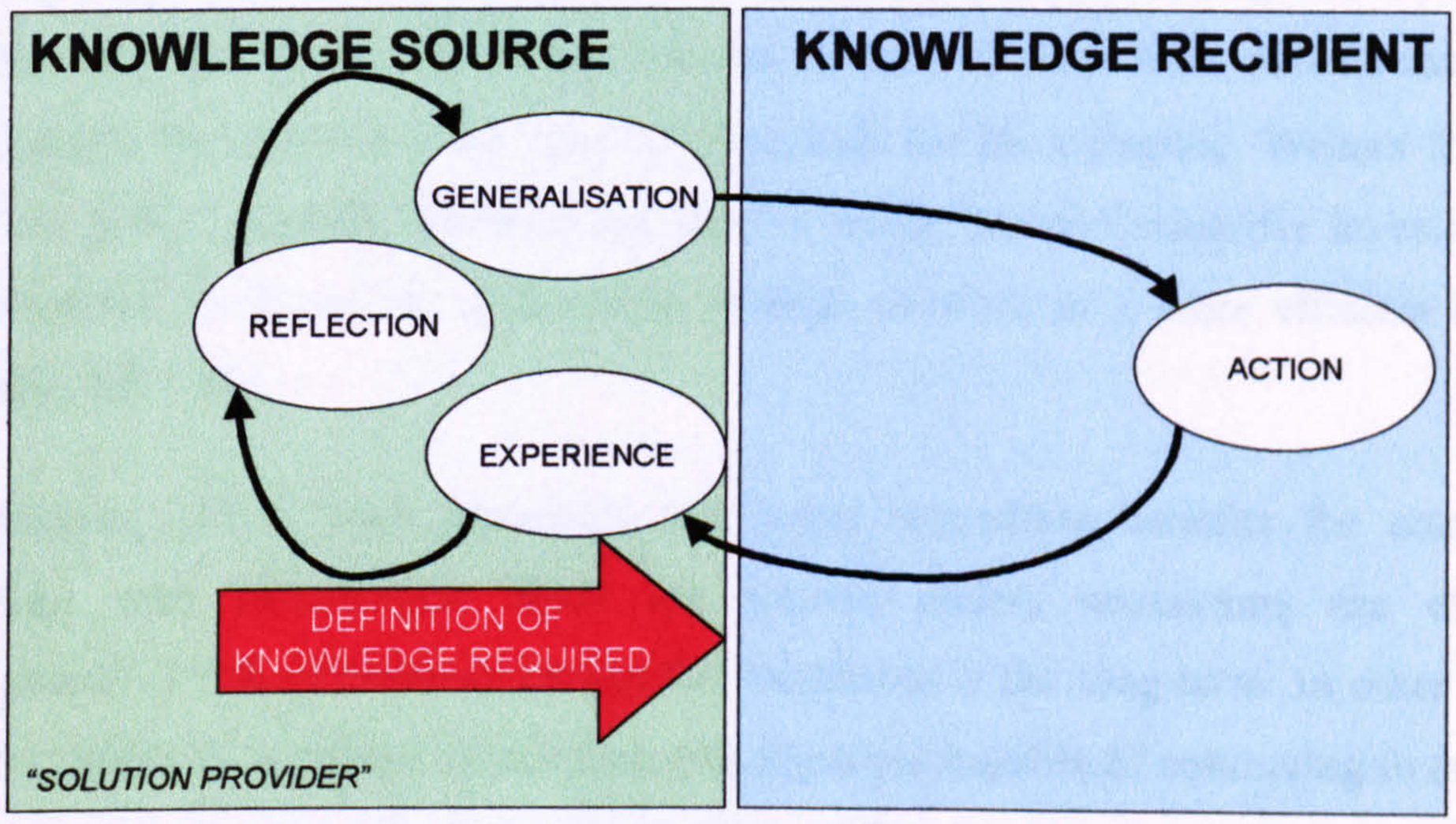


Figure 7.1 – "Push" Learning Concept

"Push learning" is the common approach used by consultants in conventional working practices in the construction industry in attempt to drive change. Thus, it is also related to traditional academic research projects. Often companies pay consultants or academics to analyse their production technology, or to devise a specific training course. One of the driving forces behind this behaviour is the desire for fast solutions to emergent problems and to get an external agent to do all the analytical work on behalf of the

company. In competitive environments, time is not an abundant resource available to a company and answers have to be found quickly before competitors do. Furthermore, contracting production experts (senseis) saves costly resources that certainly would be necessary to develop appropriate knowledge. The next example presents a typical example of a "push learning" situation:

> *"When they arrived at the plant around 10:00 P.M., the Japanese team took one look at the new cell and pronounced it all 'no good'. They explained that among other problems it was laid out backwards (the work should have been flowing counter clockwise) and it would be necessary to move all the machines immediately..."* (Womack & Jones, 1996:129).

The supply of information and advice in a "push" mode has the potential to bring quick increases in performance and radical changes in the way people do things. After all, accurate recognition of the root cause of any problem and the formulation of innovative solutions might never happen if people continue to use the existing knowledge and practices. Broome (1990) asserts that the introduction of ideas from outside can create unsettlement, but the end result may be beneficial for the company. Writers from the Scientific School already defended the idea of using "trained scientific investigators" since workers could not, by themselves, arrange to work in a more efficient manner (Gilbreth, 1911:91).

Nevertheless, while "push learning" can bring immediate benefits for companies struggling with competition, there are serious doubts concerning the effective development of self-sufficiency among the workforce in the long-term. In other words, there are doubts if this mode of learning makes people capable of continuing to develop, transform or even accept new knowledge long after the training courses and reports have gone.

7.4.3 "PULL" LEARNING

"Pull learning", on the other hand, happens when individuals have a high control in the definition of the problem, action and knowledge required to improve the performance of their own process. In the "pull learning" situation, the people working in production are in charge of learning for themselves by exploring their actions as they work, as

illustrated in Figure 7.2. In this situation learners are in charge of their own learning process. Such ownership can lead to higher commitment and motivation for individuals to apply, maintain and improve new ideas in practice.

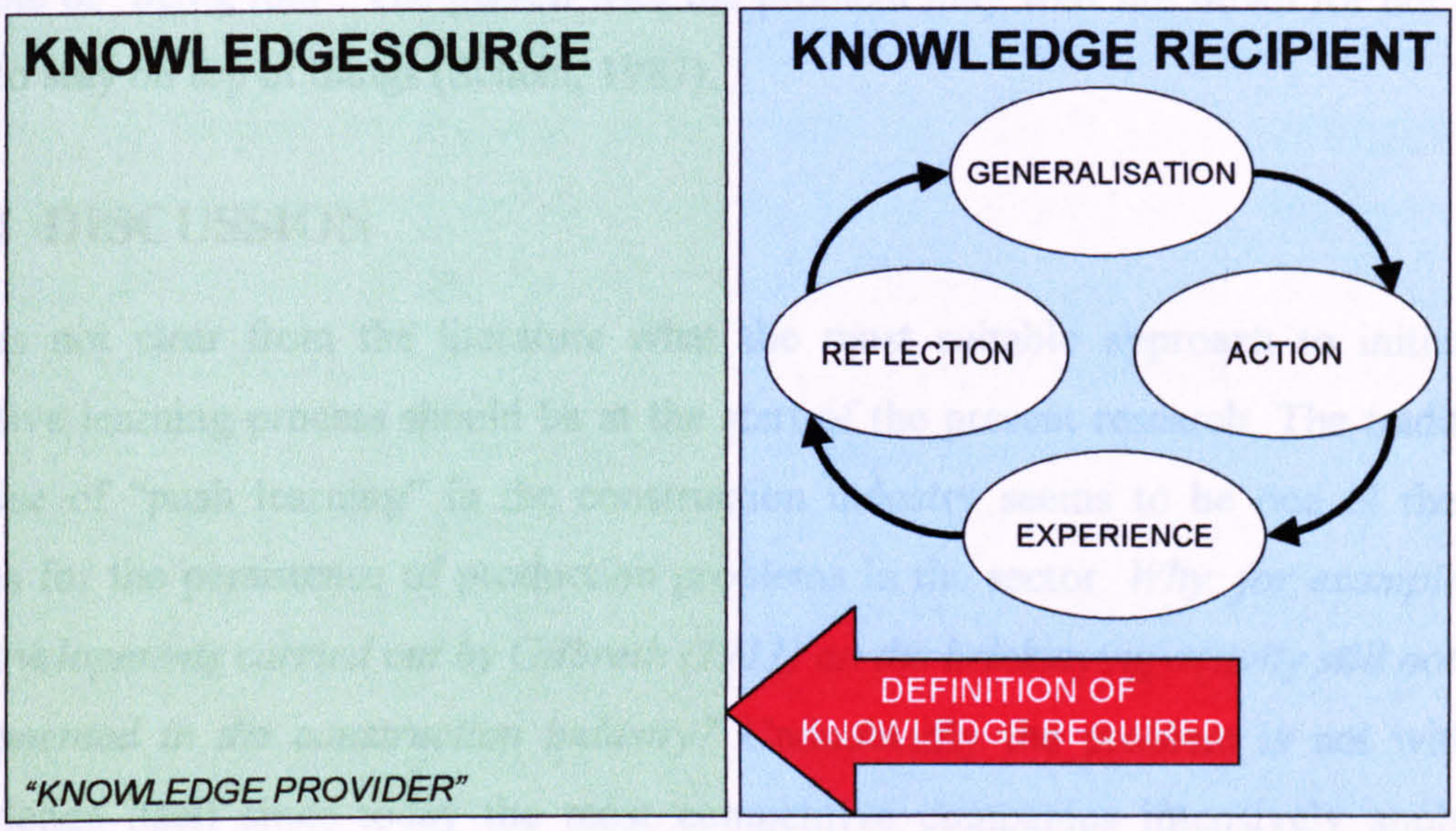


Figure 7.2 – "Pull" Learning Concept

Experts in this situation change their role from "solution provider" to "knowledge provider" where they have lesser power in the learner's decision making and only play a supportive role in providing knowledge when required. As "knowledge provider" the expert accumulates learning from the process of helping people to solve their problems. However, now the principal aim of the "knowledge provider" is to develop capabilities among people so they can develop their own solutions in future problems.

The "pull learning" approach is defended by the majority of the current literature on learning and change management. Lessen (1993:61) recognises that there is less ownership of knowledge if it is forced on learners as opposed to knowledge which people acquire through their own diligent and persevering effort. Likewise, Senge (1990) asserts that people learn better when they need to learn about something and not when someone else thinks they need to learn.

Nevertheless, consultants, academics and managers often see themselves as experts who are paid to give advice and tell to others what to do. It is rare to witness "experts" helping people to figure out the solution for themselves, even if that involves withholding what may seen to the "experts" as an obvious solution. Schein (1987)

argues that when an expert attempts to get others to do what he/she think they should do, people will resist and often manage to subvert what the expert has offered. One of the reasons for this is the fact that people seeking help or advice often resent being in the role of 'being told'. The person with the problem may well fall down for not being able to stay on top of things (Schein, 1987).

7.4.4 DISCUSSION

It was not clear from the literature what the most suitable approach to initiate an effective learning process should be at the start of the present research. The traditional practice of "push learning" in the construction industry seems to be one of the root causes for the persistence of production problems in the sector. *Why, for example, are the developments carried out by Gilbreth (1911) on the bricklaying activity still not fully implemented in the construction industry?* Undoubtedly the problem is not with the knowledge itself since today the most competitive companies intensively apply the same time and motion principles used in that study.

On the other hand, when the imposed changes that characterise "push learning" are compared with "pull learning", it is clear that the major issue is about ownership of the learning process. This ownership is a critical factor in increasing the scope for creativity and imagination among production personnel. On the other hand, approaches to self-directed learning can lead the learners to feel overwhelmed by an infinite number of options and the lack of clear guidance on what to do next. People may have a clear sense that all is not well, or that practice could be improved, but fail to translate their feelings into concrete and precise requests to a "knowledge provider".

The exploratory study described next explores the effects of the "push" and "pull" approaches in terms of creating a "learning mood" to new concepts and principles of operations management within the construction environment. The researcher started with "push learning" approach, but participation in the analysis from site managers and operatives. He then adopted a more radical approach by allowing managers to "pull knowledge" from the researcher.

7.5 LESSONS LEARNED IN CASE STUDY 7

7.5.2 INTRODUCTION

The host company for Case Study 7 was small (20<employees<100), but it had a long tradition in British construction dating back to 1887. With headquarters in Bournemouth, the company also has branches located at Dorchester, Warminster and Warwick. At the time of this research, some of its managers were taking part in a research programme that was used as a vehicle to promote innovative practices in the construction industry. This research programme aimed to investigate *Action Learning* as a mechanism for driving innovation and cultural change for construction. The ADAPT programme of the European Social Fund, the Innovative Manufacturing Initiative of EPSRC - *Engineering and Physical Sciences Research Council* and the *Chartered Institute of Building College* were the main sponsors of this programme.

Members of the *Revans Centre for Action Learning and Research*, University of Salford, were responsible for organising and supporting an Action Learning SET in this company. Originally, the organisers conceived this construction Action Learning SET as a pilot programme to be implemented within twelve months. SET meetings occurred once a month and when the present research started they were already on their eleventh meeting. The SET under study comprised five middle managers, working in different branches of the company and chosen by the Chairman of the company, to take part in the experiment. Important topics had already been investigated within this group previous to the present research, such as "what were the upper management competencies, the company's management structure and their own ability to do their job properly". The redefinition of the management structure for the entire organisation and an internal training programme were direct results of their own investigation.

The next section describes in general terms the meaning and dynamics of Action Learning. This description is necessary because Action Learning was the researcher's main communication channel with the organisation and the major approach used to enable learning. Moreover, it was the characteristics of this approach that led to the main conclusions at the end of the chapter.

7.5.3 DESCRIPTION OF THE ACTION LEARNING APPROACH

The literature does not show common agreement regarding a definition of Action Learning. Action learning is based on individual learning from experience through reflection and action on their own working practices, and then sharing this experience with others who are also learning by experience (Morris, 1987; McGill & Beaty, 1996).

Revans (1983), one of the principal thinkers on the subject, understands it as a community mission where many are learning, or being changed, by their involvement in an action to solve a real problem of wide concern. The Revans Centre for Action Learning and Research, based at University of Salford, defines Action Learning as "*a process of inquiry, beginning with the experience of not knowing what to do next, when finding that an answer is not available from current expertise*" (Botham & Vick, 1997).

Action Learning follows Kolb's (1984) learning cycle where people learn about the world and about themselves through reflection on past actions and plan future actions from reflection on the cumulative understanding of the real world. The driving force that moves this cycle forward is the attempt to answer the following fundamental questions (Revans, 1983):

- *What are we trying to do?*
- *What is stopping us from doing it?*
- *What can we do about it?*

These questions are debated through discussion in an Action Learning set and by asking questions during, or outside of, meetings. As the process continues, members of a SET learn to understand and define better some of their own problems and pick out issues that might be open to some experimental action. Their successes or failures in trying out ideas in real life situations, and the regular learning from other people's experiences in a supportive environment, are the main sources of learning in this approach (Revans, 1983; McGill & Beaty, 1996; Powell, 1999).

Revans (1983) asserts that Action learning accomplishes three objectives at the same time. Firstly, it tries to make useful progress on the treatment of an ill-defined real

problem. Secondly, it tries to give to the members of the SET sufficient information for them to be able to find out the solution or even an appropriate course of action to solve the problem. Thirdly, it tries to avoid teachers' and consultants' attempts to "teach" set members about solutions. Instead, it tries to get an agreement to correct problems about the conditions in which everyone can learn.

Members of a SET look inward at their problems and weakness and then try to improve one recognisable attribute at a time. In addition, members look outside their own knowledge and experience to 'benchmark themselves' against the world's best (Powell, 1999). In order to be effective, all SET members need to explain his/her action and listen to the other participants' views of these actions. This impartial scrutiny, resulting from this cross-examination by fellow colleagues, helps to strengthen the learning process (Revans, 1983). All these factors help the set members to take an active stance towards life and to overcome the tendency only to think, feel and write about problems without taking action (McGill & Beaty, 1996).

7.5.4 "PUSHING" THE LEARNING

7.5.4.1 RESEARCHER'S ROLE

At first, the researcher was contracted as a consultant to carry out the analysis of the production system in the host company. From the outset, the researcher decided to direct the focus of his analysis on the bricklaying process in order that the SET could enable direct comparison with the examples available in the "Learning Bank"[1]. The researcher also decided to follow an orthodox (and therefore safe) path for such a study. Thus, the plan was to carry out a detailed data collection on site, analyse the data with the participation of the workforce and, finally, present a conclusive report to the Action Learning SET.

The report would contain a suggestion of an action plan; a follow up programme and a recommendation of a second diagnosis in order that the SET could evaluate for themselves the progress of improvements. His conclusions would be supported by

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1 Learning Bank: **data collected in the case studies, including the "meta-case", associated with the theoretical framework**

construction examples available in the "learning bank". Thus, the SET would see for themselves the 'pros' and 'cons' of their own operational practices against abstract principles of best practice and concrete examples.

As this shows, the researcher intended to play the role of a "change agent" where he would use the knowledge developed on the critical revision of the literature and detailed examples extracted from the previous case studies. His aim was to bring immediate change in the actions and thinking of the Action Learning SET by confronting them with the contrast between their reality and possible scenarios obtained through the application of the principles of production management investigated in this thesis. Therefore, his initial attempt intended to create a "learning mood" by applying the "push learning" approach.

7.5.4.2 DESCRIPTION OF THE SUBJECT OF ANALYSIS

During the first meeting with the Action Learning SET the researcher suggested focusing the study on the bricklaying activity in order to benefit from his existing "Learning Bank". The SET members accepted the suggestion and indicated a construction site located in Devizes, southern England, as the target for this investigation. The site comprised the construction of a new single storey primary school with a gross floor area of approximately 881 m^2.

The construction was founded on part solid and part suspended ground slab with a lightweight steel frame. The external walls used brick cavity construction with aluminium windows and hardwood external doors. The roof was predominantly a steel deck construction covered with aluminium sheeting. The design also specified conventional mechanical and electrical services and a gas fired heating system. Figure 7.3 presents an external view of the construction as it was at the beginning of the research.



Figure 7.3 – View of Case Study 7

The foundation, concrete floor and steel structure were already constructed at the start of the data collection. The roof was in the last stages and the bricklaying subcontractors had already completed the external walls and were halfway to completing the internal walls.

