INFLUENCE OF PERFORMANCE MEASUREMENT TOWARDS CONSTRUCTION RESEARCH AND DEVELOPMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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DEDICATION

I dedicate this piece of research to my dearest husband Kushan and my little angel Kithmini

DECLARATION

This thesis is submitted under the University of Salford rules and regulations for the award of a PhD degree by research. While the research was in progress, some research findings were published in refereed journals and conference papers prior to this submission (refer to Appendix A).

The researcher declares that no portion of the work referred to in this thesis has been submitted in support of an application for another degree of qualification of this, or any other university or institution of learning.

Udayangani Kulatunga

ABBREVIATIONS

BSC	Balanced Scorecard
CSFs	Critical Success Factors
EFQM	European Foundation for Quality Management
GDP	Gross Domestic Product
KPI	Key Performance Indicators
NPD	New Product Development
PM	Performance Measurement
PMS	Performance Measurement System
R&D	Research and Development

ABSTRACT

The UK construction industry is being challenged to produce economically, socially and environmentally acceptable products; to satisfy its stakeholders, to improve efficiency and effectiveness of the construction processes and to address resource constraints and sustainable goals. In this context research and development (R&D) activities are identified as vital to address the challenges faced by the construction industry. Despite the importance, there are number of issues that hinder the success of construction R&D activities such as lack of accountability of the R&D resources, inadequate mechanisms to evaluate the success, output not addressing the requirements of the stakeholders, lack of communication and coordination between the parties involved in the R&D process etc.

Consequently, these issues have resulted in producing research results with low applicability and have discouraged the investment towards construction R&D. Furthermore, it has been revealed that the cause of a majority of the issues in construction R&D is directly or indirectly rooted with the lack of evaluation mechanisms implying the need for performance measurement (PM). Therefore this study addresses this eminent need by exploring the influence of PM on the construction R&D.

The study was argued to be residing in the interpretivism paradigm. A single case study method was used to refine a conceptual framework developed through literature review and expert interviews. Semi structured interviews and a questionnaire survey were used as the data collection techniques. Content analysis and cognitive mapping techniques were used for the analysis of the semi structured interviews whilst descriptive and inferential statistics were used for analysis of the questionnaire survey.

The study reveals critical success factors (CSFs) which need to be managed by PM to influence the success of construction R&D. Further, the study reveals that there is a discrepancy between the importance and implementation of CSFs thus, justifying the need for PM within the construction R&D. Moreover, the study introduces a Performance Measurement System, which evaluates the success of construction R&D activities.

CHAPTER 1 INTRODUCTION

1.1 Background to the study

The contribution from the UK construction industry towards the economy and the built environment is significant. It contributes around 8% to the gross domestic product (GDP) while providing employment to around 2.1 million people (Department for Business, Enterprise & Regulatory Reform, 2007). The production and the uses of the built environment are constantly changing due to the expectations of the society, environmental considerations, government rules and regulations etc. As a subset of the built environment, the construction industry has a greater responsibility in responding to these changes and making a better built environment (European construction platform, 2005; CRISP, 2004; Fairclough, 2002). Along with these expectations for a better economy and a built environment, the construction industry is subjected to a number of challenges such as improving the efficiency and effectiveness of the construction processes and materials, addressing the growing concerns of environmental considerations, health and safety issues, complying with sustainable development requirements and addressing cost, time, quality parameters whilst improving the image of the industry (see Department for Business, Enterprise & Regulatory Reform, 2007; DTI, 2007; European construction platform, 2005; Hampson and Brandon, 2004; Fairclough, 2002; Laing, 2001).

Among the methods suggested to address the aforementioned challenges, engagement in Research and Development (R&D) activities is noted as being prominent. In this regard, some seminal work done within the construction industry identifies R&D as an overarching strategy for the construction industry in addressing its goals (Hampson and Brandon, 2004). Further, R&D has been identified as a driving force for the success of the construction industry (Barrett, 2007). Hence, prioritising R&D activities, creating longer term R&D programmes and increasing investment on R&D activities have been recognised as vital factors for the growth of the construction industry (Hampson and Brandon, 2004; Fairclough, 2002). In addition, Dulaimi et al (2002) assert the lack of R&D within the construction industry as one of the main reasons for its underperformance. Moreover, the creation of intangible benefits from R&D activities cannot be neglected. The exploration and creation of new knowledge and capabilities gained through R&D activities help organisations to compete successfully in the marketplace (Lim and Ofori, 2007; Gilkinson and Barrett, 2004).

The Fairclough report (2002) revealed that the main research providers within the UK construction industry are universities, construction organisations and other independent research institutions such as Building Research Establishment (BRE), Building Services Research and Information Association (BSRIA) and Construction Industry Research and Information Association (CIRIA) with universities being the largest group of research providers. The research carried out within these organisations varies depending on the organisation's priorities and availability of skilled employees to undertake research work etc. For instance, universities follow a systematic approach to research work, investigating issues in a more rigorous manner with good theoretical background (see Fairclough, 2002; Brandon et al, 1999), though they are often accused of lack of practicality (Gilkinson and Barrett, 2004; Barrett and Barrett, 2003; Townsend, 1999). As research is not their primary activity, the construction organisations prefer to engage in research which could provide them with quick results (Fairclough, 2002; Brandon et al, 1999). Nevertheless, many assert that the collaborative research work between universities and construction organisations yields success as it combines theory with practice.

1.2 Justification for the study

A few decades ago, it was believed that imposing financial constraints could negatively affect the freedom and creativity of R&D activities (Roussel et al, 1991). However, this has been challenged due to the rising cost and resource constraints involved in R&D activities, thus consideration is given to identifying the correct allocation and utilisation of finance and other resources. Further, more attention is paid to ensuring the outputs are properly aligned with the expected goals, increasing the efficiency and effectiveness of R&D activities, ensuring the accountability of resources consumed and making clear the contributions from R&D activities towards the organisational developments. Despite the importance of R&D activities for the growth of the construction industry, there are number of issues which affect its success. Inappropriate mechanisms for reporting expenditure (Seaden and Manseau, 2001; Lorch, 2000; Hodkinson, 1999), inadequate mechanisms to evaluate the successfulness of activities (Lorch, 2000), lack of clear and visible links between investment and contributions (Print, 1999; Hodkinson, 1999) have negatively affected construction R&D activities, resulting in a decrease in investment in R&D activities. Further, when the expectations are not met, a low level of contribution from industrial partners is evident (Barrett and Barrett, 2003; Print, 1999). Moreover, lack of feedback on the progress and success of R&D activities and lack of communication between the parties involved (Dulaimi et al, 2002; Print, 1999; CRISP consultancy commission, 1999) have reduced the interest and attraction for contributors to ongoing R&D activities.

These issues illustrate a need for effective controlling, monitoring and validating mechanisms within construction R&D to enhance its success and this study suggests that the implementation of Performance Measurement (PM) within the construction R&D function would achieve this goal. PM has been identified as a means of assessing the progress made towards accomplishing the set goals (The Procurement Executive's Association, 1998). Further, it has been asserted by some that PM not only evaluates the efficiency and effectiveness of activities in achieving goals but also evaluates other factors that influence such achievements and ultimately satisfy the stakeholders (Moullin, 2002; Kerssens-van Drongelen and Bilderbeek, 1999; Neely, 1998). There are a number of positive impacts of PM such as continuous evaluation of work, increasing the accountability, direction and motivation of employees, improving communication and assisting in the implementation of strategy etc. (see Franco-Santos et al, 2007; Greiling, 2006; Martinez, 2005; Neely et al, 2002; Magretta and Stone, 2002; The Procurement Executive's Association, 1998). Furthermore, the studies carried out in other disciplines have revealed a number of benefits and has claimed that long term competitiveness relies on the implementation of PM within R&D activities (Yawson et al, 2006; Bremser and Barsky, 2004; Kerssens-van Drongelen et al, 2000; Pearson et al, 2000). Thus, the implementation of PM within construction R&D would be able to improve the efficiency and effectiveness whilst satisfying the stakeholders involved within the process.

Accordingly, the justification for this study is twofold. Firstly, PM can be identified and highlighted as a valuable means of evaluating the success of construction R&D activities and hence a necessity for its success. Secondly, though there are number of studies on PM and R&D in other disciplines, a paucity of literature is evident within the construction sector creating a gap between the need for PM in construction R&D and its availability. Therefore, this study is aimed at addressing this gap in construction R&D with particular reference to its PM applications.

1.3 Aim and objectives

The aim of the study is to explore the influence of PM on the construction R&D function. Accordingly, the following objectives are formulated to address this aim:

Objectives:

- identify the importance of R&D in the construction industry
- identify the current position of construction R&D
- evaluate the importance of performance measurement in construction R&D function
- explore how performance of construction R&D function is measured
- determine the critical success factors of construction R&D function
- develop a performance measurement system (PMS) that enables management to assess the successfulness of the construction R&D function.

To fulfil the aim and objectives of this study, the following research methodology is used.

1.4 Research methodology

As denoted in Figure 3.20, the research methodological framework of this study can be broadly divided into three sections: establishment of the research problem; research methodological design; and the data analysis and write up. The first section explains how the researcher arrived at the research problem via the researcher's initial impetus, literature review and expert opinions (see Section 3.2). The second section discusses the adherence to Kagioglou et al's (2000) nested model in identifying the research philosophy, approach and techniques of the study, the case study design and data collection process. Interpretivism is established as the philosophical stance for the study whereas case studies as the research approach (see Section 3.3.1 and 3.3.2 for justifications). Whilst increasing the depth against the breadth of the study, a single case study design was preferred with the unit of analysis being the R&D function (see Section 3.3.3.1 and Section 3.3.3.2). Further, by considering the characteristics of the construction research base, collaborative research work was identified as the scope of the study. Accordingly, data was collected from academic members and industrial partners involved within university lead collaborative research environment. The study used unstructured interviews to gather expert opinions regarding the phenomenon under consideration. During the exploratory stage of the case study, semi structured interviews and a questionnaire survey were used. Furthermore, documents were reviewed as a supplement to the aforementioned data collection techniques. Finally, expert opinions were gathered to refine the PMS and to establish the influence of PM towards construction R&D function.

The third section of the research methodological framework explains how the study analysed and arrived at the conclusions to fulfil the aim and objectives. Content analysis and cognitive maps were used for the analysis of semi structured interviews whilst descriptive and inferential statistics were used for the analysis of the questionnaire survey. The data analysing process was supported by using a number of computer aided software programmes namely: NVivo (version 2), Decision explorer (version 3.1.2) and SPSS (version 13). The study corroborated the findings through source, methodological and discipline triangulation thus increasing the acceptability of the findings.

1.5 Contribution to knowledge

This study contributes to theory by identifying the influences of PM on construction R&D function and arriving at a definition for PM in construction R&D. In addition to that, the study identifies critical success factors (CSFs) of construction R&D function. The study contributes to practice by the implementation of Performance Measurement System (PMS) developed through the study.

1.6 Organisation of the thesis

The chapters of the thesis are organised as follows:

1.6.1 Chapter 1: Introduction

Chapter 1 of the thesis provides an overall view by discussing the key issues which led to the initiation of this study, its aims and objectives, a brief introduction about the research methodology and contribution to theory and practice of the study.

1.6.2 Chapter 2: Literature review

Chapter 2 provides the key issues identified from literature in progressively formulating the research problem of the study. Accordingly, general and construction specific literature related to R&D and PM is presented and synthesised.

1.6.3 Chapter 3: Research methodology

Chapter 3 provides the research methodological design and the research process followed during the study. The chapter details the research philosophy, approach and data collection and analysing techniques used for the study.

1.6.4 Chapter 4: Conceptual framework

Chapter 4 conceptualises the phenomenon under consideration by developing a framework to illustrate the key areas identified from the literature and expert opinion and shows the issues which will be focused on during the course of the study.

1.6.5 Chapter 5: Data analysis and findings

Chapter 5 analyses and presents the findings of the empirical evidence which was considered through the case study. The analysis and the findings are presented based on the stages of the case study: exploratory, development and explanatory and under three main subject areas: influence of PM, CSFs and performance indicators and measures of construction R&D function.

1.6.6 Chapter 6: Conclusion

Chapter 6 draws conclusions for the aim and objectives of the study based on the empirical investigations. Further, the implications for the theory and practice are also provided followed by the limitations and future research areas.

1.7 Summary and link

This chapter gives an overall view regarding the subject area under consideration in this thesis by introducing and justifying the research area, providing a summary on the research methodology and contribution to knowledge and presenting the structure of the thesis. The next chapter presents the literature review of this study.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The previous chapter introduced the research area under investigation for this study. This chapter focuses on identifying the key research areas pertaining to this study through a comprehensive literature synthesis. Accordingly, the chapter is structured as follows:

- First, it identifies the importance of Research and Development (R&D) in general and discusses the life cycle of a new venture.
- Second, the role of R&D within the construction industry is discussed specifically in identifying solutions to the challenges faced by the UK construction industry.
- Third, the status of the UK construction R&D is investigated by identifying the main research providers and their inherent characteristics. Following this, the discussion evaluates the UK construction R&D.
- Fourth, the chapter explores the subject area Performance Measurement (PM) by identifying its importance, its development over past decades and discusses some commonly used PMSs.
- Fifth, the chapter combines the two main areas of this study: construction R&D and Performance Measurement. Accordingly, this section details the importance of PM in R&D by using studies carried out in various disciplines and justifies the need for PM within construction R&D.
- Finally, the need for identifying the critical success factors in establishing the performance measures are discussed.

2.2 Research and development in general

2.2.1 Need for research and development

Globalisation, advancement in technology and environmental factors challenge existing working practices, thus demanding increased efficiency and effectiveness of activities while optimising the use of resources. The ability to offer products and services with higher quality and lower prices, have become important factors for organisations in order to secure the greatest market share. The change from *"cost-led-pricing to price-led-costing"* has led to a reduction in the cost of production

(Nixon, 1998). To survive in the competitive marketplace, organisations have to address the current and future needs of their customers. Rapidly changing customer needs, competitiveness in domestic and international markets, resource and economic constraints have forced organisations to engage in more Research and Development (R&D) activities and to find solutions to the challenges they are facing (Business Link, 2007; Kerssens-van Drongelen et al, 2000; Cooper, 1998). Research carried out in various sectors has indicated that R&D has had a significant impact on productivity (HM Treasury, 2002). In addition to the direct benefits from R&D activities, spill over effects such as knowledge transfer has created social returns and added value to the economy as a whole (HM Treasury, 2002). Based on a survey conducted with Industrial Research Institute member companies in USA, Scinta (2008) reports that a significant increase in the R&D expenditure is evident for years to come as companies are optimistic about the gains yield from R&D activities. Similarly, based on the findings of R&D scoreboard 2007, massive investments for R&D activities are evident (Carr, 2007). Further, Carr (2007) views the increase of R&D investments as a factor which indicates future success and as a sign of business confidence. On the down side Tubbs (2007) claims that the organisations who under invest in R&D compared to their competitors shows a decline in their organisational performance and competitiveness.

Trott (2005) identifies four categories of R&D as basic research, applied research, development, and technical services. These categories are briefly discussed below (see Figure 2.1).

- Basic research: This is also referred to as fundamental science, which involves work of a general nature intended to be applied to a broad range of uses or to new knowledge about an area. Outputs of basic research will result in scientific papers for journals and some findings will be developed to produce new technologies.
- Applied research: This involves the use of existing scientific principles/ knowledge to solve a particular problem and is sometimes referred to as an application of science. It is from applied research that new products emerge.
- Development: Development uses existing knowledge but focuses on a product to overcome a problem associated with it and to improve its performance.

- Technical services: This involves providing services for existing products or processes, mainly for cost and performance improvements.

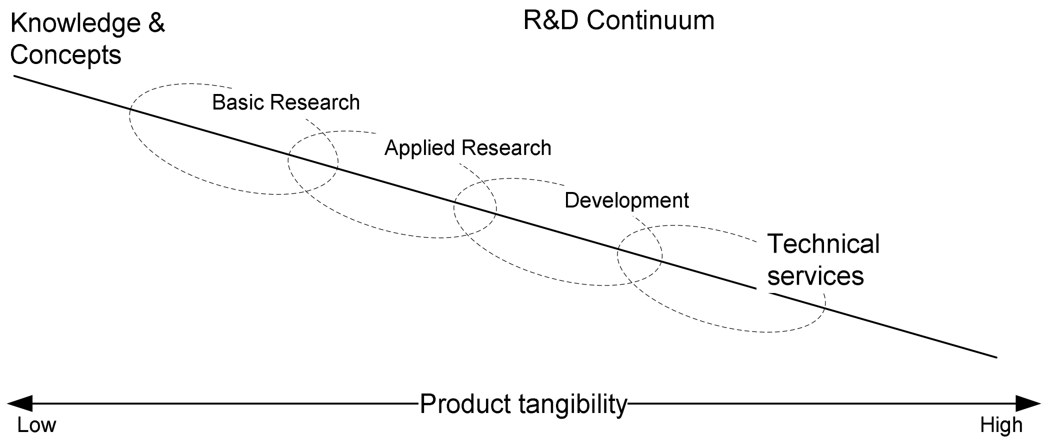


Figure 2.1: Categories of research and development (Source: Trott, 2005)

2.2.2 Strategic impact of research and development work

Product development in most industries has been challenged by the increased pace of innovation, shortened product life cycle, development of information and communication technologies and globalisation (Dahan and Srinivasan, 2000; Soderquist and Nellore, 2000; Tomkovich and Miller, 2000). Companies have to excel not only in efficiency, but also in quality, flexibility, and innovation (McNair and Liebfried, 1992; Wheelwright and Clark, 1992; Bolwijn and Kumpe, 1990). Accordingly, the scope of R&D activities includes a broad array of fields to fulfil the requirements of company, customer, and shareholder needs (Cooper, 1998; Cooper, 1995). Consequently, these demands placed upon R&D require a more strategic role for the R&D activities (Edelheit, 2004; Athaide and Stump, 1999; Comstock and Sjolseth, 1999; Khurana and Rosenthal, 1997). van Rooij (2008) also takes the view that R&D activities need to be integrated within the business strategy. Accepting its strategic role, Trott (2005, p: 253) asserts that over the past years, R&D has been *"guided by the aims of its financiers via its business strategy"*. Hence, R&D activities have been identified as a critical determinant of strategic success (Herath and Bremser, 2005; Bremser and Barsky, 2004). Further, it is identified that business strategy can provide a framework of goals within which R&D can generate a number of options to choose from (van Rooij, 2008).

Having identified the need for R&D and the strategic impact of R&D in general, the Section 2.3 moves on to the literature review and synthesis of R&D related to construction industry. Before that, the section below discusses the life cycle of a new venture in order to understand the typical phases that a R&D function (see Section 3.3.3.2) undergo.

2.2.3 Life cycle of new ventures

The life cycle of a new venture (new product/process/services) can be divided into a number of distinct phases. The exact division of these phases is governed by the complexities of the final output, management structure of the organisation etc. (Aw, 2005). The development of a new venture can involve a number of activities which are carried out by multidisciplinary teams, different departments and are influenced by various decisions. By considering these factors Saren (1984) identifies five types of models.

- departmental stage models: based on the departments or functions which hold responsibility for the tasks carried out in the innovation process;
- active stage model: based on the activities that are performed;
- decision stage model: represent the innovation process as a series of evaluation points to decide if the work should go ahead or be abandoned;
- conversion process model: based on the concept that the innovation process is a conversion of inputs to outputs; and
- response model: focuses on the individuals' or organisations' response to change of ideas or project proposals in terms of acceptance or rejection of ideas or proposals.

There are strengths and weaknesses within the above models. The departmental stage model has the disadvantage of handling the idea in isolation within departments, and is characterised by the lack of ownership of the idea (Lim et al, 2006). The involvement of cross functional expertise and activities carried out during each stage is identified in the active stage model. However, this model assumes straightforward progression without indicating any alternative paths available (Saren, 1984). Further, the activities are supported by relevant departments thus passing the tasks from one department to the next (Takeuchi and Nonaka, 1986). The activities are seen, therefore, as the responsibility of the departments, creating similar drawbacks to the departmental stage models. The decision stage model consists of specific decision points to evaluate the success of activities and can be incorporated in the department stage and active stage models. Saren (1984) claims that the aforementioned models indicate that the new venture moves in a rational manner. The conversion process model takes the standpoint that conversion of inputs to outputs avoids assigning the responsibility to separate departments (Hart and Baker, 1994), avoids the sequential approach and the presence of activities (Saren, 1984). The response model is based on the responses to a change of idea/proposal thus evaluating the factors which influence the decision to move ahead or to reject (Hart and Baker, 1994).

In addition to the above models which represent the involvement of different decisions, activities, departments, and responses, the life cycle of a new venture can be divided into number of distinctive phases. Pillai et al (2002) divide it into three phases: project selection phase (initial screening, detailed evaluation, project selection); project execution phase (effective resource management to accomplish project goals within the stipulated time and cost); and project implementation phase (focusing on customer satisfaction and return on investment). Further, there are number of models proposed by various authors depicting various activities in a new venture development (see Table 2.1). It is noticeable that the phases of those models proposed by different authors follow a similar pattern, whilst activities coincide with one another. By reviewing the characteristics of the models, the researcher categorises the phases of development of new venture into four categories as Initiation, Conceptualisation, Development and Launch (Figure 2.2).

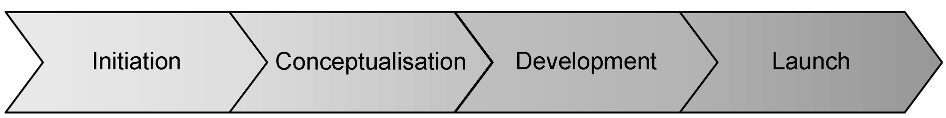


Figure 2.2: Phases of a new venture

The initiation phase involves idea generation regarding the new venture. This is followed by the conceptualisation phase, which involves identifying the requirements of the parties involved and available resources and carrying out an analysis to check the feasibility of the new venture. The third phase involves the actual development and piloting of the new venture to test its validity. Finally the product will be launched at the launch phase. Some models consider a maturity phase where they examine the effect of the new venture on the market (see Price, 2004). Table 2.1 summarises leading models of new venture development in relation to the identified four categories.

For the new venture to be successful within its life cycle, it requires a number of project management roles, such as effective coordination of activities, communication, resource management and evaluation of output against the goals. Despite this, the success of a new venture depends on resources such as knowledge, funds, time and commitment of people, and equipment. By taking these issues into account Kerssens-van Drongelen (1999) developed the concept of the R&D function which is defined as a *"set of activities necessary to effectively and efficiently initiate, co-ordinate and accomplish the product and process development activities of a company"*. Similarly, Fisscher and Weerd-Nederhof (2000) define the R&D function as a set of resources and competencies that carry out the R&D process. By combining the phases of the new venture (Figure 2.2) with the resources and competencies needed for its success, the researcher has arrived at the following diagram which illustrates the R&D function (Figure 2.3).