7.5.4.3 DATA COLLECTION AND PRE-ANALYSIS

The entire diagnosis process took four weeks during November 1997 and used the same protocol used in the previous six case studies. The fact that the site manager was one of the Action Learning members facilitated the access to archival records and the openness during daily conversations. The data collection itself took two weeks and was carried out by the researcher alone. Appendix 5 summarises the quantitative and qualitative information collected during this period. Table 7.1 summarises some of the principal observations related to the application of the principles in study.

Table 7.1 - Facts from Case Study 7 and their Relationship with the Principles in Study

PRINCIPLE	FACTS
Reduction of Cycle Time	♦ Excessive volume of batches attributed to the long distance to suppliers ♦ Large quantity of small spots of work-in-progress throughout the building, mainly in the interface with the steel structure ♦ Excessive distance between workplace and mixer (>100m) ♦ Delays in the assembling of scaffolding and frequent design changes resulted in poor synchronisation between processes
Reduction of Variability	♦ Systematic measurement, identification and elimination of root causes have never been carried out by any of the workers ♦ Standardisation was non existent and the design was practically the only tool used to communicate the desired product outcome ♦ No poka-yoke devices were identified.
Increase of Transparency	♦ The bricklaying process was relatively inter-dependent of other processes regarding the definition of flows and design interfaces ♦ There were no visual controls or information displays in the workplace or surrounding environment ♦ There was no systematic activity to maintain a clean and orderly workplace, though the site was in an acceptable condition
Build of Continuous Improvement	♦ There were no regular formal problem solving activities ♦ Informal problem solving activities took place when it involved design and specification problems. However, there was no attempt to discover the root cause of problems or elaborate more definitive solutions ♦ The site manager was the only person responsible for devising improvements on the site ♦ There were no standards available to be used as hypotheses of best practice ♦ The only control verified was the schedule control and even that was not used to feedback improvement activities ♦ The bricklayers had no previous exchange of ideas or information with the upstream operations (e.g. roof, design)

Table 7.1 shows that there was a general lack of most heuristic "implementation approaches" investigated in this thesis. Furthermore, the few practices that matched the implementation approaches were not integrated in a coherent system. The roof subcontractor, for instance, had started a long time before the bricklaying activity ("change in the order of the process"). This practice could offer a significant benefit in terms of compression of time and reduction of delays due to bad weather. However, there were no continuous improvement activities for capturing the lessons learnt, or attempts to bring both trades to discuss ideas of how to improve the interface between their operations (e.g. "standardisation").

In summary, the bricklaying process in this case study, just like the others observed previously, lacked adequate implementation and integration of flow principles. Figure 7.4 illustrates the poor situation of this case study regarding the pattern matching analysis. Open-ended interviews, photographs, filming and quantitative indicators collected during the two weeks spent on this site helped to substantiate this finding (*see* Appendix 5.

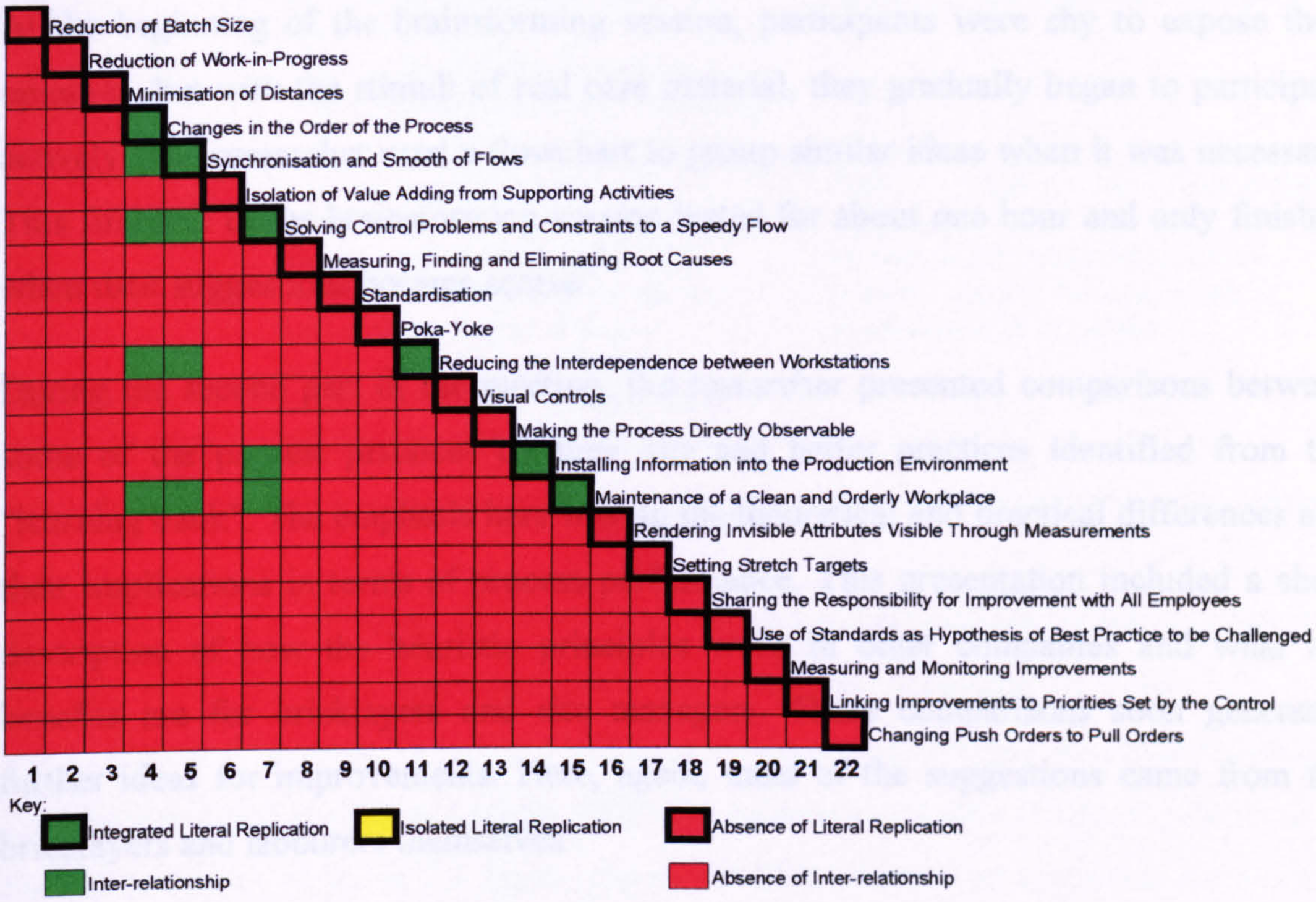


Figure 7.4 – General Pattern Matching Assessment of Case Study 7

It was difficult to establish which of the four theoretical principles should receive priority in the formulation of an action plan for this company. But, nevertheless, it was envisaged that the pre-analysis would be useful in initiating a discussion with the people on site, as described next.

7.5.4.4 BRAINSTORMING SESSION ON SITE

Following the data collection, the researcher organised a meeting on site in order to improve his analysis of the situation by gathering the worker's and site manager's opinion. The meeting took the form of a brainstorming session and had the participation of the site manager and the two bricklayers and labourer involved in the process under

analysis. At the beginning, the participants were told about how a brainstorming session works since that was the first time they had a meeting of this kind. The session continued with a presentation of all information collected during the two observational weeks, including photographs, work sampling graphics, filming, quantitative indicators and flow diagrams. The presentation of quantitative data included comparisons with benchmark references.

At the beginning of the brainstorming session, participants were shy to expose their opinions, but with the stimuli of real case material, they gradually began to participate actively. The researcher used a flowchart to group similar ideas when it was necessary. This first half of the brainstorming session lasted for about one hour and only finished when their suggestions became scarce.

During the second part of the meeting, the researcher presented comparisons between some of the poorest practices on their site and better practices identified from the "learning bank". The emphasis here was on the theoretical and practical differences and their implications in terms of process performance. This presentation included a short description of how the heuristic principles work in other companies and what the benefits are for bricklayers and site managers. These comparisons soon generated further ideas for improvements. Here, again, most of the suggestions came from the bricklayers and labourers themselves.

Table 7.2 presents the ideas suggested in the first and second part of the brainstorming session according to the researcher's interpretation of the intended aim. The suggestions for improvement were fairly distributed among process and operations. However, it was clear that the workforce did not understand the difference between process and operations, or the practical implications of this differentiation. The emphasis of their suggestions was usually on changing equipment and not on eliminating process steps.

Table 7.2 – List of Ideas Produced during Brainstorming Session on Case Study 7

	IDEAS	
FOCUS	**FIRST HALF**	**SECOND HALF**
FOCUS ON PROCESS	Planning the storage Planning the work in packages Assembling loading bays on scaffolding Smaller equipment to transport mortar (aimed at reducing batch size) Buying half blocks To design the building in module To use windows that follow the module	Reduce the size of the pallet Diagonal lift to supply materials on the scaffolding (reduction of movements) Design integration Improve communication with design
FOCUS ON OPERATIONS	Improving access ramps Installing ladders on scaffolding Developing telescopic scaffolding Changing spot-board for plastic box Reducing the weight of blocks Buying only 25 kg cement packs Improve drainage on concrete floor Reduce gaps on scaffolding's platform	Better wheels on transportation equipment Mechanised transport of pallets Improve gears of the manual lift Mechanised lift of pallets

At the end of the meeting, the researcher asked the participants to select what they thought to be the most important ideas from the list presented in Table 7.2. Each participant could choose five ideas and the vote was secret. Secrecy was important since the labourer's and bricklayers might otherwise be afraid of contradicting the opinions of the site manager. As Table 7.3 shows, the distribution of votes revealed that the workers were more concerned with those solutions that reduce cycle time. Notice that the solutions they had chosen always seemed to lie outside the operatives blame This meeting ended with the formulation of an action plan following a 5W2H structure (*Who? Where? Why? When? What? How? How much?).* The plan focused on the five most voted improvements shown in Table 7.3. The participants were reminded that this action plan would be suggested to the Action Learning group, but there was no guarantee that they would accept or implement it.

Table 7.3 - Priorities of Improvement Following Brainstorming

PROBLEM	Votes	Cycle time reduction	Reduction of Variability	Increase of Transparency	Continuous Improvement
DESIGN (13 votes)					
Design in module	4	XXX	XXX		
Improving communic. with designer	3		XXX	XXX	XXX
Planning the work in packages	4	XXX		XXX	
FORKLIFT (7 votes)					
Hiring a Mechanical Fork lift	3	XXX			
Improving the gears of the manual lift	1	XXX			XXX
Developing diagonal lift	1	XXX			
Reducing the size of pallets	1	XXX			XXX
Installing loading bays on scaffolding	1	XXX	XXX		
WORKING CONDITIONS (5 votes)					
Improving site conditions (ex: ladders)	2		XXX		XXX
Only 25 kg cement packs	1	XXX	XXX		
Reducing the weight of blocks	1	XXX			
Changing wheels of wheelbarrow	1	XXX			

7.5.4.5 PRESENTATION OF FINDINGS TO THE COMPANY

A report named "*Diagnosis of Bricklaying*" summarised the detailed analysis of their existing bricklaying practice along with the quantitative and qualitative data. Illustrative examples extracted from the "learning bank" depicted the meaning of the pattern matching analysis. The description of the proposed *5W2H* action plan included the relationship of the problems with the performance on sites. The report recommended that the actions should be implemented as early as possible, in order to avoid the risk of people losing motivation and commitment towards improvements.

All members of the Action Learning SET and the Chairman of the company received a copy of this report. Additionally, during a meeting of the Action Learning SET at Salford University, the researcher had the opportunity to give further explanations of the main ideas for improvement and the connection with the principles in the study. This presentation used video footage of the site in order to reinforce the connection between the report and the reality observed on site. The main idea was to motivate the group to elaborate a plan and take immediate action with respect to the problems presented in the report.

7.5.4.6 MAIN OUTCOME OF THE "PUSH LEARNING" ATTEMPT

Despite the incisive attempt to promote improvements in the production system, the response from the company staff was a great disappointment to the researcher. The poor practice and performance of the bricklaying process demonstrated in the report did not lead the members of the Action Learning SET to elaborate and implement improvements. Rather, the site agent of the site under investigation became very defensive and his colleagues backed him up. Even though the site agent had participated in the data collection and analysis, he was not able to accept the contents of the report. The situation was rather puzzling since all members had shown, at the beginning of the research, a clear commitment to elevate their standard practices to higher levels and to develop innovative ideas. During this period, the researcher began to have serious doubts regarding the actual meaning of "*Action Learning*" since the group was not taking any action at all. Like many teachers that fail to convince learners to change, the thought that the learners were to blame.

Researchers from the Revans Centre, responsible for supporting the Action Learning SET, revealed later that the actual reason for the lack of actions among the SET members was the nature of report itself. According to them, the managers were extremely concerned with the impact that the report would have on their image as competent professionals, particularly on the site manager who helped in the diagnosis. After all, this internal image would have direct consequences on their own job security and promotion within the company. As a result, the findings of the report were put aside and the suggestions for improvement ignored.

The belief that management has a hidden agenda when introducing new practices is a normal reaction in organisations according to the literature. Carlopio (1993) asserts that change in practice usually happens due to competition threats rather than positive agreements considering individual benefits derived from change. Broome (1990) also agrees that imposed changes, such as the ones attempted in the first part of this learning exercise, carries the risk of provoking negative reactions in any company, such as denial and blaming others.

7.5.5 "GESTATION" PERIOD

In the immediate period after presenting the report "*Diagnosis of Bricklaying*" there has been not a single action from the construction Action Learning SET being supported. Yet, the waste implications of the flow problems found on site were unequivocal and required prompt action. The next paragraphs attempt to explain the reasons why the researcher came to understand that this was need for a necessary 'gestation' period for the SET members.

Although change in Action Learning occurs in an emergent, rather than planned fashion, the "Three-Step Model" described earlier in this chapter provides a good structure to explain what was actually happening within the SET. The mutually supportive environment provided by Action Learning had enabled the SET members to flounder around in the search for new ideas without direct pressure from daily business (Powell, 1999). In this environment of 'floundering', the SET members were open to 'unfreeze' their existing working practices, as recommended in the first stage of the "Three-Step Model" of change. Their freedom to think and reflect on the business problems had given them the confidence to accept the analysis of bricklaying without necessarily having to agree with the researcher's conclusions.

The problem was simply that the researcher had tried to "push" better production management ideas onto contractors which appeared to be most appropriate to help this company reduce waste and increase productivity. This "push learning" approach helped open up the processes of change by 'unfreezing' the SET members' thinking about process flow and waste and by confronting them with the actual facts observed on site. According to the Three-Step Model, the next step in implementing change should be a move to a new level of thinking, where learners would analyse the present situation and identify alternatives and then select the most appropriate course of action. The subsequent step should be stabilise the SET new ways of working in order to ensure that these ways are relatively protected from regression (Burnes, 1996).

However, what often happens after the 'unfreezing' period is what Powell (1999) calls 'requisite mythering', as illustrated in Figure 7.5. This is a period where a SET needs 'time to think' about the new ideas through continuous discussions and questioning within the group. This is perhaps the most important period in the change process since

it determines the level of ownership and commitment of the SET members towards the maintenance of present actions and development of further improvements.

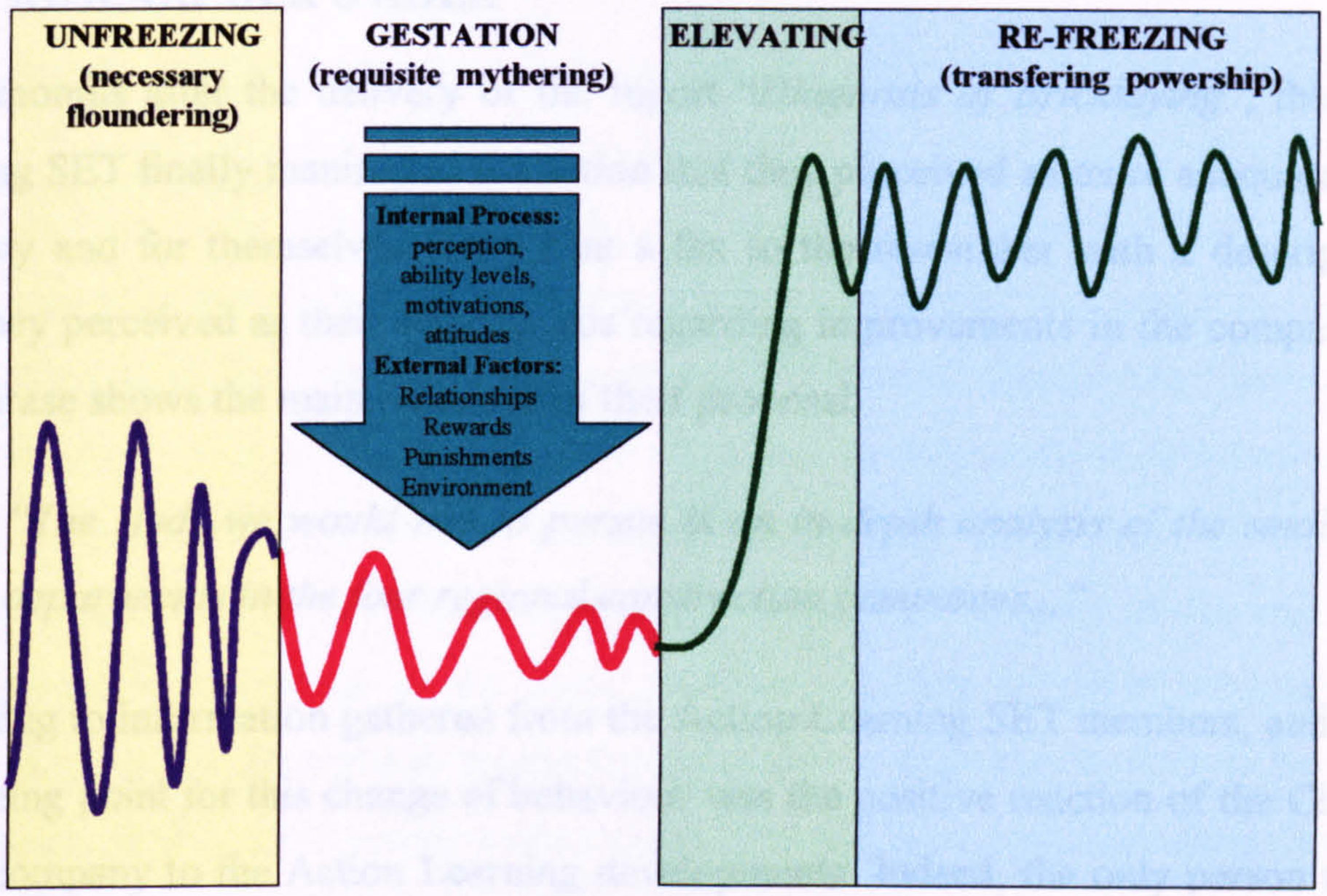


Figure 7.5 – Representation of Successful Gestation of Ideas within Action Learning

In order to achieve a successful 'gestation' of ideas within Action Learning it is important to provide adequate conditions for both internal and external factors that affect the learning process. In this way, the perceptions of the individual within the SET, their ability levels and their attitude towards new ideas are critical conditions to SET members own new ideas. Poor attention to '*motivator factors*' such as the sense of achievement, recognition, responsibility and personal growth, or '*maintenance factors*', such as salary and job security, can prevent learning from occurring (Mullins, 1993).