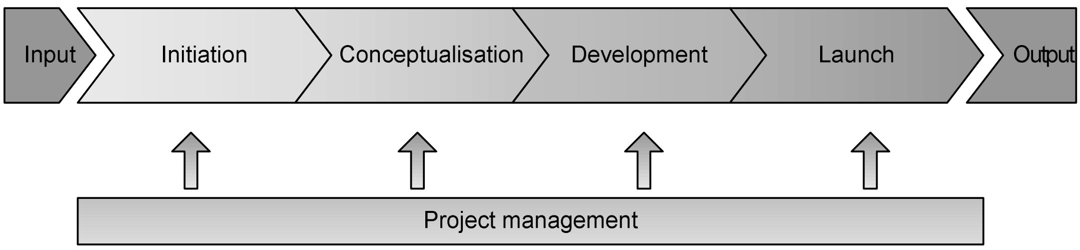


Figure 2.3: R&D function

Table 2.1: Phases and activities involved in new venture development

	Snelson and Hart (1991)	Theije et al (1998)	Loch and Tapper (2000)	Cooper (2001)	Price (2004)	Moultrie et al (2006)
Initiation	Idea generation Screening ideas	Concept stage	Generate idea	Discover scope	Opportunity recognition	Project generation
Conceptualisation	Concept development Business analysis	Specification stage Basic design stage Detail design stage	Select fund Generate concept Define specs	Business case	Opportunity focusing Commitment of resources	Requirement capture Concept design
Development	Product development Test marketing	Engineering stage	Design Test	Develop Test and Validate	Market entry	Implementation
Launch	Commercialisation		Launch	Launch	Full Launch and Growth	
Maturity					Maturity and expansion Liquidity event	

When designing the R&D process pertaining to this study, the concepts of *"active stage"* and *"conversion"* models were used (see Saren, 1984). Agreeing with Saren (1984) the researcher also believes that the life cycle of a new venture should not be a rational or sequential one. Nevertheless, the researcher believes that the identification of activities involved within the phases of the life cycle of the new venture would help to prioritise them and lead to the successful accomplishment of them. The identification of activities involved during different phases would facilitate effective controlling and monitoring of the activities. It ensures the establishment of milestones and short term goals for their accomplishment, during a particular phase, and direction of the team members towards those goals. Though it is recommended to overcome the phase based approach and to integrate the phases of the life cycle of a new venture, Sun and Wing (2005) comment that such integration could dilute the essential activities involved in R&D work. Thus, the model designed for this study combines the characteristics of the active stage and conversion process models acknowledging the iterative processes, while representing the activities involved within each phase for ease of understanding of the R&D work.

Having identified the life cycle of a new venture and supporting resources and activities for a new venture to be successful, the next section discusses the importance of R&D to construction industry.

2.3 Role of research and development in construction

2.3.1 The UK construction industry

The built environment makes a substantial contribution towards the social, economic and environmental developments (Lorch, 2004) thus Clarke and White (2006) claim it as a major economic driver. Agreeing with this views, Saxon (2003. p: 3) asserts that the nation's lifestyle and economy rests in a *"cradle of built environment and utilities"*. Society expects the built environment to be accessible and comfortable for all, durably enjoyable, efficient and flexible to changing demands, available and affordable (European Construction Platform, 2005). Being a subset of the built environment (Lorch, 2004), the construction industry has a vital role to play in making these expectations a reality. Hence, Fairclough (2002) suggests the construction industry should create a proper vision and be responsible for making sure that the built environment addresses society's needs.

McCaffer (2004, p: 2) asserts that the construction industry comprises of a number of activities and different segments: house building, commercial and industrial building, infrastructure and civil engineering, repair and maintenance; services sector including materials and component suppliers, plant manufacturers and plant hire. Appreciating the presence of a spectrum of activities and segments within the construction industry, Gann and Salter (2000) illustrate the *"actors"* and *"activities"* within the construction industry (see Figure 2.4). Accordingly, the construction output (e.g.: houses and other buildings, infrastructure, repair and maintenance work) is delivered by "*project based firms*"; materials, components and equipment required for construction output is produced and supplied by the *"supply network"*. They are regulated by such bodies as government and local authorities, and technical assistance is given through education, R&D institutes and the government etc (see Figure 2.4).

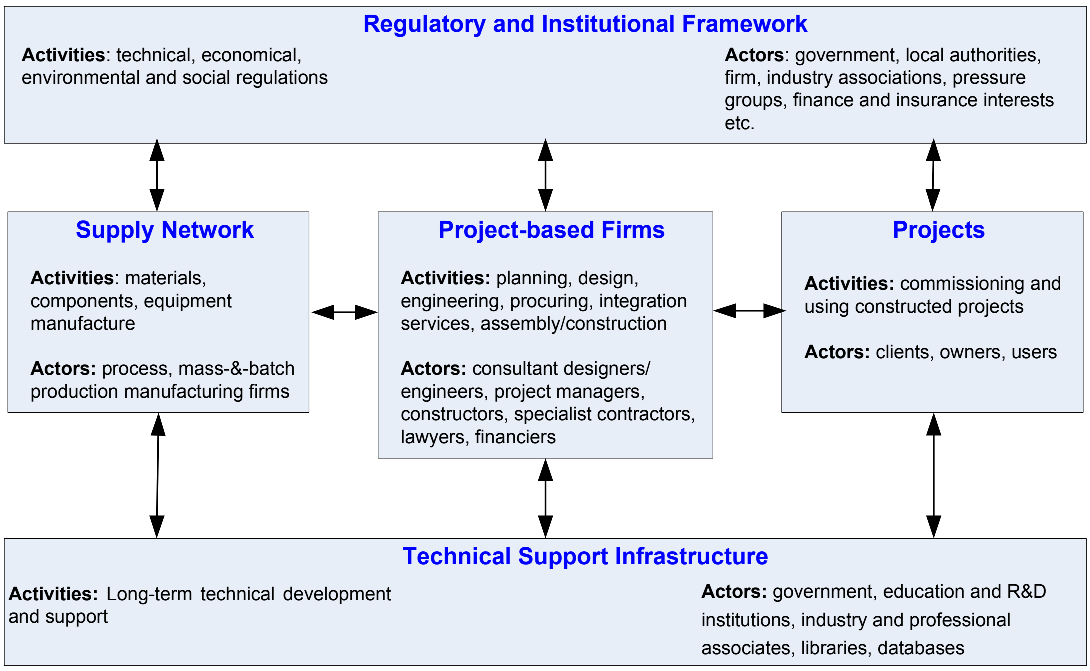


Figure 2.4: Main activities and actors of the construction industry, Source (Gann and Salter, 2000)

The contribution, which the construction industry makes towards the economy, is significant in most countries and the UK construction industry is no exception. It accounts for 8% of Gross Domestic Product (GDP) and employs approximately 2.1

million people (Department for Business, Enterprise & Regulatory Reform, 2007). Further, the industry produces, maintains, and adapts approximately 60% of fixed capital investment such as buildings and infrastructure upon which other economic activities depend (Fairclough, 2002). Therefore, the influence of the construction industry on the economy is immense. Hence, Cripps et al (2004) state that the construction industry is fundamental for the present and future success of the UK.

This section identified the significant contribution from the construction industry towards the built environment and the economy. Whilst making these contributions, the construction industry is being challenged in numerous ways by its stakeholders. The following section discusses the challenges faced by the construction industry.

2.3.2 Challenges faced by the UK construction industry

There are number of challenges which the UK construction industry encounters. As a result of demographic and climate changes, globalisation, and the decline of natural resources society is facing a vast number of challenges, thus society depends on the construction industry to provide better living and working environments (European construction platform, 2005). In addition, construction processes, desirability, cost, sustainability and utility of finished products have had an effect on the quality of life of the general public (Fairclough, 2002). Further, the construction industry is under pressure to meet sustainable goals by optimising the use of natural resources and by minimising environmental impact (Department for Business, Enterprise & Regulatory Reform, 2007; European Construction Platform, 2005; Fairclough, 2002), by designing energy efficient buildings and reducing construction waste (Plooij-van Gorsel, 2000). Moreover, the construction industry has to increase its efficiency by reducing construction costs and life cycle costs of buildings, minimise site activities and construction time, and improve the quality of its products (Hampson and Brandon, 2004; Foresight Construction Associate Programme Panel, 2001). As a result, the industry is being challenged to produce economically, socially and environmentally acceptable products while meeting the aspirations and needs of its clients (Sexton and Barrett, 2003).

Furthermore, the construction industry needs to improve the satisfaction of its stakeholders (Hillebrandt, 2003). Moreover, Pearce (2003) asserts that the construction industry is being required to contribute to sustainable development, i.e. to provide a better quality of life for everyone today, and for the generations to come by increasing the stock of productive assets of the economy such as man-made (buildings and infrastructure), human (construction labour force), social and environmental capital (reducing the environmental impact, optimisation of natural resources). In order to align with sustainable development, the construction industry's activities are being required to provide economic, social and environmental benefits (DTI, 2007).

In addition to the above challenges, the worldwide study by Courtney and Winch (2002) revealed a number of factors which hinder the development of the construction industry. These includes factors such as concentration on initial costs, fragmentation of responsibilities, poor design management, lack of long-term relationships, culture of conflict, poor construction quality, failure to meet time and cost targets, inadequate briefing, low profitability, poor working conditions and safety, poor image of construction, low use of technology and information technology. Further, the construction industry has scored low in the Excellence Model (British Quality Foundation) indicating the dissatisfaction of the customer due to unfocused services, dissatisfaction of society due to un-sustainability and dissatisfaction of people due to poor recruitment and low profits and growth in the overall business (Saxon, 2003). As a result of these negative impacts, Pearce (2003) believes that the construction industry suffers from a problem of self-image.

The above discussion shows the significant contribution made by the construction industry towards the built environment, the economy and towards the wellbeing of society as a whole. Further, the challenges faced by the construction industry are also discussed. However, it was identified that due to a number of reasons, the construction industry is underperforming and thus has a bad image. Accordingly, the section below takes this discussion forward to identify how R&D activities could help the construction industry to address these challenges successfully, find solutions for the factors which hinders its performance, whilst satisfying the needs of its stakeholders, making profits for the business and ultimately enhancing its self image.

2.3.3 Importance of research and development in construction

In his report Sir John Fairclough asserts that society needs to benefit from a modern, efficient, high quality construction industry and suggests innovation, driven by R&D, as the best way forward (Fairclough, 2002). Expanding this view Barrett (2007) states that R&D can contribute towards finding solutions to the challenges faced by the construction industry and making it highly valued by its customers. Thus, he recognises research work as a factor which influences better practice within the construction industry (Barrett, 2007). Not limiting the importance within the UK, R&D is being identified as a key factor which develops the construction industries worldwide (Fox and Skitmore, 2007).

The contribution from R&D on the development of the construction industry is immense as it helps to enhance the effectiveness of construction organisations and to raise their international competitiveness through technological advances and managerial developments (Hampson and Brandon, 2004). To remain competitive in the market, organisations should ensure their customer expectations are properly met, and future demands of their customers are properly addressed. In this respect R&D acts as a valuable *"input"* for the development of organisations (Business Link, 2007). Edelheit (2004) argues that speed in marketing a new venture is important in challenging competitors as well as safeguarding their market share. In addition, increased quality and the ability to produce products with lower prices have become vital factors for competing in the marketplace (Karlsson et al, 2004; Edelheit, 2004). Further, clients and consumers expect the organisations to search for new ideas and thereby to provide better construction outputs (Lim and Ofori, 2007; Seaden et al., 2003; Gann, 2000). In this regard, R&D can lead an organisation to successfully compete in the market through developing new and improved construction materials, products with lower costs, and improved quality.

The demand for housing facilities, renovation of infrastructure, preservation of cultural heritage, reduction of traffic congestion require the construction industry to engage in R&D (Plooij-van Gorsel, 2000). Further, the contribution from R&D is recognised in addressing the sustainable goals of the construction industry. Development of environmentally friendly products and materials, waste management methods, energy efficient construction processes and building designs etc. are some of the outcomes of R&D applications in achieving sustainability (European Construction Platform, 2005). In the UK construction industry, R&D lays the foundation for achieving the objectives of 'Rethinking Construction, Accelerating Change' and the 'Successful Operation of Government's Strategy for Sustainable Construction' (DTI, 2004) while providing maximum value for clients, end users, and stakeholders through quality products and services (DTI, 2005a).

Plooij-van Gorsel (2000) argues that competitiveness of the construction industry depends largely on its capacity to innovate new construction processes and techniques, in product development and in the organisation of the workforce. Since R&D has been identified as one of the vital factors behind the progression of innovation (Carr, 2007; DTI, 2005a; DTI, 2004; Roberts, 2002; HM Treasury, 2002), the capacity for innovation within construction industry can be influenced through the engagement of R&D activities. Further, it has been claimed that the innovation gained through the active participation of R&D work embeds well in construction organisations (Fairclough, 2002). Such innovations align well with the environment, work practices and procedures of the organisation. Thus, Fairclough (2002) stresses the need for encouraging the construction sector to actively involve in R&D.

R&D activities not only generate tangible benefits such as new and advanced construction products, material, processes, but also generate intangible benefits such as creating informal contacts, membership of international networks, and facilitating knowledge transfers. Some of the intangible benefits of research activities are implied yet unspoken between stakeholders involved in research activity (Gilkinson and Barrett, 2004). Gilkinson and Barrett (2004) assert that people take on board the knowledge and good practices from research workshops and seminars to further strengthen the processes of their own organisations. This supports the view of Cohen and Levinthal (1989, 1990) who state that R&D activities improve an organisation's absorptive capacity i.e. the ability to identify, absorb and exploit new information from the internal or external environment. This has led organisations to build up their manpower and improve their organisational capabilities, leading to increased productivity and efficiency and in the end to have a competitive advantage in the market. Lim and Ofori's (2007) study revealed that construction organisations who participate in R&D activities gain intangible benefits such as the development of good rapport with the clients, recognition and prestigious status. Besides, Gilkinson and Barrett (2004) have observed that such knowledge transference has enabled organisations to change their processes, strategies, and reconsider the existing processes to reduce waste, cost and time. These intangible benefits of R&D work would help the research community in initiating successful partnerships, and thereby initiating and engaging in successful research activities to address the problems of the construction industry as a whole. Moreover, Seaden (2002) asserts that the dissemination of construction research findings would benefit the industry as a whole and its clients.

Fairclough (2002) highlights the need for developing a strategic vision supported by a R&D framework to improve the performance of the construction industry. Similarly, creating a R&D culture to maximise the efficiency and effectiveness of construction activities are highlighted by Hampson and Brandon (2004). In their study Hampson and Brandon (2004) identify *"leadership in R&D"* as the *"overarching vision"* which facilitates the achievement of the other visions of the construction industry. This indicates the significance of R&D in accomplishing the overall goals and objectives of the construction industry. Furthermore, when considering the role of R&D within the construction industry, it can be argued that its agenda cannot be narrowed down to the construction processes or initial costs of buildings but needs to address a wide spectrum of areas such as health and safety issues, sustainable development, and economic growth.

Despite the importance of R&D as discussed above, its value is being questioned. Sometimes the outcomes of R&D are not accepted universally (Twiss, 1992). Furthermore, in some instances R&D produces unexpected results which fall outside the business strategy, thus leading the organisation to frustration and incurring financial losses (van Rooij, 2008; Mitchell and Hamilton, 2007). Within the construction R&D Gilkinson and Barrett (2004) revealed that some of the industrial partners involved in their study claimed the research activities they were involved in had no impact on their businesses. Additionally, R&D activities incur overhead costs in marketing, additional time and resources to search the commercial opportunities of various research proposals (Seaden, 2002). Courtney (1999) claims that even though the costs of research are certain, rewards of research are uncertain. Seaden (2002) also acknowledges that there is little profit from construction research work. Similarly, a group of contractors who participated in a study carried out by Lim and Ofori (2007) revealed that the financial risk involved in research activities has restrained them from funding construction R&D activities. Further, Guerrera and Waters (2006) report that money spent on R&D activities is wasted when no clear link between such investments and financial performance is established. As a result of the risk associated with R&D and the utilisation of resources, some tend to view R&D as an alternative rather than a core part of their business (Roberts, 2002).

The rapid changes and challenges from the economy and society demands that the construction industry engage in new construction, maintenance and renewal work. In this regard, R&D activities are critical in safeguarding the success of the construction industry within the competitive market. R&D activities facilitate the construction industry in successfully addressing the challenges placed upon it through new and advanced construction processes, materials and products, improved services and management activities and also improved operations by construction organisations so as to successfully compete in the market place and to raise their self image. Though R&D activities include a risk component, its role in fostering the wealth of society and the construction industry is widely recognised. In some instances R&D may not rapidly deliver tangible outcomes, nor generate massive profits, but construction organisations and their employees could benefit in the long run by developing their businesses and careers through intangible benefits. Further, studies have revealed positive relationship between the investment of construction R&D and productivity. Thus, it can be argued that what is required is effective monitoring and control to minimise the risks associated with R&D activities and to maximise their contribution rather than rejecting R&D altogether.

Having established the role of R&D in addressing the challenges and requirements of the construction industry, the section below explores the current status of the UK construction R&D activities.

2.4 Status of construction research and development

2.4.1 What is construction research?

The word research has its origins in the French word *"recherché"* which implies *"investigate thoroughly"*. Collins dictionary defines research as a systematic investigation to establish facts or collect information on a subject. The research would disclose potential ideas and facts for new or advanced products, services, or processes. Nevertheless, merely having a good idea or new facts is not sufficient. They need to be tested and examined for potential risks in order to turn them into reality (Business Link, 2007). Such translation of research findings or knowledge into new or improved products, services and processes is termed as development.

By appreciating the above views about *"research" and "development"*, OECD (2002, p: 30) defines R&D as *"creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications"*. Since, knowledge is expanding rapidly; an organisation or industry cannot depend purely on its own scientific knowledge, but has to absorb it from elsewhere (Trott, 2005; Cohen and Levinthal, 1989, 1990). Accordingly, Cohen and Levinthal (1989) perceive two faces of R&D: one to generate new information and the other to absorb knowledge from other sources which is known as the *"absorptive capacity"*. Roussel et al (1991) concur with the aforementioned view and defines R&D as the development of new knowledge and the application of scientific or engineering knowledge from one field to another.

When reviewing construction related research, some of them are directed towards developing new models for the management of the construction process while some are about transferring organisational and management techniques from other disciplines into construction. Paulson (1975) identifies four areas of construction research. They are: manpower and organisational development (education and training, evaluation of management productivity etc.); management methodologies (cost engineering, planning, and scheduling etc.); innovations in construction methods (prefabrication and standardisation); and construction industry dynamics (how can the resources of construction best be used, economic modelling, long range forecasting, and environmental policies).

Courtney (1999) identifies the reasons for carrying out construction research activities based on their output. They are:

- to underpin and extend generic knowledge, with the aim of improving the product type (buildings, bridges etc.) or the process leading to it;
- to support the development or implementation of public policy;
- to secure competitive advantage by a firm or industry sector; and
- to understand or address the requirements of a particular project.

Similar to Courtney (1999), Fraser and Fraser (2001) recognise four types of construction related research: basic research which is intended to create new knowledge; research into the social impacts of construction activities including town planning, design, environment and employment issues; research into new processes aimed at improving efficiency and safety; and research into new product development.

It appears that these categories take into account customer satisfaction up to or above expectations by developing new or improved products/processes or services, and delivering the construction output within cost, time, and quality parameters. Not limited to addressing the customer expectations, the above classifications also focus on addressing the requirements of regulatory bodies and thereby fulfil wider community needs through environmental planning, addressing health and safety issues and resource constraints of the industry etc. The need for R&D to improve in-house capabilities; to increase the competitiveness in the market through effective and efficient construction activities; and to develop management methodologies for improving the administration of construction activities are also recognised. From the above discussion it can be seen that construction R&D varies from technical studies such as the development of products, and materials to “soft” research such as management relationships.

By summarising the above, the researcher arrives at a definition for construction R&D as "*systematic investigation to establish new or improved products, processes, management methodologies to address*:

- *customer needs;*
- *resource and environmental constraints;*
- *government regulations and public policies;*
- *competitive edge of construction organisations"*.

The output from the construction industry includes domestic houses, commercial and industrial buildings, infrastructure and civil engineering work, and maintenance and repair etc. These outputs associate with several customers: clients that commission the construction output, and owners and end users that operate and/or occupy them. Hence, R&D needs to address and satisfy the requirements of these customers. In addition to this, as identified in Section 2.3.2, the construction industry is being challenged to optimise the usage of natural resources and to focus on sustainable goals, thus the R&D output needs to address resource and environmental constraints. Further, construction R&D activities are a necessity to develop health and safety regulations, and environmental and public policies related to construction. Moreover, the construction organisations that engage in activities such as planning, designing, procuring and constructing can successfully compete in the market with efficient and effective construction materials, products, processes and methodologies developed through R&D activities.

The above section arrived at a definition for construction R&D. On this premise, the following section identifies the major contributors for construction R&D activities.

2.4.2 Construction research base

It is evident from Section 2.3.2 that the construction industry is undergoing major challenges to improve its profile through efficient and effective processes, advanced technology, materials, to provide a better built environment. These challenges are forcing the industry to change its traditional approaches to design, construction, refurbishment, and maintenance. As discussed in Section 2.3.3, in order to address these challenges successfully the industry needs to engage in R&D activities, which is recognised as being a key driver for its success. Within this scenario the following section looks at the research base which carries out R&D within the construction industry.

According to Gann and Salter (2000), the technical support for the construction industry is provided by government, education and R&D institutions and industry associates (see Figure 2.4). Fairclough (2002) identifies the main players in construction research and innovation system as government funding bodies, independent research organisations, universities, firms, clients and users. Fairclough (2002) includes clients and users within the construction research and innovation system, as their desires and requirements create new directions for the industry to act upon and to engage in R&D work. Simmonds (1999) differentiates the *"research and innovation system"* from the *"research base"* by excluding the clients. Thus, the UK construction research base consists of funding bodies and organisations that carry out research activities (Simmonds, 1999). Accordingly the following section discusses the main organisations that carry out R&D within the construction industry with an evaluation of their inherent characteristics.