Action Learning seems to be able to create the right conditions presented above and contributes to an effective gestation of new ideas and their transformation into effective lasting practices. The dynamics of this approach helps people to overcome their initial reluctance to transform their words into action and begin to question old practices and to suggest new ways of doing things. The account of facts presented in the next section confirms that view.

7.5.6 "PULLING" THE LEARNING

7.5.6.1 RESEARCHER'S ROLE

Three months after the delivery of the report "*Diagnosis of Bricklaying*", the Action Learning SET finally manifested the action that they perceived as more adequate for the company and for themselves. They sent a fax to the researcher with a description of what they perceived as their actual needs regarding improvements in the company. The next phrase shows the main objective of their proposal:

> *"The study we would like to pursue is an in-depth analysis of the small works departments in the four regional construction companies..."*

According to information gathered from the Action Learning SET members, and others, the turning point for this change of behaviour was the positive reaction of the Chairman of the company to the Action Learning developments. Indeed, the only person to get a rise in salary in that year was the manager of the site where the diagnosis had been carried out. This fact gave confidence to the managers with respect to the consequences of exposing problems occurring in their own area. The potential threat of losing their jobs was substituted by a re-affirmation from top managers of the need critical reflection on current practices and that improvement was indeed necessary and could lead to individual rewards.

7.5.6.2 DESCRIPTION OF THE SUBJECT OF ANALYSIS

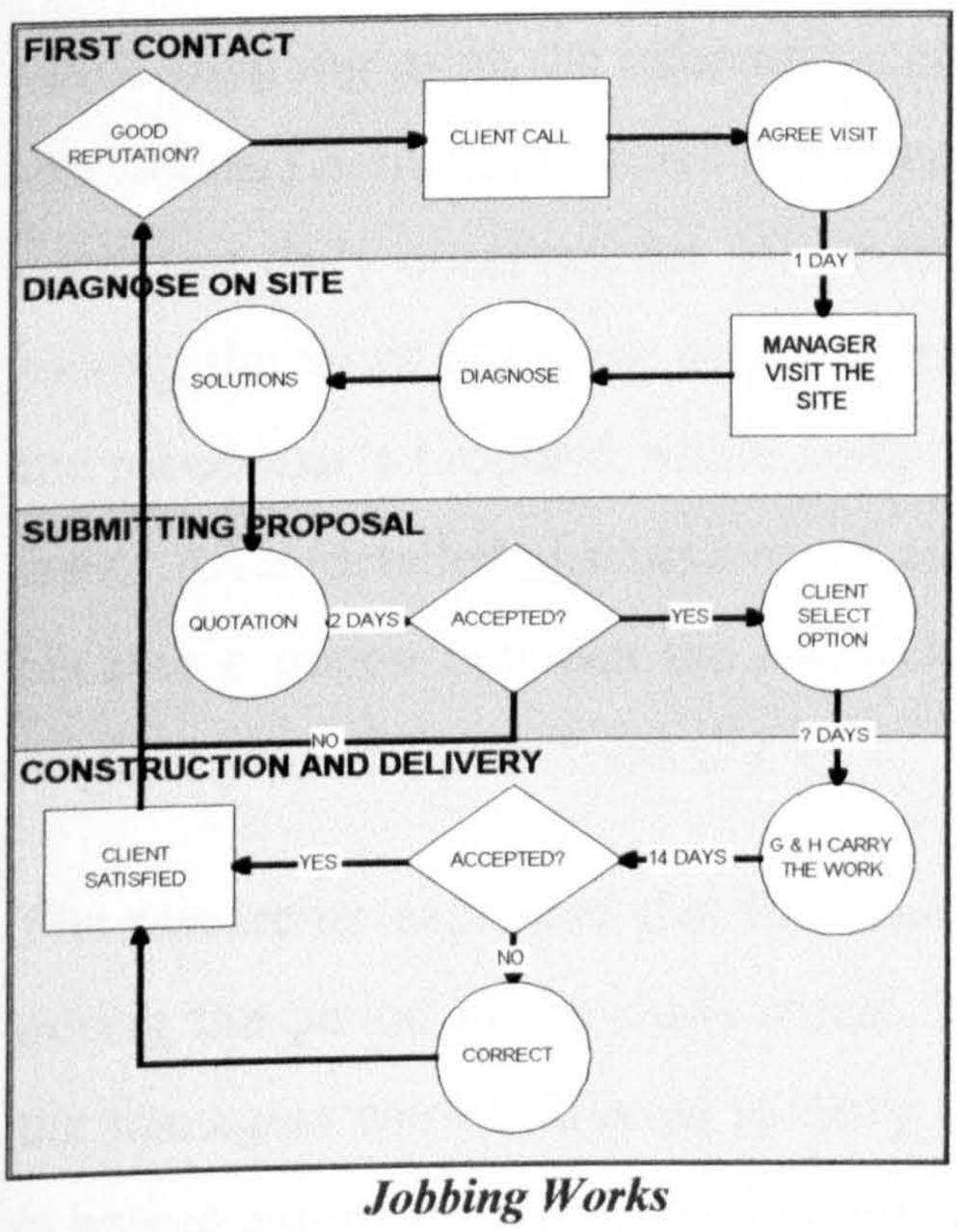
As requested by the Action Learning SET, a further analysis focused on their Small Work's Unit (or Department). This Small Work's Unit was responsible for any contract below £200,000.00. Contracts over that sum were classified as Major Works. According to the SET members, two main factors motivated them to investigate this particular organisational unit. Firstly, it was reported to the Action Learning SET that the overall margins generated in the Small Work's Unit, throughout the company, had decreased over the past few years, despite increasingly hard work by its staff. Furthermore, the group considered this Unit as an important source of revenue and an important way by which the company gained access to further work. Secondly, the report "*Diagnosis of Bricklaying*" brought attention to the urgent need to eliminate non value-adding

activities. In short, the SET now had the confidence to define their own learning needs and to specify to the "Knowledge Supplier" precisely what they wanted to learn about.

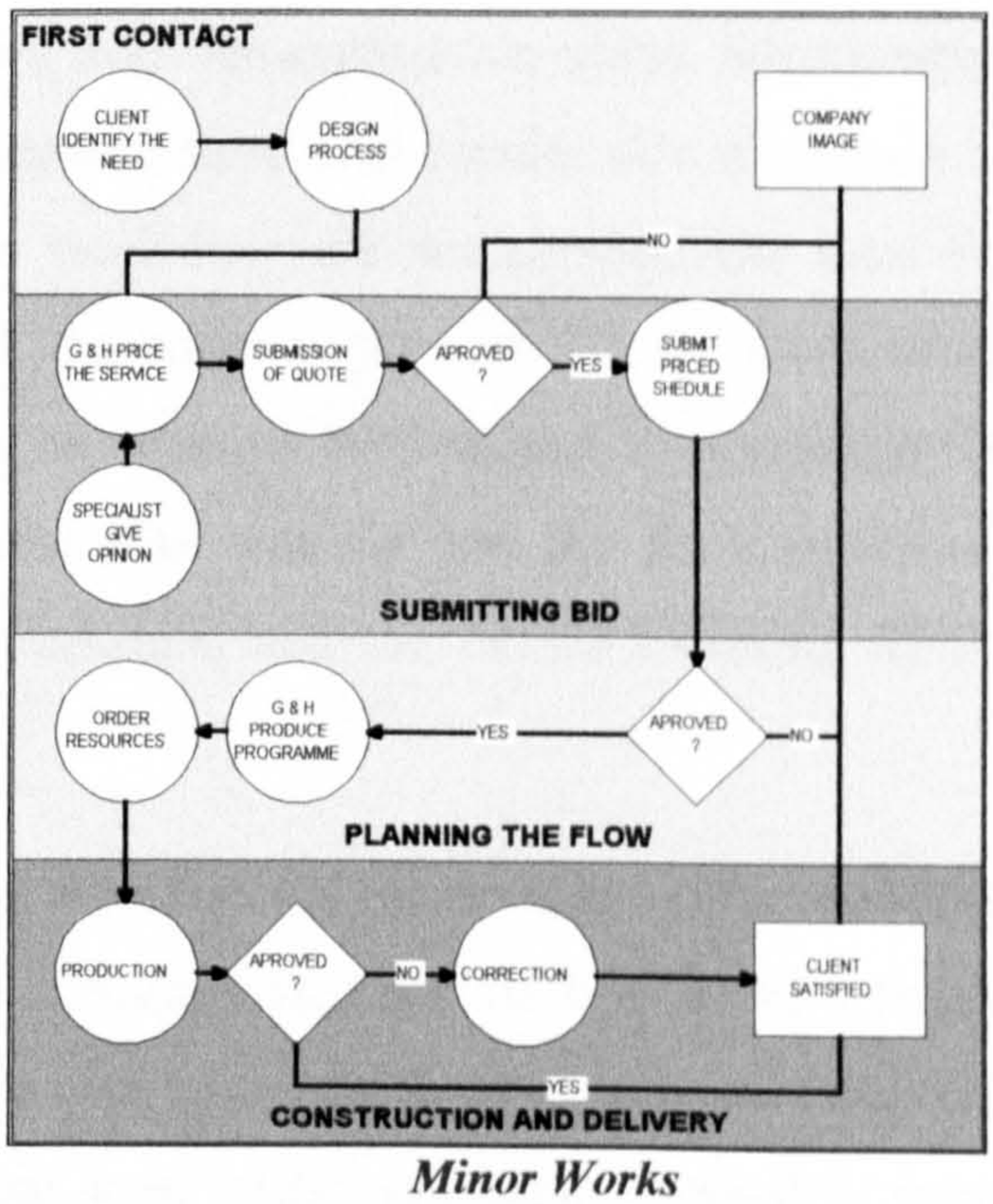
7.5.6.3 DATA COLLECTION AND PRE-ANALYSIS

a) Exploratory Visits

In order to plan the study, the researcher carried out exploratory visits to the Small Work's Unit of all four branches of the company (*Warwick, Warminster, Bournemouth and Dorchester*). One of the aims of these visits was to understand their actual business process, both to *Jobbing* (<£5.000) and *Minor Works* (between £5.000 and £200.000). The visits also aimed to gather information concerning performance of the unit and the staff opinion with respect to the main problems of their business processes. This information was fundamental to enable the researcher to elaborate diagnostic techniques connected with the staff's actual needs and limitations. Each visit took about half a day and consisted of open interviews with branch managers in their office and a visit to a typical construction site. Direct conversations with operatives improved the researcher's understanding on how the company operated. Among the results from these exploratory visits was a working description of the business process of Jobbing and Minor Works, as illustrated in Figure 7.6.



Jobbing Works



Minor Works

Figure 7.6 - Business Processes gathered from the Exploratory Visits

The exploratory visits revealed that the Small Works' Unit had basically three different types of clients: Domestic clients, Commercial clients and Insurance clients. One of the important differences between them was their knowledge about construction. The Domestic clients typically had little, or no, previous experience with construction while the Commercial client (companies, council, hospital, etc.) presented considerably more experience since they had to have regular maintenance and repair work. This factor is very important for business process analysis since each of these clients require a different approach for information gathering and decision making.

b) Planning the Data Collection

A meeting was set-up at the headquarters of the company soon after the exploratory visits aimed at establishing the diagnostic procedures to be applied. The researcher suggested at this meeting that the analysis should focus on the business process and involve all hierarchical levels of the company. He also suggested that the central focus of the study of the business process would be the distribution of the managerial time. In order to investigate this aspect it was suggested using a statistical instrument that followed the same logic of the work sampling technique. Due to logistical constraints, it was agreed that the managers themselves should carry out the observations.

At this point of the meeting, the researcher presented a data collection worksheet for work sampling using the information collected from the exploratory visits. Surprisingly, the Action Learning members had already prepared their own version of a worksheet to carry out daily observations. However, their worksheet did not consider the need for linking the work sampling observations with the business process. On the other hand, the researcher's proposal, while comprehensive, was too burdensome to operate in the field. After detailed discussion, an agreement was reached and the final worksheet became a fusion between the researcher's worksheet and the Action Learning SET's original proposal (*see* Appendix 4).

The researcher explained that the assumption was that the distribution of the activities during the period of the study would follow a Normal Distribution Curve. As a result, the managers were instructed to carry out the data collection only on typical days. The consequence of this recommendation was that some of the managers decided to avoid days near the Easter week where there was a slow down in the pace of work. The

balance between the need for rigour and the constraints of time available for data collection led to the definition of 68% as the statistical confidence level (correspondent to one *standard deviation* on the Normal Distribution Curve). Instead of robust statistical evidence the Action Learning SET expected only insights that could lead to effective actions.

During the same meeting, the Action Learning SET presented and discussed the data already available with respect to the financial performance of the Small Work's Unit in the different markets. The members considered this information an important input to improve the practical application of the study. The Chairman of the company was responsible for compiling this particular set of data. It consisted of Invoice Values, Cost, Profit Margins, Overheads and Net Profit for each client and each branch.

The Action Learning SET decided that all workers would get involved in the study through their own analysis of one of their own construction processes. They chose the "painting" process as an example since it was found in all company branches and represented a significant part of the volume of work in the Small Work's Unit. Following advice from the researcher, it was agreed that the painter's data collection would involve photographs, a simple flowchart and daily notes on any operational problems or constraints to speedy work.

c) Data Collection

Between 7th April and 24th April 1998 the managers of the Small Work's Unit carried out 976 snapshot observations of their own activities. The period of data collection was considered as typical, without any special facts that could change the validity of the results. The "estimating" activity became the key variable to define the number of observations, since it was the most frequent managerial activity. Thus, based on the period of observation, the percentage of time spent "estimating" new jobs was 26%, resulting in 5.4% of relative error in the formula below[2] (Barnes, 1980).

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2 Note that for for confidence level of 95%, which corresponds to two standard deviations, the work sampling formula is (Barnes, 1980):

$$S = 2 * \frac{\sqrt{p * (1-p)/N}}{p}$$

S = relative error
p = percentage of the activity under analysis = 26% (activity chosen: *estimating*)
N = number of observations = 976

$$S = \frac{\sqrt{p * (1-p)/N}}{p} = \frac{\sqrt{0{,}26 * (1-0{,}26)/976)}}{0{,}26} = 5{,}4\%$$

The formula above is valid for 68% of confidence level (*see* item 4.5.3.2). It means, for instance, that every 68 times out of 100 that someone watched a manager working, he would be involved in the "estimating activity" in 26% +/- 1,3% of the time.

The worker's data collection did not present any great difficulties and was carried out in parallel to the manager's data collection. During the first day of data collection at each branch, the researcher had the opportunity to explain the objectives, procedures and benefits of the study for the workers. Firstly, the painters described their process flow in a simple flowchart with the researcher's assistance. Secondly, they received a disposable camera in order to get visual images of what they considered "best practices" or typical process problems. Thirdly, the painters were asked to make daily notes on the problems they were facing and relate that information to the process stages described in the flowchart. In this way, the Small Work's diagnosis had reached all levels of the organisation and included information from various perspectives on the performance of the business process.

d) Pre-Analysis

The aim of the pre-analysis was to organise the information and put forward the researcher's main findings from the point of view of the principles in study. In this way, the challenge of this pre-analysis was to integrate the large variety of data and findings in a consistent and concise manner. The strategy has been to reference all data and findings to the correspondent stage of the business process and then perform the analysis from a theoretical point of view. The data enabled the generation of various graphics that answered specific questions that the Action Learning SET had raised during the previous meeting. Most importantly, the content of the observations enabled the link between the use of managerial time, market focus and business process, as desired by the SET members. For instance, Figure 7.7 shows the proportion of managerial time dedicated to each phase of the business process.

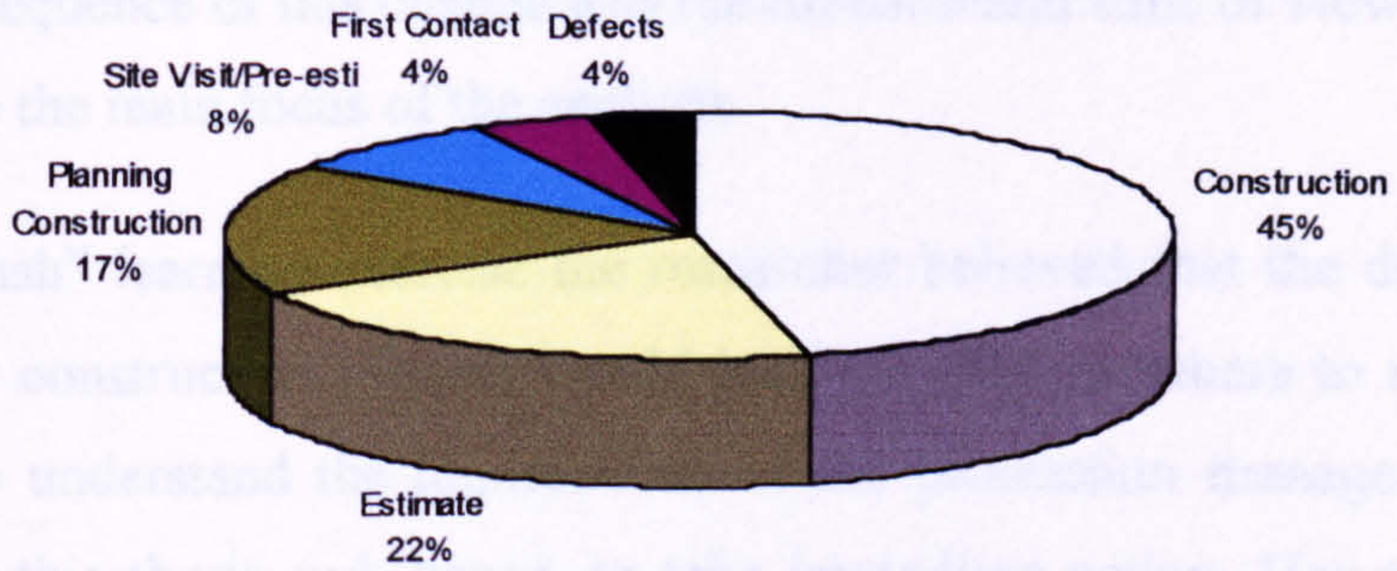


Figure 7.7 –Use of Managerial Time throughout the Business Process

The fact that the researcher had the opportunity to circulate freely throughout the entire company gave him a broad view of the way the various branches actually operated the business process. Questions such as "*What is the market focus at the Dorchester branch?*" or "*What is the media most often used by managers?*" helped to focus the analysis on the actual needs of the Action Learning SET. Each of these questions received a list of suggestions for improvement based on the available "learning bank" and on the suggestions obtained during the conversations and open-ended interviews throughout the company. The production management principles in study were the main instrument used to explain the impact of applying the improvements in the business process.