2.4.3 Research organisations

2.4.3.1 Independent research institutions

There are a number of independent research organisations which provide R&D work to the construction industry such as Building Research Establishment (BRE), Building Services Research and Information Association (BSRIA), Timber Research and Development Association (TRADA), HR Wallingford, Steel Construction Institute (SCI) and the Concrete Society. Among these BRE dominates the non university research sector within the industry. Some of the independent institutions carry out research for a particular industry, product or activity such as timber and steel. According to Courtney (1999) and Seaden (2002), building materials and component sectors have shown interest in research work by investing in R&D activities. These investments are significant, especially when compared with R&D carried out within construction organisations. However, Fairclough (2002) revealed that an increased proportion of construction research is moving towards universities, decreasing the role of these research institutes.

2.4.3.2 Universities

The largest group of construction research providers are universities (Cripps et al, 2004). In the year 2001-2002, around £73 million was allocated and over 2,000 PhD students were dedicated to construction research areas. Research carried out in universities is more disciplined and focused on the long term research issues (Fairclough, 2002). Universities train future practitioners and researchers for the industry and are identified as knowledge reservoirs (Jacobsson, 2002). Universities have complex and multi objectives which primarily target society as a whole (Seaden, 2002). A considerable difference can be identified in the research culture between universities and construction organisations (see Table 2.2). Universities have the opportunity and the need for studying a particular issue deeply, rigorously and over a long period of time (Barrett and Barrett, 2003). Thus, Mahoney (1997, p: 113) states that academic members have chosen *"a career of learning"*. In spite of this, universities have international networks of knowledge that ease the task of constant search of new ideas, technologies, processes (Brandon et al, 1999). Therefore, research carried out within universities includes in depth analysis of the theoretical background to research problems and is well structured, but cannot generate fast solutions as it consumes considerable time.

Despite the advantages of university based R&D, they are often accused by the industry of not addressing real life organisational problems, and for having low levels of relevance/applicability to the needs of the industry (Gilkinson and Barrett, 2004; Barrett and Barrett, 2003; Townsend, 1999). The inconsistency between research outcomes produced by universities and the industry's needs has adversely affected the appropriate usage and implementation of the research outcome.

2.4.3.3 Construction organisations

McCaffer (2004) and Cripps et al (2004) postulate that construction organisations are not research oriented and too small to fund and to create their own research infrastructure. Most construction organisations do not see many financial benefits of R&D activities (Cripps et al, 2004; Courtney, 1999). In addition, lack of professionally qualified people has hindered the capability of these organisations to engage in R&D work (Gann, 2001; Brandon et al, 1999). It has been revealed that of 160,000 contractors, fewer than 20,000 organisations employ people with professional or technical qualifications, while only around 2,000 organisations employ five or more people with such qualifications (Gann, 2001). Fairclough (2002) argues that even though some construction organisations show the desire to engage in R&D activities, their size and day to day activities have prevented them from engaging in long term, formal R&D in a structured manner. This is supported by the findings of Print (1999, p: 4) who stated that *"construction organisations are head down focusing on today's problems without having time or need to look to solve tomorrows problems"*. Moreover, construction organisations lack the long term commitment for research work and prefer to do research with fast pay back and *"quick wins"*. Brandon et al (1999) state that R&D carried out by construction organisations are not consumed by the industry as a whole but benefit the sponsoring organisation only.

In terms of the small and medium scale contractors (SME) and large contractors there is a considerable difference regarding the investment of money for R&D work. SMEs tend to invest money on technology to improve their existing organisational competencies and capabilities which would add value in a quicker way (Sexton et al, 1999). Furthermore, technology, which has a higher risk component is not welcomed by SMEs. According to Sexton et al (1999), SMEs are more interested in *"safe evolutions"* rather than *"risky revolutions"*. In contrast, large construction organisations operate in a more dynamic market and thus invest in long term and formal technology.

However, Brandon et al (1999) assert that construction organisations have a better perspective regarding practical problems within the industry and have the ability to implement research outcomes and act upon the results. Research carried out in these organisations target their own research needs and address the problems in a more practical way. These findings are further supported by a study carried out by Seaden and Manseau (2001) which reveal that research initiated and directed by government policies are becoming less popular within the industry due to the perception that "*government does not always know best*". In contrast, the industry initiated R&D work has been considered more productive. Nevertheless, Barrett and Barrett (2003) comment that it is difficult to say who should play the leading role in construction research, but it depends on the type of problem being addressed, why it is addressed, for whom and by whom it is addressed. A comparison between the University based research and industry based research is given in Table 2.2.

Table 2.2: A comparison of research cultures between universities and construction organisations (adopted from Brandon et al, 1999)

University Culture	Industry Culture
▪ Resistant to rush to early solutions or transient knowledge without verifying and exploring alternatives. ▪ Prefer to build knowledge within a framework that allows incremental advances as a new concept emerges. ▪ Knowledge base can be unstable due to short term funding and transfer of personnel. ▪ Work to rigorous knowledge building agenda rather than current problem solving agenda. ▪ A major output is the research skills developed by researchers undergoing the process.	▪ Expectation appears to be short term, practical, problem solving consultancy – often a 'quick-fix'. ▪ Ignorance of research work that has gone before and sometimes an unwillingness to learn. ▪ Lack of familiarity with the research process. ▪ Inability to translate research funding into products and services ▪ Fast pay-back with quick wins preferred. ▪ Engagement with universities sometimes difficult as partners, prefer to be in contractor-subcontractor relationship.

The above literature review stipulates that R&D work carried out by universities and construction organisations operate at two ends. If taken in isolation, at one end the universities develop theory with little involvement in industry and at the other end construction organisations engage in R&D activities to solve real life problems of the industry with little theoretical knowledge. It was evident that the inherent characteristics of these organisations have fuelled these different approaches. Nevertheless, it can be argued that successful research activities need to be built on good theoretical background with rigorous analysis by focusing on practical problems. Having a good theoretical background brings in any existing knowledge about the research problem, evaluates the alternative approaches that could be used to address the research problem and eventually proposes the best solution. Therefore, addressing a research problem with good theoretical background is different from addressing a problem without a theoretical background and thereby coming up with a solution merely *"by chance"*. In spite of this, addressing a practical problem could attract the industrial partners' interest in the research process, when it is evident that they are benefiting from that research process. With this in mind, the following section appraises the collaborative research work within the construction industry to try to understand how theoretical and practical aspects can be used to compliment each other within R&D.

2.4.4 Collaborative research activities

Fairclough (2002) asserts that from 1920-1980 a clear demarcation between the public and private sectors was identified in construction research. This separation between publicly owned universities and privately owned construction organisations can be identified as a restraining factor for effective research work within this sector. As discussed in section 2.4.3.2 and 2.4.3.3, research work carried out by universities and construction organisations has its own advantages and disadvantages. The former carry out in depth studies to investigate a problem whereas the latter lack the motivation and ability to involve in rigorous investigations due to the nature of their work and their inherent characteristics (see Table 2.2). Nevertheless, research carried out by construction organisations has a higher propensity to address practical problems of the industry, thus increasing the degree of success. If research therefore is carried out with the collaboration of universities and industry partners, it would merge theory and practice hence generating greater success.

Such merging of theory and practice is viewed by Gibbons et al (1994), who claim that a new system of knowledge production is emerging, where distinctions between public and private sector research is becoming blurred. Similarly, Calvert and Patel (2003) also see a significant increase in collaborative research activities between universities and industrial partners. Fairclough (2002) identifies a similar trend with regard to construction research. He asserts the new model for construction research is one with distributed networks among public-private partnerships with interdisciplinary members.

The collaborative research activity provides incentives for researchers as well as for the industrial partners (Calvert and Patel, 2003). A study carried out by Gilkinson and Barrett (2004) proved that collaborative research work between industry and academia generates intangible benefits by speeding up the processes of the organisation by enhanced thinking; reinforcement of procedures and strategies, business goals; competitive advantages and inspirational activities such as motivation and awareness. They identify such knowledge transfers as a virus which affects the organisation positively to increase the productivity and efficiency of work undertaken. While acknowledging this fact McDermott and Swan (2001) identify the mutual trust and knowledge sharing occurring when collaborative research attempts to harness best practices within their organisations. Furthermore, successful research collaborations help to strengthen partnerships between industry and academia and encourage them to engage in such collaborative work in the future (Gilkinson and Barrett, 2004).

In brief, it can be viewed that attitudes, expectations, ways of dealing with issues, learning cultures are different between universities and construction organisations. As a consequence, commitment towards construction research activities varies from universities to industrial partners. While the former seeks to investigate an issue rigorously with the support of theory, the latter prefers to seek fast solutions to address day to day practical problems. However, the outcome of research activities initiated by industry is considered more compelling as they address real life problems. The collaborative research work between universities and industry minimises the technical, managerial and cultural differences thus enhancing the success of R&D activities. A proper blend of theory with practicality, to solve the real life problems of industry, would gain much success for the research effort. When the ideas and knowledge of people who are specialised in different domains are combined, the R&D effort can be successful. Accordingly, university-industry partnerships can be acknowledged as a better way of carrying out construction research activities. Collaborative research merges the experience, knowledge and expectations of the industrial practitioners and academia. As a result, the outcome of such work is more applicable to industry, is easily understood and has greater possibility of adoption. Therefore, such collaborative research can be used as a strategy to obtain more work and to expand finance for future research activities. On this premise, the scope of the study is considered as collaborative research work (see Section 3.3.3.2).

2.4.5 Issues in construction research and development

It was evident from Section 2.2.3, that the R&D function involves resources and competencies to carry out the R&D process. During this process, the new venture goes through initiation, conceptualising, development and launch phases and consumes and converts the inputs into outputs (see Figure 2.3). Throughout the life cycle of the new venture, its progress needs to be carefully monitored, evaluated and coordinated to achieve the desired standards required by the parties involved. Accordingly, failures with regard to resources and competencies have generated a number of issues within the construction R&D function, which are discussed below.

The importance of financing the construction research activities is well acknowledged (Dulaimi et al, 2002; Hodkinson, 1999). In his vision statement, Hodkinson (1999) identifies commitment to finance construction research and a properly financed academic research base as vital factors to enhance construction R&D activities. However, a lower level of investment is evident for UK construction research activities when compared with the other countries such as France, Japan and Scandinavia (Gann, 2000). Further, the UK construction R&D intensity is lower than in other sectors such as manufacturing (DTI, 2006; DTI, 2005b; DTI, 2004; Dulaimi et al, 2002; Fairclough, 2002; Seaden and Manseau, 2001; Laing, 2001; Egan, 1998). Furthermore, the Institute of Civil Engineers (2006) notes a significant downward trend in the UK construction R&D funding which has reduced to £50-55m per annum from £140m in the late 1990s. Table 2.3 illustrates a comparison of UK construction industry investments with other industries based on the latest findings of the R&D scoreboard 2007. It can be seen that compared to the pharmaceutical, food production and chemical industries, the R&D intensity for construction industry is low (Department for Business Enterprise and Regulatory Reform, 2007). Further, the R&D investment per employee for construction is also accounted less when compared with pharmaceutical, food production, electricity and chemical industries.

Although the industry initiated R&D work is considered more productive (see Section 2.4.3.3), McCaffer (2004) and Fairclough (2002) consider that the construction industry does not invest considerable money on research. One of the main reasons behind lack of investments on construction R&D is due to the difficulty of assessing the effective use of funds within research activities. Print (1999) and

Hodkinson (1999) note that the research funding bodies are unaware of the money utilisation. Seaden and Manseau (2001) and Hodkinson (1999) also claim that the improper reporting of expenses has resulted in low levels of investment in construction R&D activities. Consequently, securing continuous funding for construction research has become an issue.

Table 2.3: Comparison of construction R&D with other industries (Source: Department for business enterprise and regulatory reform, 2007)

	Construction	Pharmaceutical	Food producers	Electricity	Chemical
R&D investment (£m)	53.89	7,419.51	846.53	67.09	556.79
R&D investment as % of operation profits	5.1	59.2	12.8	1.6	44.3
R&D investment as % sales (R&D intensity)	0.4	15.2	1.4	0.3	1.8
Average number of employees	97,014	217,779	407,421	60,560	118,763
R&D investment per employee (£000)	0.6	34.1	2.1	1.1	4.7

Another issue of construction R&D is the lack of industry contribution due to low applicability of the research results in addressing industrial needs (Barrett and Barrett, 2003; Print, 1999). Supporting this view, Flanagan and Jewel (2006) also emphasise the need for understanding the target audience of construction R&D activities. They state that *"merely saying that the benefits of research will benefit the construction sector is unreliable"* (Flanagan and Jewel, 2006, p: 9). When research outcome does not address the industrial needs, the results add *"noise"* to the system, confusing the industry states Print (1999). Similarly, Hodkinson (1999) comments that the research contribution made by the end product is not widely accepted and understood by industry, hence creating difficulties in securing investments in the future. When research results lack applicability, Print (1999) notes that funding bodies tend to invest in relatively small and insignificant projects to minimise the risk of loss. Thus, in order to motivate the industrial partners and secure their contribution it is important to develop explicit objectives that address their needs

(Barrett and Barrett, 2003; Print, 1999). When the objectives address the interests of the involved parties, detailed debating can take place to further scrutinise the research proposals through which the outcome can be more useful.

It has been recognised that one of the major issues in construction R&D is the lack of reporting of utilisation of funds and inadequate evaluation criteria used to measure the success of research outcomes (Lorch, 2000). The non existence of effective validation/feedback and evaluation mechanisms within construction research has been identified as a *"fundamental missing link"* (Lorch, 2000). As a result of lack of such evaluation mechanisms, the involvement of industrial partners and funding bodies have been reduced thus, further weakening the research community. According to Cripps et al (2004) to attract more funds from the construction industry, it needs to establish clear and definite links between the R&D outcome and the utilisation of funds.

Internal R&D capabilities such as a technically qualified staff, internal and external communication, and feedback mechanisms are some of the important aspects for successful research activities (Cohendet and Steinmueller, 2000; Steinmueller, 2000). However, Gann (2001) states that most of construction organisations do not have the required internal R&D capabilities. In spite of having the internal R&D capabilities, Cripps et al (2004) postulate that the wealth of construction research activities are governed by the effective collaboration between the research providers and the beneficiaries. Similarly, Dulaimi et al (2002) assert that the ability to develop superior products and services is influenced by the level of coordination and cooperation between the parties involved within the research process. Even though effective coordination of R&D activities is well accepted, some authors claim that the UK construction research base is characterised by a lack of real partnership between research funding bodies, providers and potential users (Dulaimi et al, 2002; Print, 1999; Hodkinson, 1999). Lack of confirmation of the milestones of research (Brandon et al, 1999; Townsend, 1999), and lack of communication between the research community and industry (Print, 1999; CRISP consultancy commission, 1999) have also negatively affected the effectiveness of construction R&D activities. Moreover, regardless of the importance, it is revealed that the prominence given for construction R&D is less when compared with other factors which influence the development of the construction industry (Fox and Skitmore, 2007). These findings coincide with the results of Gann (2001) which shows that R&D activities in the construction industry are neglected. Furthermore, Pearce (2003) asserts that the UK construction industry has a relatively poor record in terms of R&D as a proportion of output.

On the whole, it is evident that construction research activities have a number of issues such as low levels of investments, objectives of R&D activities not addressing the requirements of the parties concerned, insufficient involvement of industrial partners, lack of evaluation mechanisms, lack of coordination and communication etc. As shown in Figure 2.5, the researcher has mapped these issues against the life cycle of the new venture. The researcher argues that the aforementioned issues are interrelated and can turn into a vicious cycle if not managed properly. For instance, lack of sharing a common view has resulted in producing research results which lacks relevance to the industrial needs. This has in turn reduced the interest of industrial partners to get involved in research activities. When the results are not properly implemented and have a low take up rate, it is difficult to attract funding bodies to finance construction R&D activities. Moreover, the researcher asserts that a lack of evaluation criteria within R&D activities has directly or indirectly affected a majority of issues. For instance, lack of evaluation criteria has resulted in absence of feedback for the improvement of the R&D process; lack of information on the utilisation of resources; and poor monitoring of the progress of the work. Poor monitoring of the progress of work could have repercussions such as none achievement of milestones and deliverables which could negatively affect the interest of the parties involved in the research process, especially the industrial partners. When industrial partners lose interest, it could affect their commitment and contribution towards the R&D process and could affect the collaboration as a whole. As a result of lack of involvement of the industrial partner's contribution, the applicability of the research results to the industrial needs could be affected, resulting in low level of funds granted for construction R&D activities.

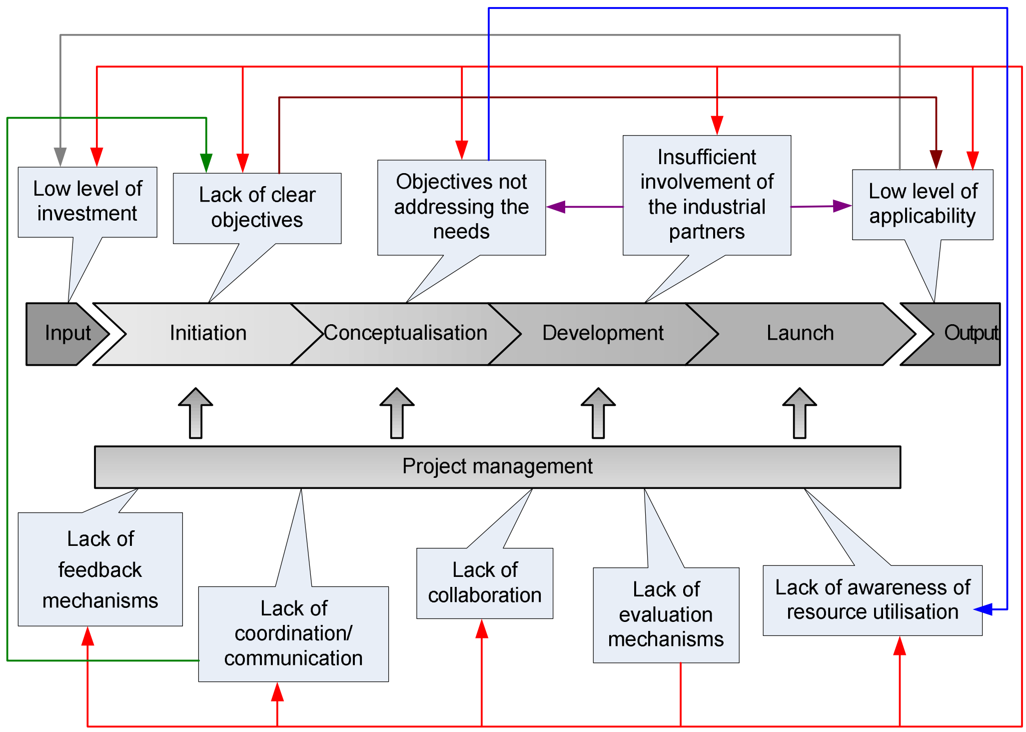


Figure 2.5: Issues in construction R&D function

The literature review provided in the sections above discussed construction R&D in terms of its important role and current position. It is evident that despite the important role of R&D in the construction industry, there are a number of issues which hinder the success of construction R&D activities. Further, it is noted that the root cause of the majority of the issues lies with the lack of evaluation mechanisms. With this premise the next section discusses literature on PM and how it could assist to minimise the issues within construction R&D and enhance its performance.

2.5 Performance measurement

2.5.1 What is performance measurement?

The Procurement Executive's Association (1998, p: 5) defines PM as a *"process of assessing progress toward achieving predetermined goals, including; information on the efficiency within which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a programme of activity compared to its intended purpose)"*.

The achievement of pre-determined goals depends on a number of influential factors such as the effective coordination of work and motivation of employees. Kerssens-van Drongelen and Bilderbeek (1999, p: 36) acknowledge this and define PM as *"the acquisition and analysis of information about the actual attainment of company objectives and plans, and about factors that may influence this attainment"*.

Similar to Kerssens-van Drongelen and Bilderbeek (1999), Neely (1998) recognises the need for a supportive infrastructure for PM to acquire and analyse measures. Accordingly, Neely (1998) defines PM as the quantification of efficiency and effectiveness of past actions by means of data acquiring, collection, sorting, analysing, interpreting and disseminating.

Moullin (2002, p: 188) defines PM as *"evaluating how well organisations are managed and what value do they deliver for customers and other stakeholders"*. He also recognises the need for interpretation and analysis of data in PM. The definitions given by the Procurement Executive's Association (1998) and Kerssens-van Drongelen and Bilderbeek (1999) elaborate on the fact that PM helps attain goals and objectives whilst Neely (1998) highlights the role of PM as quantifying the efficiency and effectiveness of past actions. However, the eventual effect of the quantification of past actions can also be considered as to attain the organisational goals.

Moullin (2002) believed that the definition of PM needs to state its purpose. Accordingly, from this definition, Moullin (2002) values the significance of stakeholders to the organisational performance. Pratt (2005) agrees with Moullin's definition as he also presumes that the survival of an organisation depends largely on the satisfaction of stakeholder needs, thus identifying stakeholder satisfaction as the highest level of performance measurement.

However, Bocci (2004) argues that including *"stakeholder satisfaction"* in the definition would limit the applicability of PM as there are other aspects to PM. Though Neely (2005) agrees that delivering value to stakeholders is essential to the success of an organisation, he also disagrees with including stakeholder satisfaction within the PM definition. Neely (2005) states that the role of the organisation and the role of PM need to be distinguished where the former refers to delivering value to the stakeholders and the latter refers to providing insight into how effective and efficient an organisation's past actions are. By considering the above arguments Kruger (2005) reports that PM is highly dependent on other factors thus, it should be refrained from developing a definition that satisfies everyone.

The researcher argues that the ultimate aim of quantification of efficiency and effectiveness of past actions is to deliver value to the stakeholders, as satisfaction of stakeholders could lead to securing their loyalty which will ensure their continuous engagement and retain them within the business. Within the context of this study (construction R&D), the value of stakeholders in the success of construction R&D was evident. As described in section 2.4.5, the dissatisfaction of the stakeholders has resulted in number of implications such as low levels of investment in construction R&D activities, lack of contribution and commitment of the stakeholders etc. Therefore, the researcher identifies delivering value to an organisation's stakeholders as the most important aspect and thus they should be acknowledged within the PM definition and, therefore, challenges Bocci's (2004) and Neely's (2005) views. This inclusion aligns with some of the popular Performance Measurement Systems (PMSs) such as Balanced Scorecard (Kaplan and Nortan, 1992) and Performance Prism (Neely and Adam, 2001) that identifies the importance of delivering value to stakeholders (see Section 2.5.4.2).

With relation to PM, it should not only be the information about the attainment of organisational goals, but also other influential factors such as communication, utilisation of resources that affect the attainment of the organisational goals. In addition to the quantification, the researcher acknowledges that PM requires additional infrastructure for it to be successful. After analysing the above review, the following factors have been identified as needing to be considered when measuring performance.