7.5.6.4 PRESENTATION TO THE COMPANY

The only media used to present the findings had been the report "*Diagnosis of the Small Work's Unit*". This report was compiled using the researcher's own findings and all the principal information available about the Small Work's business process. All members of the Action Learning SET, and the Chairman of the company, received a copy of this report.

7.5.6.5 MAIN OUTCOMES OF "PULL LEARNING"

This new learning experience involved the active participation of the Action Learning SET in the definition of what should be the focus of the study and how it should be carried out. In other words, the SET members were in charge of the learning process

and "pulled" only the knowledge they found suitable for their needs. The most important consequence of this change was the fundamental shift of view with respect to what should be the main focus of the analysis.

During the "push" learning exercise the researcher believed that the diagnosis carried out in a single construction process would lead the SET members to understand their weaknesses, to understand the implications of the production management principles investigated in this thesis and, hence, to take immediate action. However, the Action Learning SET came out with a very different view of what should be the strategy of action. It was only when they took control of their own learning that they took time to develop their own approach for analysis. They then believed that an analysis of the business process of the Small Work's Unit would be more useful and meaningful, as Figure 7.8 illustrates. Again, this change of attitude only happened because they realised that this sort of analysis was not a threat to anyone and, in fact, could even generate individual benefits.

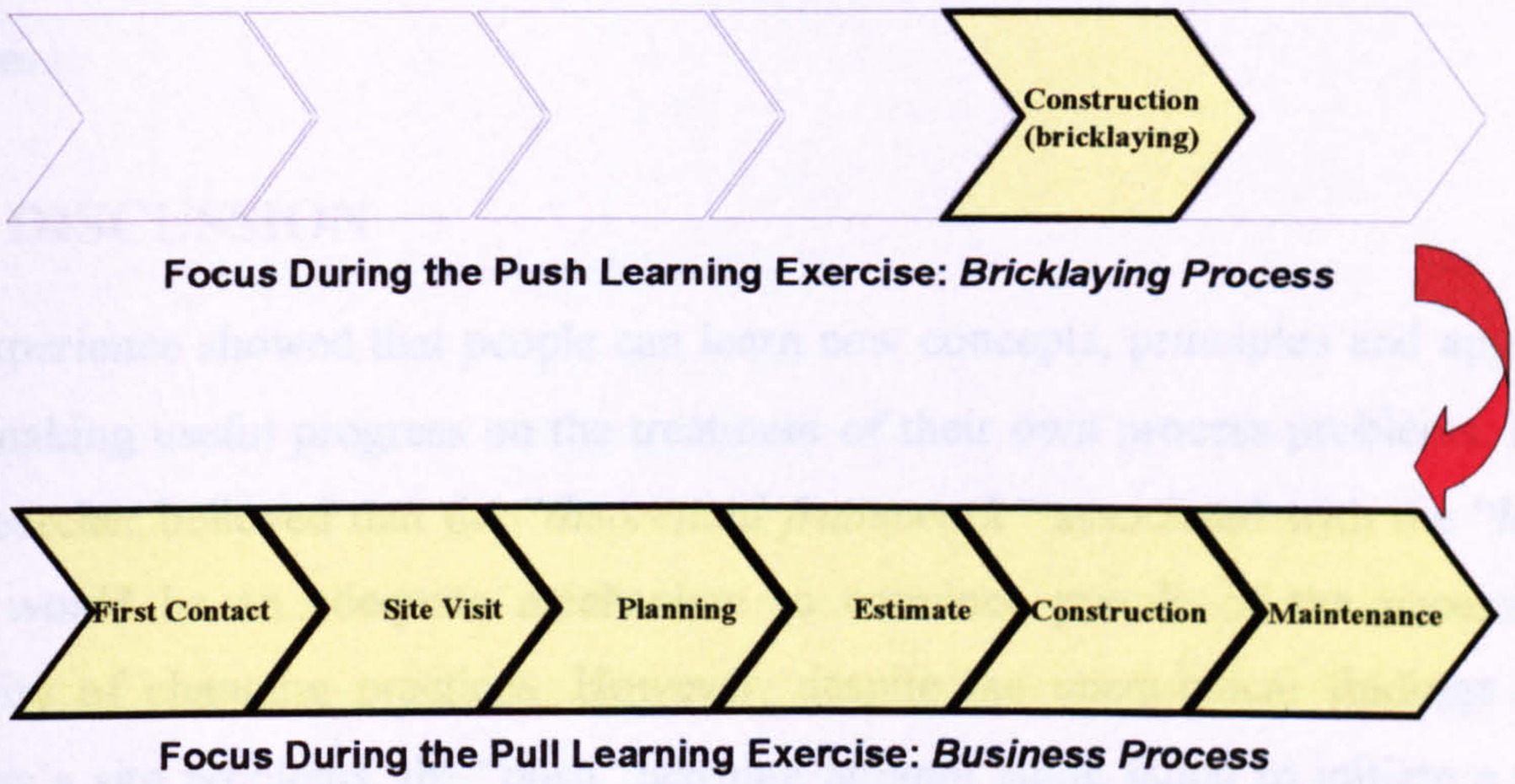


Figure 7.8 – Contrasting the Focus of the Study throughout the Study

This full involvement of the Action Learning SET in the definition of what they wanted to analyse and how to carry out the study resulted in higher motivation throughout the entire diagnostic process and higher connection of results with their actual needs. Moreover, their deep understanding of the organisational structure, values and norms, helped them to obtain a more precise definition of the exact questions that needed to be answered. For instance, the fact that they wanted to include the financial performances

in the analysis was not in the original plans of the researcher. However, financial prioritisation was among the SET main preoccupations when developing or assessing solutions.

As the Action Learning group had defined what they wanted from the researcher, his role underwent a change of emphasis from "solution provider" to "knowledge provider". His contribution focused on the guidance and advice concerning data collection techniques, theoretical ideas and the supply of practical examples. In addition, the researcher also had the opportunity of integrating new views during this experience. For instance, according to the Action Learning SET's original view, their focus should be on "*the identification of the markets that produce the optimum returns, taking into account the staff input, and then focus the majority of the company's effort on these market sectors*". In this respect, the researcher brought attention to the need to reduce non value-adding activities and increase the proportion of value-adding activities in the entire business process. Hence, managers began to understand the importance of understanding the whole business process as a flow and not as a set of conversion activities.

7.5.7 DISCUSSION

This experience showed that people can learn new concepts, principles and approaches while making useful progress on the treatment of their own process problems. Initially the researcher believed that the "*theoretical framework*" associated with the "*learning bank*" would be an adequate mechanism to convince people of the necessity and feasibility of changing practices. However, despite the unequivocal findings on this company's site problems, the "push" learning attempt alone failed to initiate a process of change because it was seen as a threat, not an opportunity. This happened not because the members of the Action Learning SET did not understand the findings but because these findings were not the information they were looking for, or even interested in. It reinforces Revans (1983) opinion that the intervention of experts in the actions carried out by an Action Learning SET is often ambiguous and should be discouraged.

In contrast, the experience of "pull learning" appears to have a better effect on changing peoples' will to critically reflect on their own practices. The environment of mutual

support created by the Action Learning SET gave the participants sufficient confidence to investigate and expose the problems of their own processes. Other studies involving the introduction of production theories into practice using Action Learning have also shown similar conclusion. Hirota, Lantelme & Formoso (1999) & Powell (1999) report the application of such approach with construction managers in Brazil and England, respectively, in which the participants had a clear benefit in terms of learning new concepts and sharing meanings about operations management whilst acting on their own problems. The results reported by the authors of that study show greater motivation and commitment of the participants towards the experimentation with the theory in practice.

However, the researcher believes that there is a risk that this total freedom of choice of learning may lead to a lack of focus and usefulness of actions on the company's actual needs. For example, it is possible that the set members in Case Study 7 decided to study the business process of the Small Work's Unit only because it could make their life easier and not because the company needed to increase competitiveness. Further study is needed in this respect to settle instruments that reduce the risk of this diversion of objectives.

7.6 CONCLUDING REMARKS

Although exploratory, this case study has given clear indications that the creation of an effective "learning mood" is more likely to happen in a supportive environment characterised by "pull learning". The case study also showed that managers could not detect all their problems and knowledge needs without fresh ideas from an outsider. In this respect, "push learning" proved very useful in provoking the initial reflection that triggered "pull learning". Therefore, the author believes that a balanced approach between "push" and "pull learning" seems the best way to introduce changes in organisations searching for improvement and innovations in practices.

The segmentation and rational structuring of the theory of production management makes the analytical process easier from an analyst point of view. Such reductionism allows the classification of case material, and construction of findings, in a more coherent and concise manner. In this respect, the use of a theoretical framework is a

helpful mechanism to enable the transfer of know-how from a "learning bank" to diagnostic reports.

In this context, the model of "know-how" transfer proposed by Lillrank (1995) is seen to be useful in practice. In other words, the abstraction of practices appears to be an effective instrument in enabling the transfer of knowledge across organisations and countries. Nevertheless, the communication of abstract findings to the workforce only worked when they had the knowledge presented at a level of abstraction which suited them and when they were motivated to accept that knowledge. They only manifested clear understanding of the abstract principles when the researcher was able to show real examples, preferably referring to similar processes, in similar situations to the ones they were engaged in practice.

The lack of preparation and previous training of the staff with respect to the principles in this study contributed to the difficulties in transmitting direct high abstract findings to the workforce. Therefore, it is hypothesised here that the communication of findings in an abstract fashion alone would only be possible if the workforce and managers had previously developed a sufficient cognitive understanding of the abstract principles under study. According to Hallpike (1979), cognitive development involves the progressive liberation of thought from the concrete phenomenal aspects of the present reality, towards the ability to operate in a purely conceptual manner. With this cognitive development in place there should be no constraints to express report findings in abstract terms.

7.7 SUMMARY

'Change management' and 'learning' needs to be incorporated into the main considerations of all researchers that deal with the introduction of principles of production management in the construction sector. Change can be treated since a mechanistic and individual perspective until a broad and complex systemic view of the entire organisation. Change can also be a treated as a process of moving from one fixed state to another, through a series of predictable and pre-planned steps or, as a continuous, open-ended and unpredictable process of aligning and realigning an organisation to its changing environment.

The researcher understands that change should not be seen as a one-time event but as part of an ongoing learning process. The literature shows that such a learning process relies on the creation of an adequate "learning mood" among members of the organisation. "Learning mood" is defined here as a state of openness to receive and experiment with new knowledge. This research experimented with two different ways of creating a learning mood in a case study: "push" and "pull" learning. "Push learning" happens when individuals have no power in defining the problem, action or knowledge that is required to improve their own process performance. "Pull learning", on the other hand, happens when individuals have a high control in the definition of the problem, action and knowledge required to improve the performance of their own process.

The results of this case study suggest that "push learning" is ineffective in creating a "learning mood". "Pull learning", on the other hand, was more effective in creating a "learning mood" and enabled the introduction of new knowledge in the organisation. Nevertheless, the "push" approach was useful in provoking the initial reflection that triggered the "pull learning". Therefore, the author believes that a balanced approach between "push" and "pull learning" is the best way to introduce and implement the new production management ideas in construction.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter 8

FINAL DISCUSSION

One never notices what has been done;
One can only see what remains to be done.

Marie Curie

8.1 OVERVIEW

All previous chapters presented detailed discussions into every specific aspect of this research. The discussions presented on Chapters 2 and 3 focused on the context and content of production management theories. Chapter 4 reviews discussed various aspects of the research method and the philosophical approach adopted in this research. Chapter 5 and 6 presented and discussed the empirical evidence collected in the six case studies and meta-case. Chapter 7 presented and discussed the literature review on change management and learning along with a discussion about an exploratory study on 'push' and 'pull' learning carried out on Case Study 7.

This chapter discusses general aspects of the research findings bringing all ideas together to provide an overview. It starts by presenting some of the main findings regarding to the replication of the four principles in study within a construction environment. Then it proceeds with a reminder of the importance and urgent need for promoting fundamental changes at the bottom line of construction organisations. Following this logic, this chapter continues with a discussion of the issues of how introduce new knowledge in construction, based on the experience of Case Study 7. The chapter ends with a review on the implications of the theory investigated in this research in terms of generating innovations in the construction industry.

8.2 REPLICATION OF THE THEORY IN PRACTICE

The evidence from all case studies repeatedly points to a lack of knowledge, organisational support or motivation among managers and workforce to implement the production principles discussed in this thesis. The flow principles proved to be workable in the construction environment but only a few managers were prepared to implement such principles. As a result, even the best case study presented only seventy percent of literal replications and only twenty percent of the expected inter-relationships.

Managers and workers readily had a "good reason" to reject the implementation of the flow principles. They preferred to accept bad, but common practices, rather than trying to achieve higher levels of performance. In this context, the researcher came to understand that "learning" is the most central problem of production management in construction.

Critical analysis of construction practice showed that a fundamental step for enabling a comprehensive implementation of the four principles investigated in this research must start with the establishment of win-win relationships between all construction parties. Solminihac, Bascunan & Edwards (1994) also concluded that teamwork within a supportive environment as the most fundamental requirement to implement better production practices in construction.

A systemic application of the flow principles is likely to affect the effectiveness and efficiency of production processes. Indeed, cases studied presenting better performance showed the larger amount of "literal replications" and corresponding theoretical inter-relationships. This research cannot establish a definitive confirmation of this relationship, since the data collection was not sufficiently comprehensive to enable a rigorous statistical correlation. Nevertheless, the cases studied presented sufficiently contrasting performance and unequivocal visual evidence, that makes it possible to suggest that such correlation actually does exist (*see* section 6.4 for further discussion).

Practitioners in the case studies often questioned about which of the four principles investigated in this research should be considered first in the development of production systems. Obviously, it is not possible to establish a general guideline for this would depend on the maturity level of the production system and on careful consideration of variables such as culture, economics and social structure. The strategic needs of some production systems may require higher attention to "quality" (e.g. reliability) and "cost" whilst others may well require focus on "speed" and "flexibility" to changes in customer orders.

It is worth emphasising that, like Nakane (1989), the researcher understands that improvements in production performance have to pass through a naturally evolutionary process, starting from improvements in quality and time and then progressing towards lower cost and higher flexibility. Therefore, whilst the business survival may require the

focus in one or two competitive criteria in the short term, it seems that a logical and evolutionary sequence is the most likely way to achieve sustainable competitive advantage in the long-term.

8.3 THE NEED FOR CHANGE AT THE BOTTOM LINE

The literature repeatedly shows that the most successful long term strategy for developing a production capability, to cope with uncertainty and pressures for higher performance, is to mastering production heuristics and technology at the operational level (Shingo, 1988; Monden, 1998) (*see Figure 8.1*). Indeed, it clearly will become easier to drive improvements throughout the entire organisation, and supply chain, when it is possible to show similar improvements at the production operational level. Without developing the expertise of personnel at the operational level of construction companies the achievement of a sustainable and creative application of the heuristic approaches presented in this thesis is unlikely to occur.

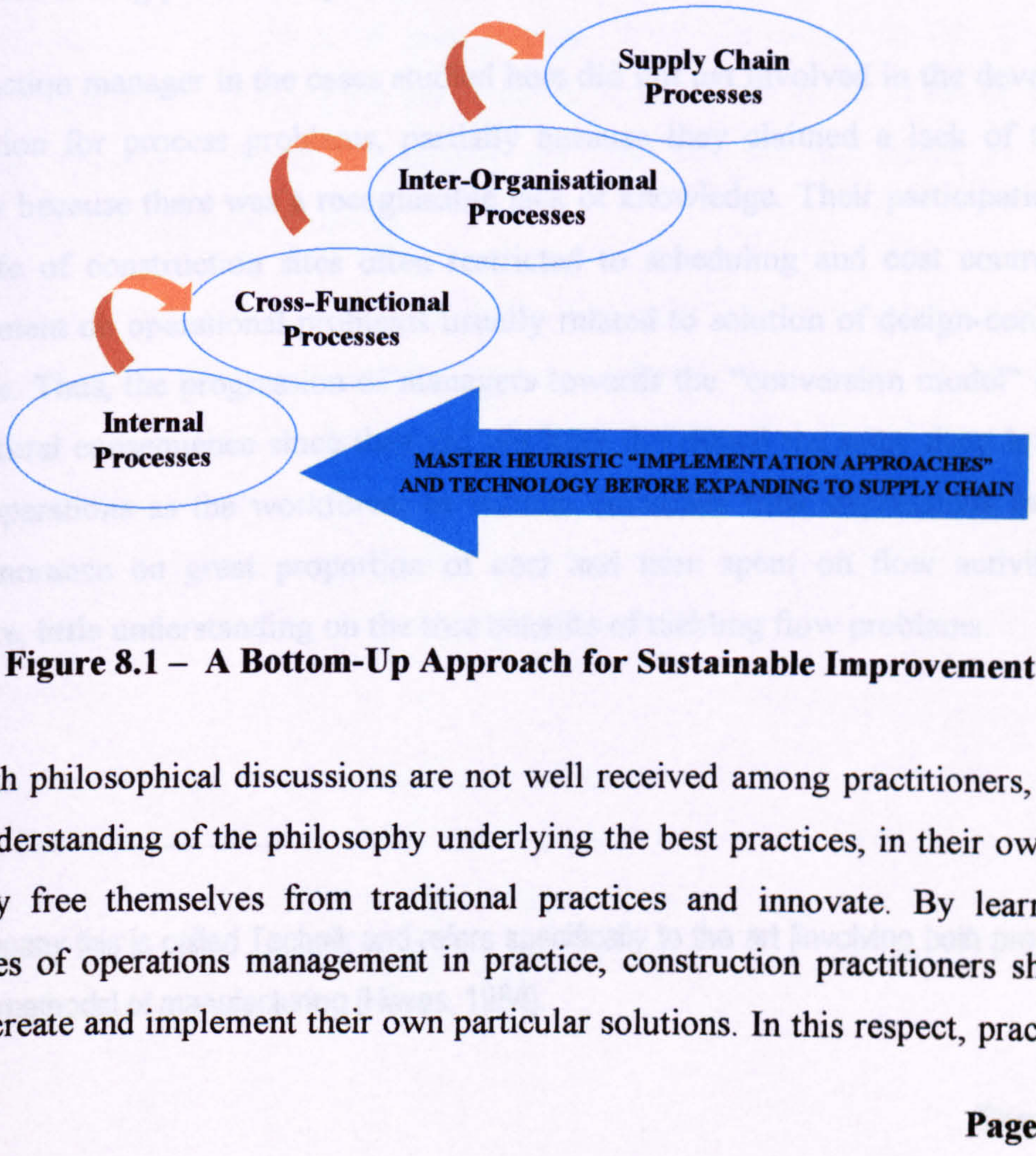


Figure 8.1 – A Bottom-Up Approach for Sustainable Improvement

Although philosophical discussions are not well received among practitioners, only by deep understanding of the philosophy underlying the best practices, in their own terms, can they free themselves from traditional practices and innovate. By learning the principles of operations management in practice, construction practitioners should be able to create and implement their own particular solutions. In this respect, practitioners

in the case studies actually expressed satisfactory understanding about many of the heuristic principles investigated in this research, as well as their implications in practice. However, some of the key heuristic approaches were unknown among most practitioners or they all failed to properly implement them in practice in an integrative manner. Hence, this thesis maintains that practitioners need to possess both the "know-how" and the "motivation" to result in real change of production practices.