- efficiency and effectiveness of actions which determine the attainment of organisational goals and other influential factors;
- delivering value to the stakeholders;
- the need for infrastructure (data acquisition, collection, sorting, analysing, interpreting and disseminating)

Having explored the term *"performance measurement"*, the following section evaluates the importance of PM.

2.5.2 Importance of performance measurement

PM has been given a prominent place in most organisations as it helps to achieve the continuous improvements (Martinez, 2005; Baldwin et al, 2001). Longenecker and Fink (2001) note that lower benefits were gained by those organisations which do not utilise PM and feedback loops for improvement of management development programmes. PM enables managers to make decisions based on facts rather than on assumptions and faith (Parker, 2000). Thus, PM has become an integral part of planning and control within organisations. Cain (2004) identifies PM as the first stage to any improvement process that benefits the end users as well as the organisations. Greiling (2006) argues that PM can be used as a means of reporting the organisational success or failure and thus, can be considered as a tool which demonstrates the accountability of the parties involved. PM focuses employee attention and communicates the priority factors of the organisation by linking the organisational strategy with the employee's occupation (Martinez, 2005; Neely et al, 2002; Magretta and Stone, 2002; The Procurement Executive's Association, 1998). Agreeing with this view, Neely (1998) asserts that managers measure performance for two main reasons: firstly to influence the subordinate's behaviour; and secondly to identify their current position in the market. The influence and motivation made by PM in requiring employees to achieve targets set by the organisation is identified by Greiling (2006) as a steering instrument. Franco-Santos et al (2007) categorise PM into five main roles: monitoring the progress and measurement of performance; strategy management through planning, strategy formulation, implementation and providing the focus for work; internal and external communication; influencing the behaviour of the parties concerned; and learning and improvement of the work. Further, PM assists managers to progress in the right direction, revise business goals and re-engineer the business process if needed (Kuwaiti and Kay, 2000; van Hoek, 1998). A study carried out by Martinez (2005) revealed positive effects from PM such as improved customer satisfaction and company reputation, increased productivity and business improvement.

By considering the above, it can be said that PM is important for organisations to evaluate their actual objectives against predefined goals and make sure that they are doing well in the competitive environment. However, Halachmi (2002) asserts that sometimes the cost of introducing and implementing PM could exceed the potential benefits. Martinez (2005) also experienced similar results in her study and revealed that the use of complicated and excessive performance measures created negative effects due to the considerable consumption of time, investments and commitment of people. Furthermore, on some occasions the use of PM applications has limited the freedom of managers due to its rigidity (Martinez, 2005). Halachmi (2005) argues that when considering the tasks involved in PM, it would be impossible to do it correctly. It appears therefore that the use of PM has both positive and negative impacts on an organisation. Nevertheless, it can be argued that the solution is not to avoid the use of PM as there are well establish positive influences as discussed above, but to design and develop PM applications which are user friendly and which negates the negative impacts by providing more positive impacts. Section 2.5.4.1 considers this and looks into the characteristics of performance measures that would generate positive impacts. The section below discusses how performance measures have developed over the past few years and how these developments can be incorporated into an organisation to enhance the efficiency and effectiveness of its activities.

2.5.3 Performance measures

2.5.3.1 Development of performance measures

According to Nanni et al (1992), PM systems have historically been developed to monitor and maintain processes which help to achieve the goals and objectives of the organisation. Performance measures have traditionally concentrated on financial aspects such as a return on investment, sales per employee, and profit per unit of production (Kagioglou et al, 2001). However, due to the rapid changes in businesses influenced by diversification, globalisation, and technological innovations, cost accounting systems were replaced with time accounting systems (Neely and Austin, 2000). Furthermore, researchers claim that time is the new strategic performance measure that should be used to drive improvements (Ghalayini and Noble, 1996). Therefore, the traditional performance measures which were based on the cost accounting systems (Ghalayini and Noble, 1996) became obsolete when measuring performance in the modern business environment and it was identified that they cannot be used as the sole criteria for assessing performance (Jusoh et al, 2008; Kennerley and Neely, 2002). Traditional performance measures are criticised for many reasons:

- encouraging short-termism (Neely, 1999; Hayes and Garvin, 1982; Banks and Wheelwright, 1979);
- lacking strategic focus (Neely 1999);
- encouraging local optimisation (Fry and Cox, 1989; Hall, 1983);
- encouraging minimisation of variance rather than continuous improvement (Lynch and Cross, 1995; Johnson and Kaplan, 1987);
- lack of external focus (Kaplan and Norton, 1992);
- inaccuracy in reflecting the interest of stakeholders (Mbugua et al, 1999; Kaplan and Norton, 1996);
- lagging metrics (Ghalayini and Noble, 1996); and
- over reliance on financial aspects (Clarke and Clegg, 1999; Olve et al, 1999; Ernst and Young, 1998).

The inadequacies of financially based traditional measures to cater for current business needs led the way to look beyond them. Further, it was realised that there are number of intangible assets or non financial aspects (such as customer relationships, skills and knowledge of the employees) which could affect the organisation's performance. Kaplan and Norton (2001) argue that many organisations are keen on managing the intangible assets such as customer satisfaction, responsiveness of the operating processes rather than managing financially based tangible assets. Therefore, they state that the evaluation of performance needs to reflect and accommodate these changes within their systems. Thus, the use of non financial performance measures has emerged (Gomes et al, 2007; Thakkar et al., 2007; Tangen, 2004; Neely, 1999; Kaplan and Norton, 1992).

With these grounds, a new generation of PM has evolved by supplementing financial performance measures with non-financial measures. Accordingly, PMSs such as Balanced Scorecard (BSC) (Kaplan and Norton, 1992), Performance Prism (Neely and Adam, 2001), Skandia's Navigator (Edvinsson and Malone, 1997) were developed. However, the use of both financial and non financial measures creates a problem by generating a larger number of measures and the organisations have the challenge of integrating these measures in order to better reflect their performance.

Intangible assets create indirect value to the organisational performance. Improvements in intangible assets generates financial benefits having gone through a chain of activities or passing several intermediate stages. Zigan et al (2008) claim that organisations will not succeed in providing best value for their customers without proper understanding of how and why they need to develop their intangible resources. However, if the organisation wants to identify contributions from its intangible assets, the value creation made through them should be more visible. As a result of this, the next generation of PM evolved creating visible links between the organisational objectives and its resources including the intangible assets. This includes strategy maps developed by Kaplan and Norton (2000), success and risk maps developed by Neely et al (2002), and Roos et al's (1997) IC-Navigator model. These models visualise how the organisational assets aid creation of business value.

Since PM data is to be used in decision making, the exercise of PM should be able to generate adequate information for management to take decisions. Furthermore, due to the rapid changes in the market, management needs to get a true picture of their company's performance. Failing to provide this information would mislead management in their decision making. Therefore, Pike and Roos (2001) assert that the next generation of PM needs to address three main issues: appropriateness and adequacy for the purpose of measurement; information adequacy and practicality; and organisational alignment. Adding to these three challenges, Neely et al (2003) emphasise that the next generation of PM would need to demonstrate the cash flow implications of non-financial and intangible assets. Lee et al (2003) claim that the performance of an organisation depends not only on its own performance, but also on the performance of their partners. Thus, Busi and Bititci (2006) assert that the focus of PM has gone beyond the four walls of a company and the need for sharing information related to performance with their partners in the value chain has arisen.

The researcher acknowledges the requirement to go beyond the limits of an organisation as pointed out by Lee et al (2003) and Busi and Bititci (2006). This acknowledgment can be supported by the findings of section 2.4.4 which revealed that R&D work carried out with the collaboration of universities and industrial partners is more successful. It was also identified that in addition to the above partners, the funding bodies play a vital role in providing the necessary finance for construction R&D activities. Hence, the degree of success of construction R&D depends not only on the performance of a single organisation but also on their partners and funding bodies. This creates the need for assessing the performance of the parties involved in collaborative research work.

The above section evaluates how PM has developed over the last few decades through several generations. It also discussed the challenges faced by PM in the generations to come. With this understanding, the discussion moves to the next section where the characteristics of PMSs are explained followed by commonly used PMSs with their advantages and disadvantages.

2.5.4 Performance measurement systems

2.5.4.1 Characteristics of performance measurement systems

In order to overcome the problems associated with traditional performance measures and to facilitate effective and efficient PM in the current business environment, new performance measures have come into practice. A number of PMSs have been developed integrating multiple performance measures which capture different perspectives of the organisation such as shareholder value, customer satisfaction, financial perspective, capabilities of the employees and internal business processes (Neely and Adams, 2001; Lynch and Cross, 1995; Kaplan and Norton, 1992).

Jusoh et al (2008) and Bryant et al (2004) state that the use of multiple performance measures which covers a diverse set of financial and non financial measures positively correlates with the organisational performance. Appreciating this fact, Drucker (1990) and Russell (1992) state that there is a need for the alignment of the financial and non-financial measures to fit within a strategic framework. Kennerley and Neely (2002) assert that whilst the non-financial measures reflect the organisational objectives the financial measures indicate the bottom line results. According to Schlesinger and Heskett (1991), a relationship exists between internal service quality, employee satisfaction, employee retention, external service quality, customer satisfaction, customer retention, and profit. Due to this relationship, Hronec (1993) argues that PMS should be a balancing tool. Kaplan and Norton (1992) reinforce this by stating that the PMS should be a balanced method, addressing all the required aspects of an organisation. Moreover, the significance of non-financial, customer based and quality related measures were highlighted when implementing PMSs (Gomes et al, 2007).

In addition to the use of both financial and non financial measures, the incorporation of lagging and leading indicators are also identified as beneficial. Lagging indicators inform what has already happened, or in other words the final result of an action (Macpherson, 2008). On the other hand, leading indicators notify the future performance level (Macpherson, 2008). Leading indicators reflect the success of processes that achieve the outcome thus, based on the results of the leading indicators; corrective actions can be taken to avoid the damages which could affect the lagging indicators.

Many authors have recognised and emphasised the need for linking the strategy of the organisation with performance measures (Robson, 2004; Tangen, 2002; Kaplan and Norton, 2001; Parker, 2000; Neely, 1999; Gregory, 1993; Lynch and Cross, 1995; Dixon et al, 1990; Globerson, 1985). When the performance measures are linked with the strategy, the achievement of performance measures reflects the level of achievement of the organisation's strategy. According to Bititci et al. (2000) PMS needs to have the following characteristics: sensitivity to changes in the external and internal environment of an organisation; review and prioritise internal objectives when the changes in the external and internal environments are significant enough; deploy changes to internal objectives and priorities to critical parts of the organisation, thus ensuring alignment at all times; and ensuring that gains achieved through improvement programmes are maintained. In addition to the above characteristics, performance measures should be derived from the few key success factors, and should be easily controllable by the employees (Thakkar et al, 2007), provide timely and accurate feedback, and have a specific purpose (Fortuin, 1988; Globerson, 1985).

Even though a PMS is developed with good characteristics, it should be preceded by the proper integration of the results of PM to organisational management. Failure to do so could result in waste of the resources utilised for the implementation of PM.

Having identified the characteristics of PMSs, the section below discusses some commonly used PMSs.

2.5.4.2 Performance measurement systems

2.5.4.2.1 Performance measurement matrix

Keegan et al's (1989) performance measurement matrix is developed based on the concept of integrating financial and non-financial aspects of organisational performance. Accordingly, it incorporates cost, non-cost, external and internal factors that influence organisational performance. However, the links between these categories are not explicitly described and this is identified as one of the main weaknesses of the matrix (Neely et al, 2000).