Nevertheless, the career structure in construction does not drive site managers, or their workforce to have experiences in developing systematic analysis and development of solutions at the bottom level of production. In contrast, other professions, such as mechanical engineering and electrical engineering, give strong emphasis on the development of the basic skills and knowledge to solve very operational problems early in their career. Also, in countries like Japan and Germany, a thorough domain of the operational side of production is the first step in the career progression of most production managers in the manufacturing industry. In Germany, for instance, the technical expertise of a manager is recognised as a key factor to facilitate his/her acceptance among production personnel[1].

Construction manager in the cases studied here did not get involved in the development of solution for process problems, partially because they claimed a lack of time and partially because there was a recognisable lack of knowledge. Their participation in the daily life of construction sites often restricted to scheduling and cost control. Their involvement on operational problems usually related to solution of design-construction conflicts. Thus, the progression of managers towards the "conversion model" seems to be a natural consequence since they did not have developed the same deep knowledge about operations as the workforce. In various occasions their expressions revealed a total ignorance on great proportion of cost and time spent on flow activities and, therefore, little understanding on the true benefits of tackling flow problems.

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[1] In Germany this is called Technik and refers specifically to the art [involving both products and methods] of manufacturing (Hayes, 1984).

8.4 CREATING A LEARNING MOOD TO NEW IDEAS

It became clear throughout the research that the production management literature has to develop a richer narrative concerning implementation issues while improving the robustness of its own fundamental concepts. In this respect, construction research has been marked by the introduction of new ideas of "production experts" onto the construction site with emphasis on "push" learning approaches. It is clearly present already in the early studies of Frank Bunker Gilbreth. In other words, the workforce and site managers often have no say with respect to how they could learn better about production, or what they perceive as their actual production problems, or what they would improve in production given the chance. Nevertheless, the implementation of "pull learning strategies" demands a supportive organisational structure and culture which was not available in the majority of the case studies.

Fortunately, Case Study 7 presented the ideal situation for experimenting with both "push" and "pull learning". The researcher found that "push" learning alone is too ineffective since people may feel unconnected with the content of learning, and even fear from the true intentions of management. "Pull" learning, on the other hand, assumes that people can recognise with relative accuracy the actual needs of their own processes. However, that is not usually the case and the end result may be the perpetuation of traditional practices.

In this context, the results from Case Study 7 suggest that a composition of a "push learning strategy" with a "pull learning strategy" offered better results on the creation of a "learning mood" towards lean production principles. The "push" strategy moves people from their natural inertia and provokes the generation of innovative ideas. The "pull" strategy, in contrast, guided the knowledge provider (researcher) to the actual process needs and increases the commitment of people involved towards the process improvements.

The exploratory study in this construction company also showed that it is possible to achieve the transfer of ideas from one industry to another through abstraction of principles and correspondent heuristic implementation approaches. Yet, adequate understanding of the construction's own peculiarities has still not diminished in

importance since adequate knowledge on that matter is necessary to enable effective adaptation of abstract ideas.

8.5 IMPLICATIONS OF THE THEORY IN INNOVATION

One of the direct benefits of developing a deeper understanding of the principles and heuristics presented in this thesis is the possibility of transforming those ideas into innovative practices and products. Observation of construction practices showed that the implications of the "flow" concept in construction practice still is not fully understood in the construction industry. The dominance of the "conversion" paradigm has limited the focus of innovations to the development of new material, new equipment and new design solutions, without appropriate consideration of the process flows. Furthermore, none of the managers interviewed had shown clear understanding on the importance of analysing the "process" (flow of material or information) first, and only then considering "operations" (flow of equipment or people).

Hence, the use of the flow concept in R & D is, without doubt, a fundamental requirement for enabling higher efficacy of innovations in the construction industry. In general terms, innovations should contribute for reducing non-value adding activities and increasing the efficiency of value adding activities in the sector. The analysis of bricklaying in this thesis illustrates the range of possibilities for generating innovative ideas from the reflection upon "abstract flow principles". The following items present some of these ideas:

a) *Reducing the Batch Size*: the application of this approach in construction could drive a large number of innovations and improvements in the entire supply chain. The development of new packing systems directly adapted to the needs of the workstation is a clear example of viable innovative idea. Pallets were too big and heavy for moving fast across the site observed and, because of that, demanded excessive handling. The transportation system in the entire supply chain could be less costly and slow, with proper application of this heuristic. Indeed, trucks should be smaller and enable more flexibility in terms of variations in volumes for transportation;

b) *Reducing the Work-in-Progress*: the main drive force for innovations here is the challenge of enabling just one visit of each workstation to the workplace in order to complete all operations. In other words, the aim is to equal the throughput of production with the work-in-progress at the level of the workstation. Hence, managers applying this approach in practice are likely to generate innovations in terms of design solutions on the interfaces between processes. Additionally, newer practices in terms of the productivity-related bonus should be developed to drive better working practices;

c) *Minimising Distances*: planning and continuously revising the layout plan could actually a drive for innovation for most of the companies analysed in this research. However, there is a strong need for better tools for developing workflow planning. These could include a more intensive use of IT on the construction site and protocols such as Last Planner. Foremost, workflow planning needs to be developed with the support of the people that actually carry out the work. Therefore, these tools need to be easy for operating and must allow rapid consultation and update. Innovative ideas under the same heuristic should also include the more intensive application of ergonomic studies in workstations and components, in order to reduce the fatigue and effort of construction workers;

d) *Isolating Value Adding Activities from Support Activities*: construction is still a labour intensive industry. Thus, the efficiency of the value adding activities is still heavily dictated by the degree of people's focus on the value adding activities. In this respect, in all set-up activities there is a great potential for developing and applying innovative ideas, since bricklayers spend excessive time with these activities. The challenge for innovators in this topic is then to enable the set-up of a bricklaying workstation within a "single digit set-up time" (set-up carried out in less then ten minutes). The examples presented by Shingo (1988) shows that it has been possible to achieve that even for extremely heavy machinery in the car industry. Thus, reducing the set-up in bricklaying workstation should be far more easier (e.g. compact scaffolding allowing quick assembling and transportation);

e) *Changing the Order of the Process*: the innovations here are mostly related to solutions in the design stage. The focus should be on eliminating the rigid process interfaces or enabling these interfaces to cope with the variability of upstream

processes. Different processes should be allowed to operate independently of each other as much as possible. The idea of a robust design proposed by Tagushi & Clausing, (1990) is very useful here because it requires the identification of the principal sources of variability and the use of this information for developing preventive design solutions.

f) *Synchronising and Smoothing the Flows*: one of the challenges identified here is the need for maintaining continuity of activities across projects, even when the construction company has no other project. Better communication among different construction companies should enable exchange of information on the availability of workforce. It could then enable a feeling of long-term employment among the workforce and, thus, commitment to achieve better production practices;

g) *Solving the Control Problems and Constraints to a Speedy Flow*: critical analysis of the case studied shows that there is considerable room for innovation in the weight, size and packing system of construction material and equipment. Containers were too heavy or big and the packing system offered little help for handling. Another application of this approach is on the reduction of excessive time mangers spent controlling schedule and budget. More intensive use of IT should free construction managers from these activities and enabling them to focus on the construction flows and on the development of better construction practices;

h) *Measuring, Finding and Eliminating the Root Cause of Problems*: the most direct innovation in this respect, seems to be the development of easier and less time-consuming tools adapted for the characteristics of construction sites. Visual scanning and electronic sensors, for instance, are technologies already available that could contribute to the elimination of time spent on measuring a process status. Obviously, such innovations do not eliminate the urgent need for training the construction workforce on the logic underlying these tools;

i) *Standardisation*: written standards were extremely ineffective in the case studies due to the lack of teamwork and problem solving activities. Nevertheless, it became clear that the abstract meaning of standardisation has far larger possibilities than simply developing descriptions of practice in written documents. Information on standards could be displayed in the packing system or equipment, for instance. Most

importantly, information on standard procedures should be available when the worker needs and where it needs;

j) *Poka-Yoke*: there were few "literal replications" on poka-yoke devices across all the case studies. There is substantial opportunity for developing poka-yoke devices for updating existing construction machinery. Interactions with the electronic and manufacturing industries is certainly required for developing such innovations. Critical analysis of construction also showed that there is room for innovations in the design of construction components through the use of the poka-yoke idea. These components should have built-in instruments that reduce the possibility of errors during the assembling process on site;

k) *Reducing the Interdependence between Workstations*: as explained earlier, the innovations here came from solutions in the design of interfaces between processes. Innovations in this area should contribute to reduce the direct interference between processes;

l) *Use of Visual Controls Enabling Immediate Recognition of Process Status*: construction is poor in terms of visual controls despite the high variability found in most construction sites and the large areas for circulation of workstations. Construction machinery and components require the development of visual controls that reduce or eliminate the possibility of errors in production or the need for spending time on measurement and control activities. Andon devices (electronic panels for production control) customised for construction could be an excellent supporting tool for production managers in the sector;

m) *Making the Process Directly Observable*: restrictions in construction sites do not allow direct observation of all process stages in certain phases of the construction process. Alternative tools could be used in this respect such as CCTV video cameras, visual controls attached to workstations and so on. Everyone, including the client, should be able to understand the status of the process when they want it and wherever they are (use of internet);

n) Incorporating Information into the Process: as discussed earlier, this approach is a supporting instrument for a number of other approaches. Information on

standardisation or schedule deadlines, for instance, could be incorporated into equipment, components of the building and pathways. IT solutions could help in this respect with the introduction of information in real time, as it already happens in other industries;

o) *Maintaining a Clean and Orderly Workplace*: most construction managers did not know about 5S programs. Although in other industries it is already normal practice, the author considers that the application of such level of organisation in housekeeping practices is a true innovation in the construction industry. However, 5S programs rely on co-operations and motivation of everyone involved. Hence, it certainly will require better relationship between managers and workforce than what was witnessed in the case studies;

p) *Rendering Invisible Attributes Visible through Measurements*: most construction sites in this research had little information into the actual performance of their processes. The main reason given for the lack of measurements was the fact it is a time consuming activity. Hence, innovative solutions in visual controls and the use of IT could offer an alternative way for obtaining better visibility of the construction attributes;

q) *Setting Stretch Targets*: the barrier for applying this approach in the case studies was the lack of involvement of the workers in decision making or problem solving activities in this respect;

r) *Giving Responsibility for Improvement to All Employees*: all case studies presented little or none involvement of the workforce in continuous improvement activities. Innovations in this area would come with changes in the contractual format and on the bidding system in order to allow long-term relationship between all parties. In addition, the fragmentation of the sector requires co-operation among companies in order to improve the workforce commitment towards continuous improvement. This co-operation could result, for instance, in the development of central databanks that co-ordinate learning material and contracts across different projects and different companies. Obviously, none of these actions must violate the existing 'cartel laws';

s) *Using Standards as Hypothesis of Best Practice*: without involvement of the workforce it is not possible to expect the full implementation of this approach in construction practice;

t) *Measuring and Monitoring Improvements*: the innovations in measurements explained earlier are also applicable for this approach;

u) *Linking Improvement to Priorities set by the Control*: construction managers had difficulties in keeping track with the value and waste produced in each phase of the project. Hence, better tools are required that enable fast update of the status of the process without taking time from management. In this respect, visual controls and IT tools need to be better understood and applied in the sector.

v) *Using "Pull" Instead of "Push" Production Orders*: this approach drives continuous improvement but also affects, and depends on, all other approaches discussed in this thesis. One of the possible innovations obtained from the application of this approach is the establishment of pull production orders using supply chain networks. In the Seventh Conference of the International Group for Lean Construction (IGLC-7), Taylor & Bjornsson (1999) propose that supply chain networks could collaborate and share information using the Internet in the procurement process. The benefits of such innovation would be more efficiency in material manufacturing and distribution decreased material costs to contractors and owners and reduced transactional costs.

The examples of innovative ideas generated through the application of the flows principles presented above certainly depend on the adequate consideration of wider structural and cultural issues in the construction sector. Nevertheless, construction people should fully understand these principles before embarking on wider issues in the sector regarding production management. Only with this level of understanding, would there be systemic appreciation of the full benefit of each practice and the range of complementary practices needed for operating in an optimal level.

8.6 VALIDITY OF THE METHODOLOGY

There has been sufficient empirical evidence in the case studies and meta-case to enable the corroboration of the theoretical propositions. The validity of findings was achieved through the identification of sufficient "literal replications" and "theoretical replications" that matched the predictions described in the theory. It is worth to remind that, according to Yin (1994) a "literal replication" occurs when similar results happen and for predictable reasons. In contrast, when the empirical evidence produces contrasting results, but also for predictable reasons, it is called "theoretical replication".

Another factor that strengthen the validity of this research is the intensive use of the practitioners own interpretation and descriptions of practices on site as main input to explain the observations. Indeed, the empirical evidence presented in this thesis is not the result of speculative conjectures or pure theoretical assertions but the result of close and direct contact with the actual production practice in the construction sector. Furthermore, the validity of findings of this thesis was corroborate by the positive feedback given by practitioners on the case study reports.

The findings do not involve any particular or rare situation in a construction site and neither are could be considered as worst examples of production practice. In reality, most of the host companies were classified by the local competitors as good companies, although they admittedly could not be classified as world-class producers. They were excellent examples of the reality of the construction industry of Brazil and the UK and Brazil and, therefore, this factor also contributes to corroborate the findings.

However, the pattern matching approach is heavily interpretative in its nature since the results rely on the researcher's interpretation of practices and abstract principles. Hence, this approach alone is very useful when there is no room for ambiguity in the application of a particular heuristic and the aim is only to confirm, or otherwise, a literal replication. For instance, the identification of a literal replication relating to the practice of "visual controls" in a particular process stage can only result in a positive or negative answer.

Furthermore, production management theory is in evolution and it is rare to find a heuristic that has an absolute definition. The boundaries between heuristics are often

fuzzy and the interaction has a strong influence in the outcome of a particular practice. Furthermore, the researcher found that there were significant differences among literal replications of the same heuristic across the case studies. The pattern matching alone is limited in this respect because it does not allow establishment of "degree of literal replication". In this context, the inclusion of quantitative indicators and formal analytical techniques were fundamental in this research for determining this variations with greater rigour.

The use of indicator was particularly important in the communication of results to site managers and workforce. Most of them had no previous contact with the heuristics presented in this research. The use of objective data helped them to understand the implications of the researcher's propositions. It also contributed to reduce the complexity of analysis by focusing the attention on a limited group of key variables. Furthermore, the size of some production systems analysed in this research could move the attention of the researcher out of the actual process flow if there were no instrument to systematise observations.

Nevertheless, the researcher does not believe that the use of indicators and hard data can substitute for the systemic comprehension of the abstract principles presented in this research. If all managers and workers shared the same comprehension about the meanings and implications of these principles it is possible that lesser data would be required to present the results of this research. In this respect, it also became clear throughout the interviews that there is serious lack of common terminology among managers and workforce. So, the goal of sharing the same understanding about production management principles will certainly require more efforts in the development of a common language in the sector.

POSITION IN THE THESIS

Chapter 1 *Introduction*	**Chapter 2** *Production Management in Context*	**Chapter 3** *Theoretical Framework*
Chapter 4 *Research Method*	**Chapter 5** *Cross Case Study Analysis*	**Chapter 6** *Intra Case Study Analysis*
Chapter 7 *Exploratory Study on the Creation of a Learning Mood*	**Chapter 8** *Final Discussion*	**Chapter 9** *Conclusion*

Chapter 9
CONCLUSION

It will doubtless be claimed that in all that has been said no new fact has been brought to light that was not known to some one in the past.
Frederick Winslow Taylor (1911)

9.1 OVERVIEW

Discussions and concluding remarks presented in the previous chapters have already given a detailed account of the main findings. This chapter closes this thesis by presenting those main conclusions relating to the research questions and equivalent hypotheses, that have been verified, or otherwise, in the analysis of practice. It also presents a set of recommendations for future work in the field, based on the analysis of production theory and practice.

9.2 CONTRIBUTIONS OF THIS RESEARCH WORK

The main body of this thesis is an *explanatory study* that has tried to investigate the applicability and implementation of four production flow principles in the construction environment, using the bricklaying process as the main source of empirical evidence. The principles investigated were the 'reduction of cycle time', 'reduction of variability', 'increase of transparency' and 'build of continuous improvement into the process'. The analysis uses empirical evidence collected in seven case studies, based in Brazil and England, coupled with additional evidence assembled in a meta-case.

The flow principles under investigation have evolved throughout history and represent part of what nowadays is considered the interpretation of the best-known production practices. Therefore, the study used these principles as the referential benchmark for analysing and determining improvement needs of construction practices. The analysis revealed a substandard situation in construction, shown by a lack of "literal replications" across the case studies and low level of systemic integration of practices. Inference upon the quantitative data showed that poor integration and scattered literal replications were a major contributor for the sub-optimal performance observed in practice.

An exploratory study in one of the case studies attempted to create a "learning mood" in a construction company, aimed at implementing the flow principles. This revealed that the traditional method of trying to impose knowledge on construction personnel ("push learning") is less effective than when people "pull the knowledge".

The following sections give detailed conclusions for each of the three main research questions posed in Chapter 1.

9.2.1 ARE THERE CONSTRUCTION PRACTICES MATCHING THE PRODUCTION FLOW PRINCIPLES?

A major hypothesis set at the start of this study was that there would be empirical evidence in construction sites of working practices matching all four principles and correspondent heuristic implementation approaches. Hence, comprehensive analysis of the empirical evidence tried to identify "literal replications" and "theoretical negative replications" of this in order to confirm, or deny, such hypothesis. The process of searching for validation also helped to refine these flow principles and interpret them for application in the construction environment. The subsequent items present the main findings of this research in this respect:

- **The researcher found a few, but important literal replications for all heuristic implementation approaches investigated in this thesis**: the six main case studies supplied evidence matching most of the twenty two heuristic approaches analysed, especially those relating to "reduction of cycle time" and "increase of transparency". In the case of the heuristics relating to "reduction of variability" and "continuous improvement", pattern-matching relied heavily on the information assembled from the meta-case due to the lack of literal replications on the main case studies;

- **Abstract definitions of production management heuristics can be generalised to construction, but require creative adaptation when it comes to implementation in practice**: the frequent movement of workstations and the lower level of machinery used in most construction sites requires the development of construction own particular solutions. The development of deep understanding of the principles presented in this thesis, as well as their dynamics, was shown to be extremely important to drive successful implementation of better practices in the sector;

9.2.2 WHAT IS THE EXTENT TO WHICH CONSTRUCTION INTEGRATES THE FLOW PRINCIPLES IN PRACTICE?

Concomitantly with the search for "literal and theoretical replications" was the need to determine the degree to construction integrated those principles in relation to the descriptions found in the literature. Again, the empirical evidence confirmed the hypothesis that construction practice lacks the systemic integration of the flow principles, as discussed next:

- **"Literal replications" were scattered across the case studies**: the majority of the literal replications in the construction sites resemble pieces of a disconnected puzzle. In most construction sites these literal replications of heuristics were dispersed among poor practices and frequently lacked other fundamental complementary heuristics;

- **The best performers were those case studies with a well integrated set of literal replications**: the importance of integrating heuristics in the practice of construction became evident with the fact that the best performers had a well connected, although small, set of practices. It appears that having this cohesive group of heuristics does give the necessary stability for people to gain confidence in their own ability and, thus, they can gradually include other heuristics in their practices;

- **Lack of literal replications on the principle of 'continuous improvement' was a key barrier to the full implementation of all other production principles**: "literal replications" occurred more frequently in the principles "reduction of cycle time" and "increase of transparency". However, the lack of literal replications in "continuous improvement" in construction practice was one of the main reason for the under-achievement of these principles. The lack of involvement and trust of workers in problem solving activities was certainly one of the main obstacles for avoiding the sub-optimal operation of the production process.

- **There is great room for improvement in construction, since none of the case studies applied all the heuristics in the same extent as they are applied in other industries**: the predominance of the conversion model among managers had contributed to the poor lack of attention to flows. The observed actions and

interviews with managers and workers revealed a severe deficiency in understanding of particular heuristics and how the portfolio of heuristics should interact in practice. The lack of organisational support and structure was also another major burden for enabling people to experiment and learn better ways of doing their activities.

9.2.3 HOW DOES ONE CREATE A 'LEARNING MOOD' IN A CONSTRUCTION COMPANY?

Critical analysis of the case studies and literature review on learning and change management indicates that production management in construction requires the development of more effective implementation strategies. Learning mechanisms need to address the gaps of knowledge relating to production principles found among practitioners and the problem of poor integration among complementary practices. Case Study 7 explored this issue from the point of view of creating a "learning mood" in an organisation in order to implement flow principles. The following items summarise the main conclusions from this exploratory case study:

- **Push Learning seems to be inefficient and ineffective by itself for changing practices**: the experiment in one construction company showed that "push learning" was highly wasteful in terms of knowledge transmission. In "push learning" the "knowledge provider" (e.g. consultant, researcher) risks transmitting information in excess or misinterpreting people's actual needs. If appropriate mechanisms for motivating people are not in place, construction workers may even reject external recommendations and return to their traditional methods. Analysis of the history of production management in construction suggests that one of the fundamental reasons for the persistent failure in achieve a full implementation of the flow principles in the sector is the excessive emphasis given on "push learning" strategies;

- **"Pull Learning" seems to be a viable and effective strategy for changing practices**: construction personnel showed more ownership, commitment and, hence, motivation when they were in charge of their own learning. They used with greater intensity, their creativity for developing their own solutions which, in turn, differed from the solutions given by the researcher, but contained the same fundamental flow

principles. Thus, "pull learning" seems to be more effective for introducing flow principles because the knowledge stays on people's minds long after the researcher/consultant has gone;

- **Push Learning strategies are an important complement of "Pull Learning" strategies**: analysis of the exploratory case study suggests that "pull learning" should not replace, but work side-by-side with "push learning" strategies. "Push learning" is useful to generate insights and move people from their natural inertia in the short-term. Nevertheless, only "pull learning" seems to guarantee continuous development of knowledge in the long-term;

- **Action Learning seems to be an effective approach for promoting and enabling "pull learning":** the results from this case study suggest that the supportive environment created by the Action Learning approach is effective in promoting "pull learning". The SET members are far more active in specifying their problems, collecting and analysing data than in the "push learning" exercise. It is worth emphasising that the unambiguous support from the top manager was one of the fundamental factors that allowed the SET members to freely investigate process problems in their own area without the fear of punishment.

9.3 FINAL CONCLUSION

This research has found empirical evidence within construction practice to match all heuristic approaches for "reducing cycle time", "reducing variability", "increasing transparency" and "building continuous improvement". However, the empirical evidence also showed that these literal replications were extremely scattered and poorly integrated in construction practice. These are critical issues that need to be addressed by researchers and practitioners since there was an indication of good correlation between the degree of integration among heuristics and process performance. In this respect, an exploratory case study showed that promoting pull learning through the Action Learning approach is an effective alternative for closing the gap between production theory and practice in the sector.

9.4 SUGGESTIONS FOR FUTURE RESEARCH

Throughout this research, academics and practitioners expressed great interest in the production management concepts principles investigated in this research. The exponential growth of web sites covering the field reinforces this perception. The need for further research in the area is also propelled by recent government reports that emphasise the need for implementation of "lean production principles" in construction (e.g. *Egan, 1998*). In this context, there are a number of topics that deserve further investigation in order to advance further the knowledge in the area:

- *Integrative Implementation of Production Management Heuristics*: holistic integration of the heuristic implementation approaches in practice is an important field for increasing performance in the construction industry. Hence, further research is required for developing alternative ways for introducing this holistic thinking among managers and workers in the construction sector;

- *Innovation through the Application of Flow Principles:* this thesis discussed the implication of flow principles on the generation of innovations in the construction industry. Further research is required for identifying the full range of possibilities and produce examples that convince practitioners of the practical benefits of such innovations;

- *Revision of the Historical Evolution of Thinking in Production Management:* from a strict theoretical point of view it would be interesting to trace in more detail and depth the evolution of each concept, principle and heuristic implementation approach throughout history. This kind of study would help people to identify what went wrong and what went right in the past, and the reasons for that. By understanding the evolution of the theory it would be possible to establish more clearly new directions in the field;

- *Development Indicators for Benchmarking Production Systems for Assessing the use of Abstract Principles*: there is a strong need for quantitative indicators that enable the development of comparison among practices across different countries. The indicators used in this thesis already gave some contributions in the topic and could be used as a starting point.

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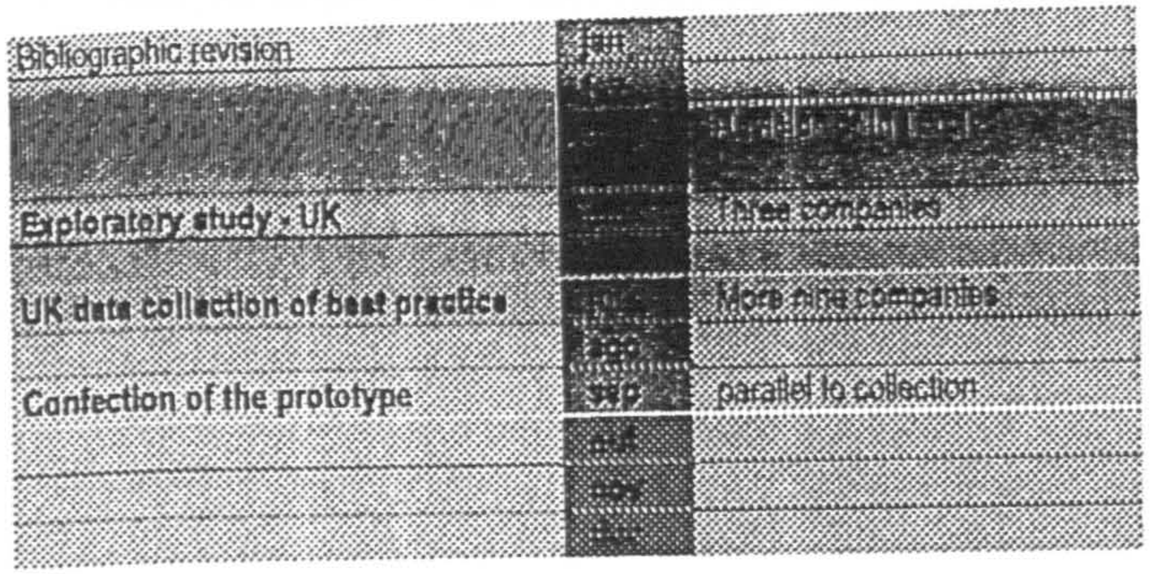
APPENDIXES

APPENDIX 1

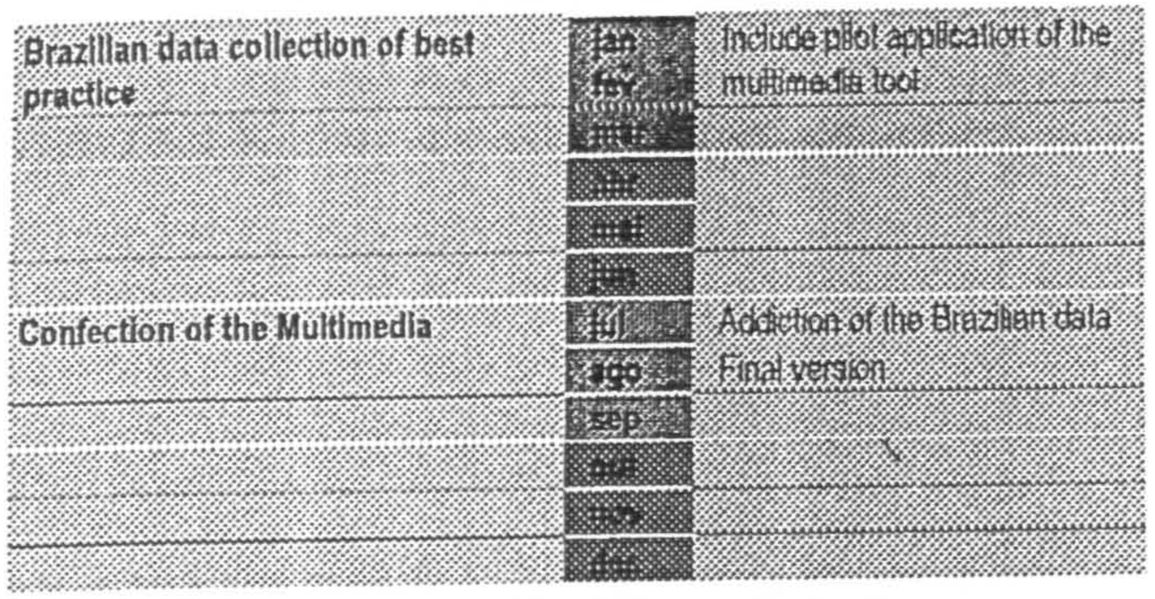
Pamphlet used in the Pilot Study

WHAT IS THE SCHEDULE OF THIS RESEARCH?

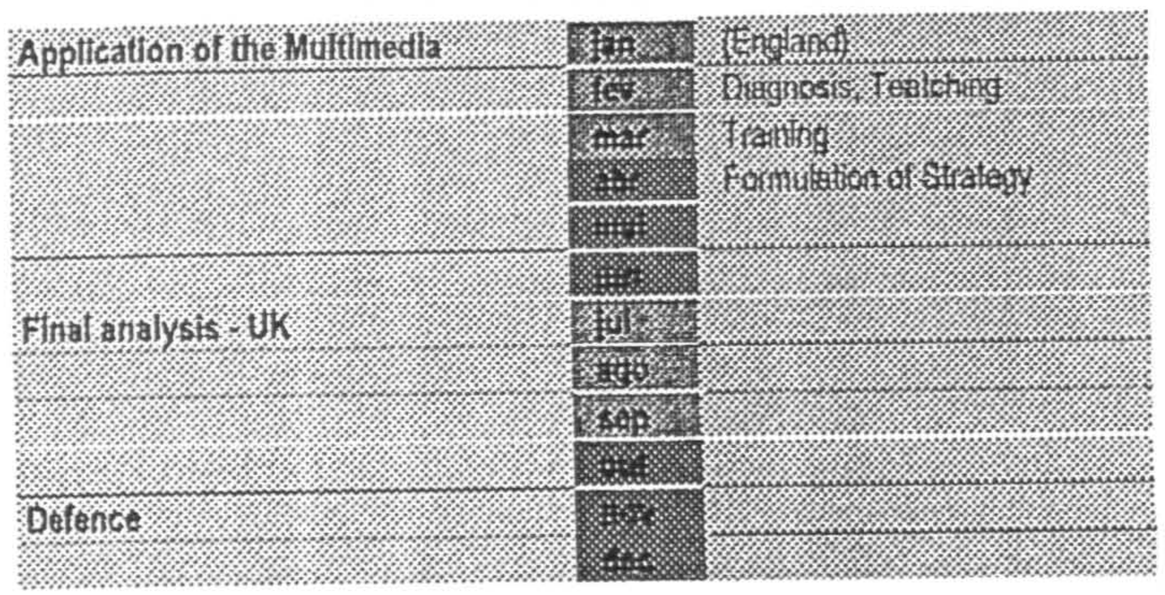
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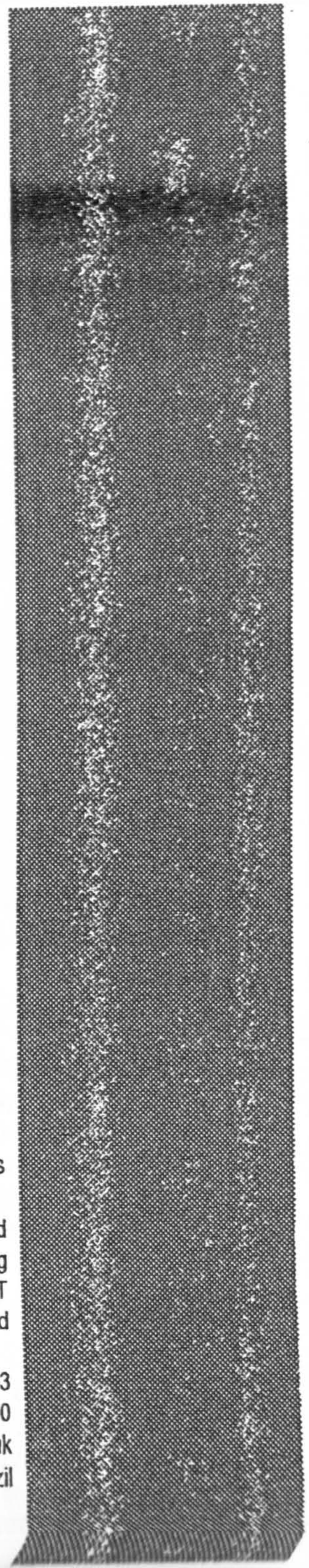
Obs: the estimate cost of this research to the Brazilian government is around U$ 100.000,00

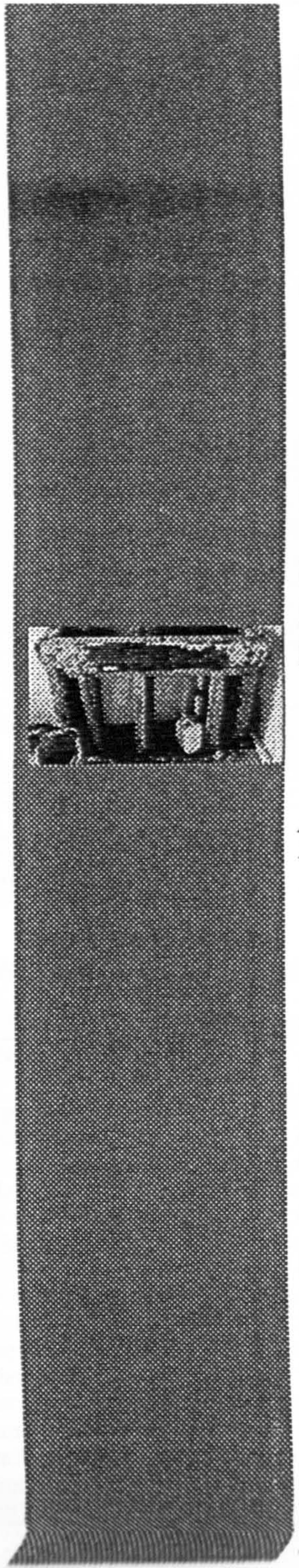
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THE UNIVERSITY OF SALFORD

RESEARCH PROJECT

MULTIMEDIA TOOL TO BES
PRACTICE BENCHMARKIN
IN THE BUILDING INDUSTR

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Salford/England
Spring - 1996

TEXT BOUND INTO

THE SPINE

OBJECTIVE

The principal objective of this research is to study the effectiveness of the use of a multimedia tool to best practice benchmarking between Brazil and UK, in order to improve the innovativeness of managers, workers and students.

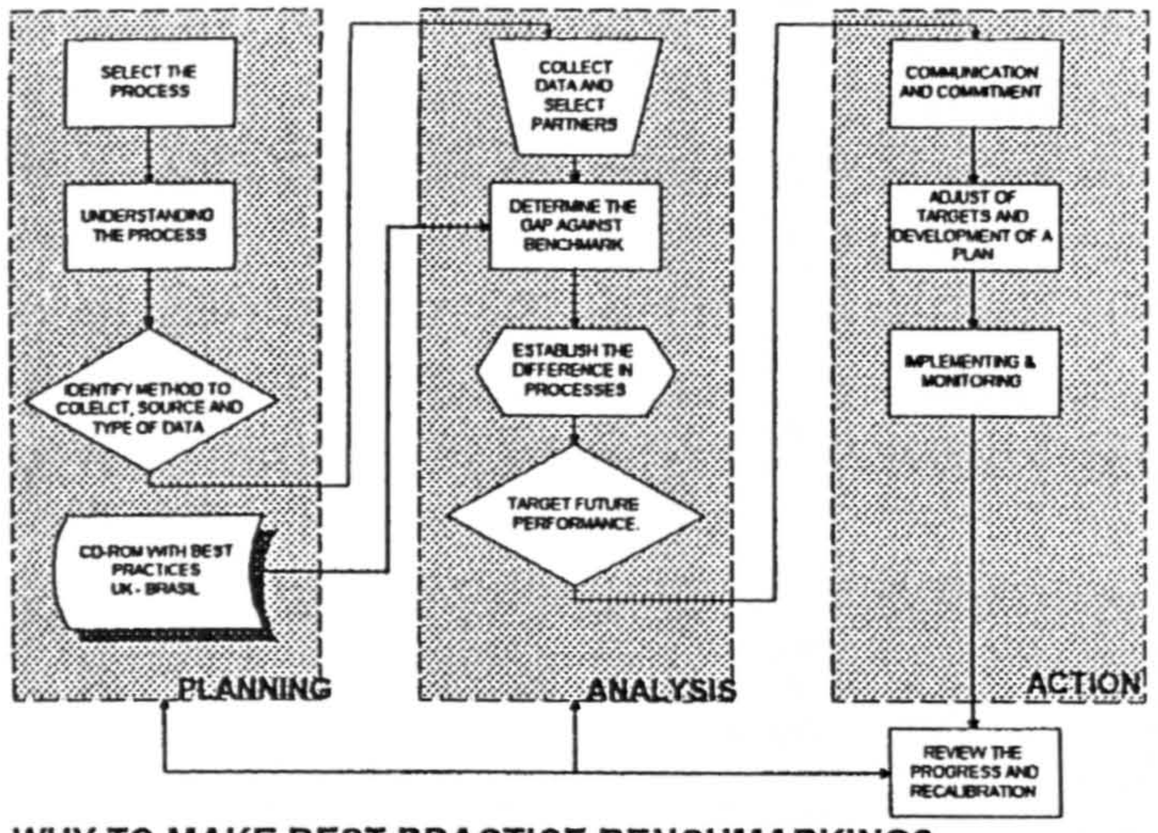
This objective will be tested in four different situations:

a) diagnostic of building processes;
b) training of foremen and site managers;
c) teaching in universities;
d) formulation of operations strategy.

WHAT IS BEST PRACTICE BENCHMARKING?

BPB can be defined as the continuous process of comparison of the current processes of the company with the best practices used by immediate competitors and firms from other regions or similar industries, leading to sustained superior performance. In the next figure is showed the steps of benchmarking and where this multimedia tool can be used:

Figure 1 - Best practice benchmarking process and the multimedia tool



WHY TO MAKE BEST PRACTICE BENCHMARKING?

The BPB permit the firm obtain a clear understanding of the gap between the operations plus a knowledge of what is required to close or orvertake the gap. In particular it could be used to facilitate the implementation of improvements through the

important innovations and how they can be applied profitably is faster.

WHAT IS NOT BENCHMARKING?

The best practice benchmarking is not a process about aiming to clone the success of other companies, or indulging in company spying. The real goal is to build a superior performance learning with the successes and mistakes of other companies, reducing the waste of time and resources

HOW TO MAKE BEST PRACTICE BENCHMARKING?

There are a great variety of ways to make the BPB, for example using data/information from magazines, newspapers, trade association reports, specialist databases, broader resource centres, using the employee background knowledge, contacts in the market, experience and direct exchange of information among the most willing to share or *using the speed, flexibility and low cost of a multimedia tool.*

WHO IS USING THAT TECHNIQUE?

The best practice benchmarking is largely used by the general industries in many decision making areas. Examples of these companies are Rank Xerox, ICL, Royal Mail, Rover Group, NCR Manufacturing Ltd, Rover, British Airways, British Steel, NHS, Motorola Ltd, BTR Group and Ford.

WHERE THE DATA WILL BE COLLECTED?

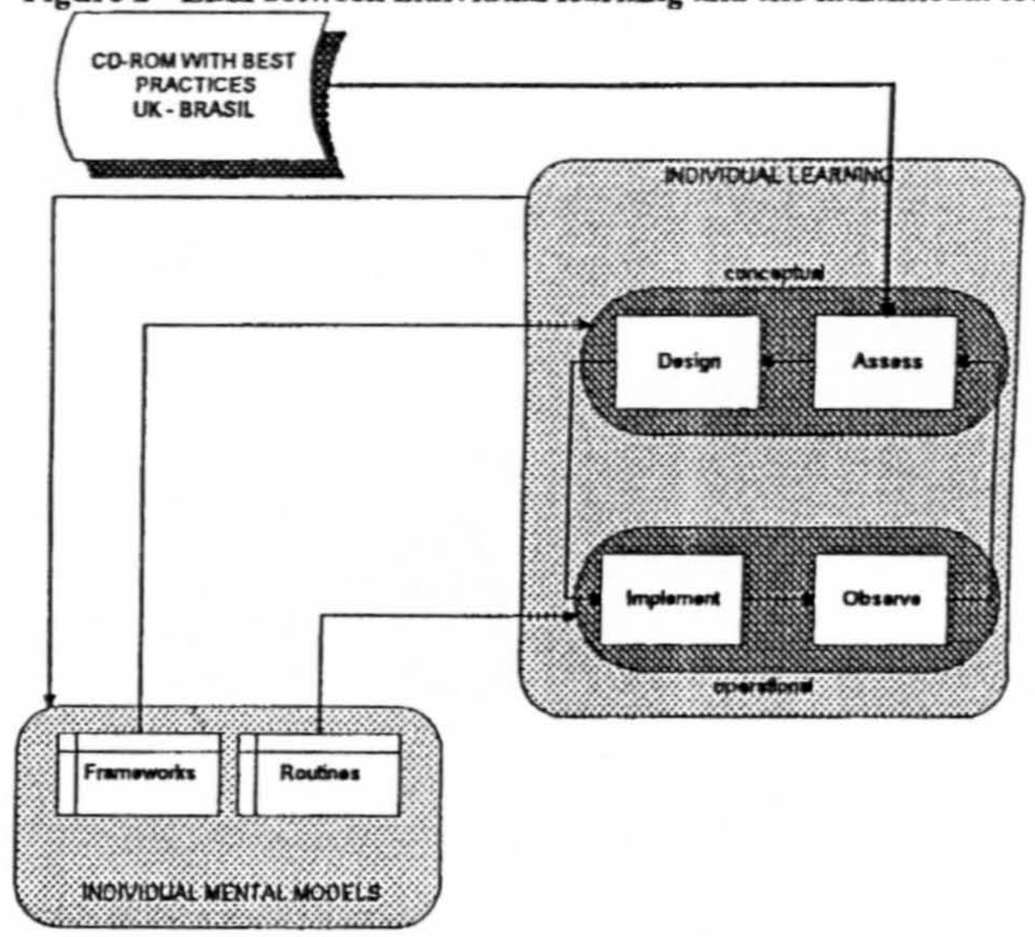
The storage of the study will concentrate in small and medium companies. This companies normally only can make benchmarking with best practices through visit in benchmarking organisations, being membership of an association, through consultants or by contracting individuals with excellent skills and background in the market.

HOW MANAGERS, WORKERS AND STUDENTS CAN LEARN USING CD-ROM IN THE BPB PROCESS?

The success of the BPB can be evaluate by the learning at the individual level. Is knowed that an organization learns through its individual members and is affected directly or indirectly by their learning. With the multimedia tool the learning process *(increasing one's capacity to take effective action)*

flexible and low cost. With a lap-top, for example, a manager can easily show, in the building site, a picture of how other companies are treating the same problem, bringing questions and ideas to the way the things are done in. The next figure illustrate the individual learning process and the data bank of best practices.

Figure 2 - Link between individual learning and the multimedia tool



SOME SUCCESSFUL FACTORS TO THE BPB:

Table 1 - Practical indications to successful BPB

MANAGEMENT ATTITUDES	KEY INDICATORS TO SUCCESS
•supportive leadership •ensure that the benchmark findings are adequately understood and accepted •ensure that strategies pursued are based on benchmark practices •agreement on the benefits to be achieved •integrate benchmarking findings with the organisation's objectives •foster viewpoint that benchmarking is the way more effective work is done and not extra work	•a comprehensive understanding of how one's own work is conducted •willingness to change based on benchmark findings •a realisation that competition is constantly changing •a willingness to share information •a focus on service best practices first and secondly on performance measures •continuous benchmarking effort

APPENDIX 2

Flow-Charts of Bricklaying

Process Mapping of Bricks/Blocks (typical situation) - Case Study 01

Step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload on central storage	Lightweight concrete size: 440x215x140	Hydraulic lift adapted to the truck	Blocks transported on pallets; No signals indicating the position for unloading	no clear instructions were given to the truck driver regarding the unload area	-------
2	Δ	Storage	------	------	Central storage	-------	-------
3	⇨	Transport until near the workplace	------	Mechanic forklift	Machine emit sound to avoid accident	Operator of machine is also a bricklayer labourer	-------
4	Δ	Waiting	-----	-------	-------	-------	-------
5	⇨	Transport until workplace	-------	-------	Manual transport	-------	Poor condition of floor on the workplace
6	Δ	Waiting	-------	-------	-------	-------	Special gang to assemble scaffolding
7	⇨	Transport until the saw machine	-------	-------	Manual transport	-------	------
8	O	Cut of blocks	-------	Saw machine (also frequent use of hammer)	Use of face protector No protection for the saw machine (rain, sound)	-------	Lack of modularization between steel structure and masonry
9	⇨	Transport until the workplace	-------	Some scaffoldings had three different levels	Manual transport	-------	------
10	Δ	Waiting	------	------	------	------	------
11	O	Place and adjust on the brickwall course	-------	♦ Use of long plumbers to verify verticality ♦ Use of special tool to finish joints ♦ Use of big and wide nails to extend the line ♦ Special tools for each particular operation	♦ Coloured signals placed on columns to identify levels ♦ Use of tape to indicate vertical distances ♦ Brick was pressed just with the hands (good mortar)	Bricklayers with formal training early in their careers	♦ Contract winning criteria: cost ♦ Ceiling, painting and drainage working in parallel ♦ Masonry dependent on the slab activity ♦ Reworks caused by problems in measurement

Process Mapping of Bricks/Blocks (typical situation) - Case Study 02

step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload on storage compound	Lightweight concrete size: 440x215x140	Hydraulic lift adapted to the truck	Blocks transported on pallets;	-------	Co-ordination of orders to avoid excess of trucks on site
2	Δ	Storage	-------	------	Area of storage compound restricted by removable fence	-------	Restricted access of trucks through the hospital park
3	⇨	Transport until near of the workplace	-------	Wheelbarrow	-------	-------	-------
4	Δ	Waiting	-------	-------	-------	-------	-------
5	⇨	Transport to cutting tool	-------	-------	Manual transport	-------	------
6	O	Cutting blocks	-------	Saw machine, press machine or, eventually, use of hammer	Use of face protector No protection for the saw machine (rain, sound)	-------	Distances between steel columns and the bricks module was not compatible
7	⇨	Transport until workplace	-------	Scaffolding with three different levels	Manual transport	-------	Special subcontractor to assemble scaffolding Windows were fixed during the construction (with glass)
8	O	Placing and adjusting to brickwall course	Prefabricated under sills made in light concrete	♦ Use of long plumbers to verify verticality ♦ Use of special tool to finish joints ♦ Use of big and wide nails to extend the line ♦ Special tools for each particular operation	♦ Bricks need to be pressed using the trowel - bad mortar ♦ Use of signs on the walls to indicate measures/ positions ♦ Use of self anchoring tie system in the steel columns ♦ Plastic cover to avoid icing ♦ Wooden board protecting the undersill ♦ Use of spray to identify positions	All bricklayers have formal training early in their career Some of the bricklayers were apprentice working side by side with professionals	♦ Subcontractor bid based on cost and quality ♦ Part of the materials were arranged in the layout just before taking out the crane from the site; ♦ One of the supervisors role was to prepare the work for the bricklayers (ex: measurements)

Process Mapping of Bricks/Blocks (typical situation) - Case Study 03

step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload on central storage	Lightweight concrete size: 625 x 215 x 125	Lift adapted to the truck	Blocks on pallets	------	Truck were benefiting from the roads that have been build for the future site
2	Δ	Storage	(also other dimensions)	-----	Large storage and far away from the workplace Poor conditions of pathway (mud)	------	No explicit orientation or visual indication with regards the position to unload
3	⇨	Transport until near the workplace	-------	------	Manual transport (one by one)	------	------
4	Δ	Waiting	------	------	Small piles	------	------
5	⇨	Transport to scaffolding	------	Scaffolding with three different levels	Manual transport	------	------
6	O	Cutting	------	Manual saw machine but most of the time use of hammer	Without using face protector	----------	------
7	⇨	Transport until brickwall course	------	------	Manual transport	------	Special subcontractor to assemble the scaffolding
8	O	Adjustment to brickwall course	Upper sills made of profile on steel boards	♦ long plumbers to verify verticality ♦ use of big nails in the bricklayers line ♦ special tool to improve joints ♦ special tool to align courses from corner to cornet	♦ Brick had to be put in the right position using the trowel (bad mortar) ♦ Construction of walls in parallel to windows & doors	Bricklayers with formal training early in their careers	♦ Wooden slab assembled on site interrupted the bricklayers; ♦ Use of pre-fabricated wooden stairs; ♦ Drainage outside of the house fixed in parallel to bricklaying; ♦ Subcontractor bid winning criteria: cost

Process Mapping of Bricks/Blocks (typical situation) - Case Study 04

step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload on the ground floor	Large brick 400 x 140 x 25	Ramp + special trolley	Use of trolley but sometimes manual unload	Use of labourers to help the unload	There was a long term partnership with the supplier that resulted in the development of this special brick
2	Δ	Temporary storage	(also other dimensions)	-------	Storage in front of the elevator	-------	-------
3	⇨	Vertical transport	-------	Elevator	In general two trolleys in each load (+/- 32 bricks)	-------	-------
4	Δ	Waiting	-------	-------	Trolleys are moved out to liberate the elevator	-------	-------
5	⇨	Transport to saw machine	-------	Special trolley	-------	-------	-------
6	O	Cutting	-------	Saw machine	Use of face protector	-------	The cuts were planned already on the design stage when setting the modularization
7	⇨	Transport until the workplace	-------	--------	Manual transport	-------	-------
8	O	Placing and adjusting to the brickwall course	Pre-fabricated lower sills (in concrete)	♦ Light scaffolding ♦ Use of weight + line to verify verticality ♦ Metallic column guiding vertical distances	♦ Brick need be pressed using the trowel (bad mortar) ♦ Building walls in parallel to electrical fittings	Bricklayers with no formal training	♦ Bricklayers receive bonus related to productivity; ♦ Electrician supervise and help the bricklayers during fitting of electrical parts

Process Mapping of Bricks (typical situation) - Case Study 05

Step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload from truck	Clay bricks 300x300x120	-	Manual transport	Labour intensive job (use of bricklayer's helpers)	-------
2	Δ	Storage	(also other dimensions)	-------	High and large storage Distant from the elevator/crane	-------	-------
3	⇨	Fill the trolley	-------	Trolley with 4 wheels	Manual load	-------	-------
4	Δ	Waiting	-------	-------	-------	-------	-------
5	⇨	Transport until near the crane	-------	-------	-------	-------	-------
6	Δ	Waiting to be lifted	------	-------	Every floor had a wooden bay to receive the trolley	------	------
7	⇨	Lifted by crane	-------	-------	-------	-------	-------
8	⇨	Transport until workplace	-------	-------	-------	-------	-------
9	⇨	Unload from trolley	------	------	Manual	------	------
10	Δ	Storage on the scaffolding	------	-------	-------	------	------
11	O	Cutting the bricks	-------	Hammer or bricklayer's trowel	No face protector	-------	The new bricks were not compatible with the design module, resulting in large number of cuts
12	O	Adjustment to the brick course	Pre-fabricated under sills in concrete	♦ Weight + line used to verify verticality ♦ Wooden guide to align brick courses	♦ Bricks need to be pressed using the trowel (bad mortar) ♦ Great number of cuttings on the wall to adapt the electrical and plumbing fittings	Bricklayers had no formal training	Bricklayers receive bonus related to productivity

Process Mapping of Block (typical situation) - Case Study 06

Step		Description	MATERIAL	EQUIPMENT	METHOD	HUMAN RESOURCES	ENVIRONMENT
1	⇨	Unload on the ground floor	Large block (clay) 400 x 290x140	--------	Manual transport	Use of helpers from other professionals to help the unload	--------
2	Δ	Temporary storage	(also other dimensions)	--------	Storage far away from the elevator	--------	-------
3	⇨	Transport to elevator	--------	Wheelbarrow	------	-------	--------
4	Δ	Waiting	-------	--------	-------	-------	--------
5	⇨	Vertical transport	--------	Construction elevator	-------	--------	--------
6	Δ	Waiting	--------	--------	--------	--------	--------
7	⇨	Transport to the workplace	--------	--------	Manual transport	--------	--------
8	Δ	Storage near workplace	--------	-------	--------	--------	-------
9	⇨	Transport to the saw machine	--------	-------	Manual transport-	--------	--------
10	O	Cutting blocks	-------	Saw machine or bricklayer's trowel	--------	-------	There was a detailed design to each single wall
11	⇨	Transport to the workplace	-------	-------	--------	-------	--------
12	O	Adjustment of to the block course	Pre-fabricated window sills in concrete	♦ Light scaffolding ♦ Weight +line used to verify the verticality; ♦ Metallic guide used to sustain verticality	♦ Brick need to be pressed using the trowel (bad mortar) ♦ Bricklayer rise the wall in parallel to electrical fittings	Bricklayers with no formal training	♦ Bricklayers receive bonus for productivity; ♦ Electrician supervised and help the fitting of electrical parts

APPENDIX 3

Check-list of Process Maturity

Case: 04

Date: April/May - 1997 Observer: *Aguinaldo dos Santos*

SAFETY

N°	ITEM	assessment -1	0	1
	STAIRS			
1	There is handrail made of resistant material			×
2	There is a stair or ramp to cross over different levels higher than 40 cm		×	
3	The handrails are painted and remain in good state			×
4	The bulbs on stairs are protected against bumps	×		
5	The colours used on safety devices of hazardous areas are easy to identify			×
	MANUAL STAIRS			
6	The manual stair cross 1,00 m over the superior surface		×	
7	The manual stairs are fixed on top and on the bottom		×	
8	The colours used on safety devices of hazardous areas are easy to identify		×	
	ELEVATOR SHAFT			
9	There are provisory closing, with hard protection passing over 1,20 m high			×
10	The provisory closing use resistant material and it is firmly attached to the structure			×
11	There is a net or a provisory floor on the elevator shaft to avoid falls	×		
12	The protecting devices are easy and fast to assemble and disassemble	×		
13	The colours used on safety devices of hazardous areas are easy to identify			×
	PROTECTIONS AGAINST FALLS ON THE SIDELINES OF THE FLOOR			
14	There is effective protection, made of rigid structure covered with net	×		
15	The protecting devices are easy and fast to assemble and disassemble	×		
	OPENINGS ON THE FLOOR			
16	All the opening on the floor are protected		×	
17	The protecting devices are easy and fast to assemble and disassemble		×	
18	The colours used on safety devices of hazardous areas are easy to identify		×	
	PROTECTION PLATFORM			
19	There is a platform of protection in the first floor			×
20	There are platforms each three floors after the principal platform			×
21	The platforms goes all around the building			×
22	The panels of the platforms are fixed with 'butterfly' screws	×		
23	The fixation of the platform on the building is made using screws or similar			×
24	The base of the platform is >2,50m + 0,80m (45°)			×
25	The secondary platforms are >1,40m + 0,8m (45°)			×
26	The surface and structure of the platform is painted and in good state			×
27	The colours used on safety devices of hazardous areas are easy to identify	×		
	SAFETY SIGNALS			
28	All provisory facilities are identified			×
29	There are communication about the compulsory use of safety equipment			×
30	There is identification of the name or number of the floor			×
31	There are alerts signals in areas for transport of materials	×		
32	There are signal on the vertical transport saying the limit of load/people			×
33	The signalling devices are easy and fast to assemble and disassemble	×		
	PERSONAL SAFETY EQUIPMENT			
34	All visitors receive hard hats			×
35	Independent of the position all the workers are using hard boots and hats			×
36	The workers are using uniform supplied by the company	×		
37	Any worker doing a job over 2,0 m uses safety belt connected with the	×		

	building			
	ELECTRICAL INSTALLATIONS			
38	The circuits and parts in movement of equipment are protected	×		
39	The electricity lines are located in areas with no transit of people or equipment	×		
40	All the electrical equipment is connected with electricity using plug and socket			×
41	High tension lines are protected from the contact of vehicles, workers, etc.		×	
	SCAFFOLDING			
42	The scaffolding have a side protection structure and a skirting board all around		×	
43	There are a net made of resistant material attached to the structure in the sides		×	
44	The colours used on safety areas and devices are easy to identify		×	
	FIRE FIGHTING EQUIPMENT			
45	The site has fire extinguishers			×
46	The colours used on safety areas and devices are easy to identify	×		
	VERTICAL TRANSPORT EQUIPMENT (ELEVATOR)			
47	The vertical transport has protection against falls			×
48	The access ramp has skirting board and side structure			×
49	The access ramps are smooth and ascendant in relation to the tower			×
50	There are some sort of shock-absorber on the bottom of the vertical transport			×
51	The work-station of the operator is isolated and has a ceiling	×		
52	The work-station of the operator is ergonomic	×		
53	The base of the vertical transport has skirting boards			×
54	The access to the equipment on the ground floor is flat			×
55	During the launch of concrete it is fixed steel devices to support the equipment	×		
56	The communication with the operator has two direction (send and receive)	×		
57	There are delimitation of the unload and load areas	×		
58	The equipment has sound alarm that work when it is in operation	×		
59	The colours used on safety devices of hazardous areas are easy to identify			×
	TOTAL	**20**	**11**	**18**

PROVISORY FACILITIES

N°	ITEM	assessment -1	0	0
	LOCAL FOR LUNCH			
1	There are a lavatory nearby			×
2	The room can be isolated during lunch time			×
3	The surface of the floor is made of concrete or other washable material			×
4	The bins have cover			×
5	There are chairs for everyone during lunch time			×
6	It is possible to move the tables in accordance with the workers wishes			×
7	The room is clean and protected from the rain .			×
	DRESSING ROOM			
8	It has floor made of concrete or other washable material			×
9	It has chairs and racks for clothes	×		
10	It has individual compartments plus lockers	×		
11	It uses the walls of the building under construction itself		×	
12	The workers use the company's uniform .	×		
	SANITARY FACILITIES			
14	The toilets are near of the dressing room			×
15	There are toilets available on the superior floors (buildings over 5 floors)			×
16	There are hygienic paper and bins on the toilet			×
17	The floor under the shower is made of non-slipping material			×
18	There are a recipient for the soap and a rack for the towel for each shower	×		
19	There are one toilet for administrative staff/clients			×
20	The distance between the toilet and the workstation is not big	×		
21	The walls in the shower are made of impermeable material			×
	LEISURE AREAS			
22	The local for lunch or other local is used for leisure times, games, television, etc.	×		
	TOTAL	06	01	15

TRANSPORT

N°	ITEM	assessment -1	0	1
	CIRCULATION PATHS			
1	The surface of the paths is consistent, smooth and flat			×
2	There is a ceiling between the mixer and the vertical transport equipment			×
3	It is possible the transit of transport equipment around the storage			×
4	There are well defined paths to the principal material flows			×
5	The flows have been defined in order to avoid crossings	×		
6	The ramps on the paths for transporting material have inclination below 10%		×	
	WASTAGE			
7	It is used boxes to storage wastage on the floors or central deposit			×
8	The wastage is transported to the ground floor using a large pipe	×		
9	The site is clean, without wastage on the way			×
10	The wastage is separated in accordance with the material type and sent for recycling	×		
	VERTICAL TRANSPORT SYSTEM			
11	There are communication devices in each floor			×
12	The company's logo is fixed on the vertical transport equipment	×		
13	The vertical equipment is near of the geometrical centre of the building		×	
14	The vertical equipment is located in wall without openings	×		
15	The area around the vertical equipment is unobstructed, allowing free circulation			×
16	The rooms for access to the vertical transport equipment are large			×
17	The path between the storage and the vertical transport is protected against the rain	×		
	STORAGE OF CEMENT			
18	There are isolation between the storage and the floor			×
19	The high of the piles are less than 10 bags			×
20	The storage has suitable high (below the shoulders of the worker)			×
21	The storage is protected from humidity			×
22	The deposit is closed and the first materials that enters is the first that goes	×		
23	The storage is distanced 30 cm from the walls	×		
24	The material is not damage during the transport and storage			×
25	There are ventilation and illumination in the storage area	×		
26	The storage is organised in order to allow access from all sides	×		
27	The storage are fixed in a way to allow the identification of the existing quantities	×		
28	The instruments of quality control are located in places of easy visibility	×		
29	There is identification of storage	×		
	STORAGE OF MORTAR/ SAND			
30	The storage for sand/mortar/stones are restricted on the sides			×
31	The base of the storage is isolated from contamination (ex: concrete)			×
32	The sand is unload in the definitive storage			×
33	The storage is protected against rain with ceiling or sheet			×
34	The storage is near of the mixer			×
35	The horizontal transport equipment is used in full capacity			×
36	The materials are supplied in small quantities .	×		
37	There are quality control when receiving materials	×		
38	The instruments of quality control are located in places of easy visibility	×		
39	The material is not damaged during the transport and storage	×		
40	The materials don't have direct contact with the soil	×		
41	There are ventilation and illumination in the storage area			×

42	The storage is organised in order to allow access from all sides			×
43	The storage are fixed in a way to allow the identification of the existing quantities	×		
44	There are measurement of the sand humidity	×		
45	There is identification of storage	×		
	STORAGE OF BRICKS/BLOCKS			
46	The storage is clean and flat, without direct contact with the soil			×
47	There is separation of different type of bricks/blocks	×		
48	The piles of bricks/blocks are below 1,60 m			×
49	The storage has high below the shoulders of the worker			×
50	The bricks are unload on the definitive storage area			×
51	The storage is protected from the rain using a ceiling or a sheet		×	
52	The storage is near of the vertical transport equipment			×
53	The horizontal transport equipment is used in full capacity			×
54	Materials are supplied in small quantity			×
55	There are ventilation and illumination in the storage area			×
56	The storage is concentrate, with space between the piles	×		
57	The storage is organised in order to allow access from all sides	×		
58	The storage are fixed in a way to allow the identification of the existing quantities	×		
59	The instruments of quality control are located in places of easy visibility	×		
60	The material are transported straight to the work stations	×		
61	There are identification of storage	×		
62	The bricks/blocks are previously transported to the work-stations			×
	PRODUCTION OF MORTAR			
63	The mixer unload the mortar on the side with the least distance to transport			×
64	The mixer is near of the vertical transport equipment			×
65	The mixer unload directly on the wheelbarrow or on prepared base on the floor			×
66	The important recommendations of the process are easy to see	×		
67	The dosage of cement is made with equipment	×		
68	The dosage of sand is made with equipment	×		
69	The dosage of water is made with equipment	×		
70	The horizontal equipment is used in full capacity			×
71	There is no double handling after the production of mortar	×		
72	There is quality control when receiving materials	×		
73	The storage are fixed in a way to allow the identification of the existing quantities	×		
74	The mortar is transported in the exact quantity to be used in the workstation	×		
	TOTAL	36	03	35

APPENDIX 4

Example of Work-sampling Worksheet

TEXT BOUND INTO

THE SPINE

CTION LEARNING GROUP — GEORGE & HARDING

BSERVATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
IME	8:00	8:10	8:20	8:25	8:30	9:00	9:10	9:15	9:30	9:32	9:35	10:00	10:05	10:30	10:50	11:00	11:20	11:40	12:00	12:30	
IRECTION																					
NFORMATION IN																					
NFORMATION OUT																					
IEDIA																					
AIL																					
AX																					
ELEPHONE		/	/	/																	3
NSHEDULED MEETING																					
CHEDULED MEETING					/	/	/														3
UT OF OFFICE																					
N THE ROAD					/																1
N SITE						/	/														2
THER OFFICE .					.																
THER?? MERCHANTS								/	/	/	/	/	.								5
IZE																					
MALL/JOBBING	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	2
INOR																					
ARKET SECTOR																					
OMESTIC																					
SURANCE																					
OMMERCIAL	/	/	/	/		/	/						/		/		/		/		ic
OURCE/ORIGIN																					
LIENT			/	/		/	/														4
PERIOR																					
OLLEAGUE																					
IRECT EMPLOYEE	/					/	/														3
BCONTRACTOR		/				/	/														3
PPLIER																					
RCHITECT/PROFESS.			/										/								2
CTIVITY																					
EETING																					
TIMATING			/	/																	2
SIGN																					
ECIFICATION																					
ANNING/PROGRAM.		/																			1
ALTH AND SAFETY																					
RCHASING								/	/	/	/	/									5
-ORDINATION	/					/	/														3
NERAL ADMINISTRA.																					
VOICING/FINAL ACCO.																					
HER ?? _____																					
SINESS PROCESS																					
ST CONTACT																					
E VISIT - PRE ESTIM.			/	/																	2
TIMATE													/	/	/	/	/	/	/	/	8
ANNING CONSTRUCT.		/																			1
NSTRUCTION	/					/	/														3
FECTS																					

RANCH: Dorchester

ANAGER: Greg DATE: 8th APR NUMBER: 01

APPENDIX 5

Summary of Indicators Used in the Pattern-Matching Analysis

Summary of Evidences Collected in the Case Studies + Case Study 7

		CASE						
CHARACTERISTIC		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Gang Composition		2:1	3:1	2:1	2:1	2:1	1:1	2:1
Productivity (m^3/hour)		0,33	0,21	0,18	0,19	0,29	0,23	0,16
Average Storage (m^3/hour/brickl.)		6,12	3,54	5,30	2,62	10,38	6,34	7,20
Process Efficiency (B/C)		0,05	0,06	0,03	0,07	0,03	0,04	0,02
Waste of bricks/blocks (%)		1	7	14	3	(b)	(c)	17,50
Work Sampling	% unproductive time	(a)	24	34	26	24	(d)	62
	% auxiliary time	*	28	29	36	24	*	7
	% productive time	*	48	37	38	52	*	31
Check List of Practices	Transport	0,43	0,69	0,28	0,49	0,36	0,43	0,31
	Safety	0,37	0,46	0,18	0,47	0,66	0,40	0,15
	Facilities	0,41	1,00	0,17	0,71	0,42	0,72	0,61
Number of Process Stages		10	8	8	8	12	12	9
Number of Photos		160	176	144	96	160	112	90
Filming (minutes)		58	36	26	22	31	22	30
Number of Visits to the Workplace to Complete the Main Processing Activity		3	3	3	3	3	3	
Average time between Visits (hours)		120	48	96	72	120	72	
Workstation Changeover Time		60	20	60	30	45	45	
Number of Parallel Activities Carried Out by the Bricklayer		2	2	2	2	0	2	
Alternative Precedence Orders With Upstream and Downstream Processes		1	1	1	1	1	1	
Number of Shared Operations with Other Processes		2	1	2	1	0	1	
Number of Inputs from Upstream Processes Necessary to Start the Process		4	4	4	4	2	4	
Number of Performance Indicators		0	0	0	0	1	0	
Number of Improvements Based on Data		0	0	0	0	0	0	
% of operatives knowing the standard		0	0	0	0	0	0	
Number of revisions in standards per year		1	1	0	0	0	1	
Existence of formal standards		Yes	Yes	0	0	0	Yes	
Total Number of Poka-yoke devices		1	0	0	2	0	2	
Number of Revisions in Layout per Month		1	1	0	1	0	0	
Number of Stages Observed from a Single Viewpoint		9	8	6	5	9	8	
Number of Visual Controls		6	6	3	3	2	3	
Number of Information Display Areas		1	4	0	2	2	2	
Number of Times the Workplace is Cleaned		1	2	0	2	1	2	
Number of Information Displays Showing the Performance Indicator		0	0	0	0	0	0	
Existence of Historical Data about Improvements		0	0	0	Yes	0	0	
Number of Targets Demanding Higher Performance		1	1	0	0	0	1	
Number of Solutions Driven by Challenging Targets		1	0	0	0	0	0	
Number of Team Meetings involving Workers/Month		0	0	0	0	0	0	
Number of Meetings between Upstream and Downstream Operations/Month		0	0	0	0	0	0	
Number of Improvements using Employees Inputs		0	0	0	2	0	0	
Number of Suggestions per Employee per Month		0	0	0	0	0	0	
Number of Improvements using Control Information		0	0	0	0	0	0	
Number of Upstream Operations receiving Orders Directly from Downstream Process Owners		1	5	0	1	0	1	

APPENDIX 6

Request received from the Action Learning SET (fax)

PROPOSAL

CONTINUOUS IMPROVEMENT WITHIN THE SMALL WORKS DEPARTMENTS

WHAT? The objective of this project is to enhance the competitiveness of George & Harding in the long term by promoting the continuous and fast exchange of ideas concerning better practices among their staff and operatives.

WHY? It was reported by Colin Harding that the overall margins generated in the small and minor works areas of the Group have decreased over the last few years despite the increasing harder working of it's staff. It is the aim of this analysis to identify the markets that produce the optimum returns, taking into account the staff input, and then focus the majority of the Group's efforts on these market sectors.

WHO? Aguinaldos dos Santos (University of Salford), Brendon Rourke (Gildea & Harding), Paul Mead (Butchers of Warminster), Paul Maher (George & Harding Bournemouth), Carl McCrudden (George & Harding Dorchester).

HOW? By using methods employed by Aguinaldo dos Santos on his earlier site based study including the following:

1. Agreeing a data collection sheet format,
2. G & H staff collecting their own data for the first week,
3. Aguinaldos dos Santos (AS) to visit the four regional offices over a period of two weeks to observe the small works managers and their colleagues and collect relevant data using video, data sheets and any other suitable methods that AS might recommend.
4. Colin Harding will provide sensitive data to AS giving the turnover and margins of the various market sectors.
5. AS to correlate all data and produce a report based on the suggested format attached.
6. AS to present his findings to the Group Managers and other relevant personnel in a similar format to his previous presentation.

WHEN? We have attached our proposed program of events.

George & Harding
Group of Construction Companies

Action Learning Group.

Small Works Review.

Revised specification for final report content.

1. The objective
of the study is to review the operation of all the Small Works (including Minor Contracts) activities in the Group and to recommend improvements and actions required to improve profitability, reduce management cost/effort and to raise customer satisfaction.

2. Statistics attached are:

2.1 Average monthly sales figures for Small Works/Jobbing divided into four sectors -

Commercial, Domestic, Insurance and inter-Company.

2.2 Minor Works overall figures for the last five months of the year 1996/97 and the first five months of this year, 1997/98.

Broken down into two sectors -

Commercial and Domestic.

2.3 George & Harding Response Maintenance sales figures for the six months to January 1998.

3. Contribution
by Aguinaldo dos Santos to include:-

3.1 A general overview of the management and administrative set up of each individual company based wholly on Aguinaldo's own observations whilst studying each one.

3.2 Summary of the market worked by each Office including:

3.2.1 Identifying the sectors of the Small Works market and Minor Contracts
3.2.2 Identifying the volume of work in each sector (WIP)
3.2.3 Identifying the margins achieved in each sector.
3.2.4 Relevant overheads attributable to each sector
3.2.5 The volume of orders per company per annum, five months in each sector.

Jobbings to November

3.3 An analysis of the data collected by individual Managers and by Aguinaldo dos Santos if possible to include:

3.3.1. Relevant management time spent on managing each sector, e.g. time spent talking to consultants, clients, Sub-Contractors, operatives, supervisors, suppliers, statutory authorities,
3.3.2 Time spent at site meetings, travelling and estimating.

Vol/cost