2.5.4.2.2 Balanced scorecard

By overcoming the weaknesses in performance measurement matrix, Kaplan and Norton (1992) have developed the Balanced Scorecard (BSC) which explicitly identifies links between different dimensions of performance (see Figure 2.6). BSC incorporates four perspectives: financial; internal business; innovation and learning and customer perspectives. These perspectives tend to answer the following four questions to ensure the organisation is doing well in the competitive market.

- how do we look to our shareholders? (financial perspective)
- what must we excel at? (internal business perspective)
- how do our customers see us? (customer perspective)
- how can we continue to improve and create value? (innovation and learning perspective)

The four perspectives of BSC minimises overloading information but focuses on the most critical success factors of the organisation (Kaplan and Norton, 1992). Furthermore, BSC can be used to translate the company's mission and strategic objectives to provide a set of performance measures, help communicate and implement strategy and enable employees to identify the drivers of current and future success factors of the organisation (Kaplan and Norton, 1996). A major strength of BSC is that it links PM with the organisational strategy. BSC differs from the traditional approach of performance measurement, as it combines both the *"lagging"* and *"leading"* measures. Furthermore, the measures in BSC are balanced not only between external measures (shareholders and customers) and internal measures (critical business process, innovation, and learning and growth) but also between the result measures (outcomes) and driver measures (measures for future improvement).

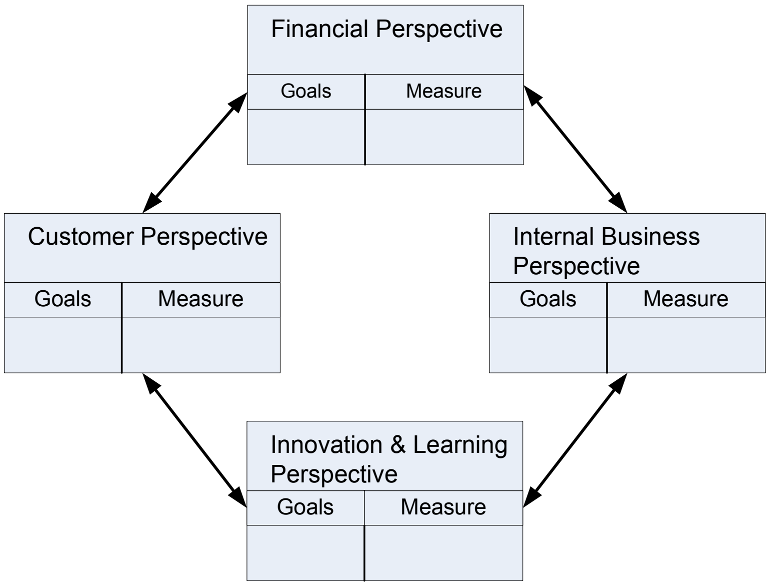


Figure 2.6: Balanced Scorecard (source: Kaplan and Norton, 1992)

Even though BSC is widely used, a number of shortcomings have been identified. The absence of a competitiveness dimension, as in the case of Fitzgerald et al's (1991) results and determinants framework, failure to consider the human resource perspective, employee satisfaction, supplier performance, product, service quality, environment and community perspectives are some examples of shortcomings of BSC (Kennerley and Neely, 2002; Lingle and Schiemann, 1996; Brown, 1996). Neely and Bourne (2000) and Schneiderman (1999) also argue that the four perspectives of BSC are insufficient. Further, Neely et al (2000) state that BSC provide little guidance for identifying and managing the appropriate performance measures of the business.

2.5.4.2.3 Results and determinants framework

Similar to Kaplan and Norton's BSC, Fitzgerald et al (1991) developed another PMS by considering leading and lagging performance measures. This PMS specifically targets PM in the service sector. It identifies six performance measures where two of them measure the results (lagging indicators) of competitive success (competitiveness, financial performance) while the other four measure the determinants (leading indicators) of competitive success (quality of service, flexibility, resource utilisation, innovation).

2.5.4.2.4 European foundation for quality management model (EFQM)

The European Foundation for Quality Management model (EFQM) is another framework which was developed on the basis of determinants (enablers) and results indicators similar to the Fitzgerald et al (1991) PMS. The EFQM model is based on the principle that *"excellent results with respect to performance, customers, people and society are achieved through leadership driving policy and strategy, that is delivered through people, partnerships and resources and processes"* (The European Foundation for Quality Management, 2000, p: 5). The model consists of five *"enablers"* i.e. criteria that the organisation can manipulate, and four *"results"* i.e. what an organisation will achieve (see Figure 2.7). The enabler criteria are concerned with how the organisation undertakes key activities while the results criteria is concerned with what results will be achieved.

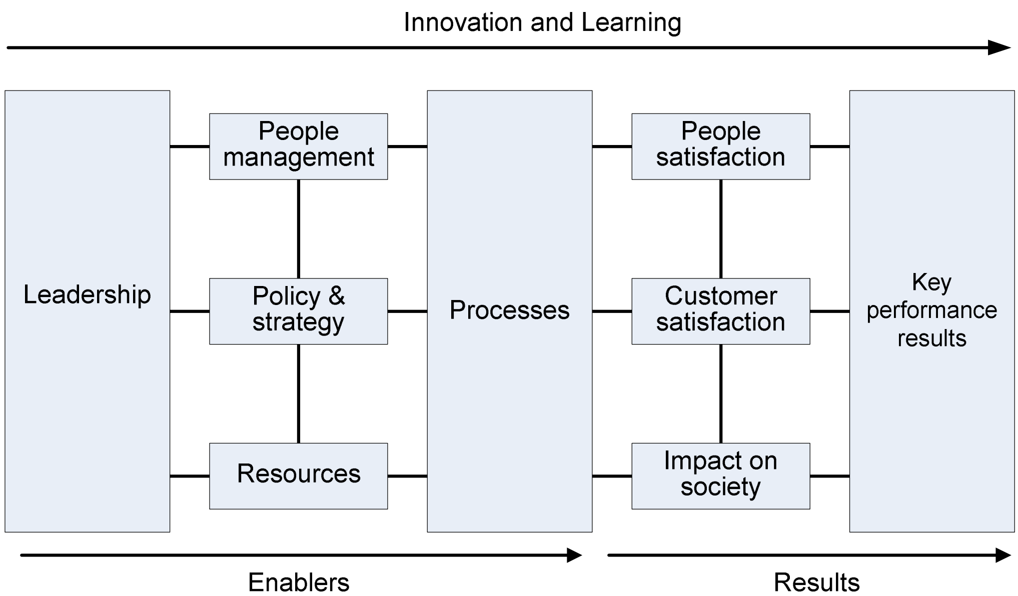


Figure 2.7: EFQM model (source: The European Foundation for Quality Management, 2000)

The model is widely used to carry out quality management and self-assessments. However, the terms used in the EFQM model are open and can be interpreted in a number of ways, state Neely et al (2000). This increases the number of performance measures within each category which leads to a problem of selecting and relying on the appropriate performance measure for the organisation.

2.5.4.2.5 Brown's framework

Brown's (1996) framework was specifically designed to evaluate the performance of research and development performance (see Figure 2.8). Brown's (1996) framework takes into consideration the horizontal flow of material and information flow of an organisation which differentiates the input (raw materials, capital), process (delivery of services, production of products), output (products, services) and outcome measures (delighted customers, satisfaction of the customers) of performance.

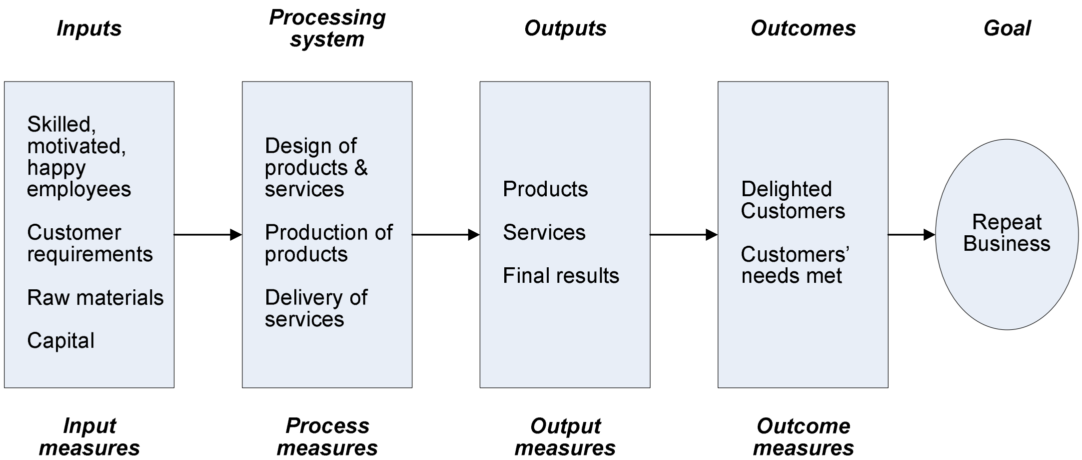


Figure 2.8: Brown's framework (source: Brown, 1996)

2.5.4.2.6 Performance prism

The performance prism developed by Neely and Adams (2001) emphasises the need for considering stakeholders who interact with the organisation (see Figure 2.9). The performance prism is not limited to addressing the needs of shareholders and customers as in the case of BSC, but goes beyond that and addresses the needs of employees, suppliers, intermediaries, regulators, and the community as they too also have a substantial impact on project performance (Adams and Neely, 2000). Performance prism consists of five interrelated aspects:

- stakeholder satisfaction: who are our key stakeholders and what do they want and need?;
- stakeholder contribution: what do we need and want from our stakeholders in a reciprocal way?;
- strategy: what strategies do we have to place in order to satisfy our stakeholders while satisfying our needs?;
- processes: what processes do we need to put in place to enable us to execute our strategies?; and

- capabilities: what capabilities do we need to put in place to allow us to operate our process?

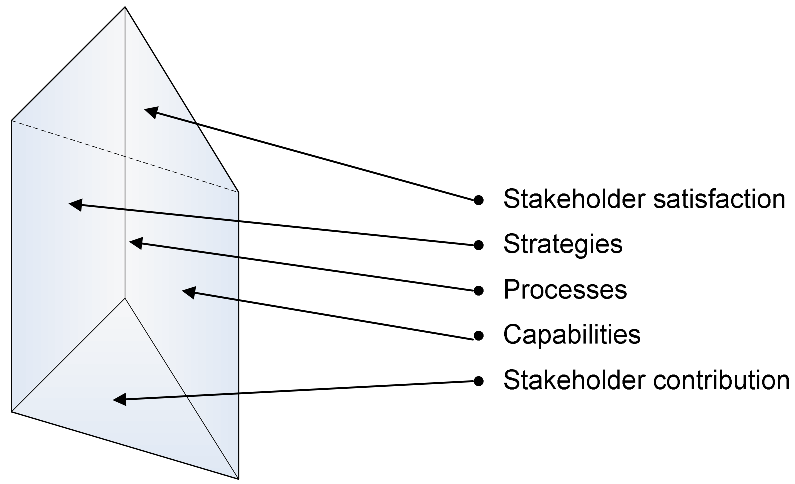


Figure 2.9: Performance prism (source: Neely and Adams, 2001)

In most PMSs, the measures are derived from the strategy, but in the performance prism it is the other way around. The strategic, process and capability aspects of the performance prism have been derived by considering the requirements needed for stakeholder satisfaction. Furthermore, the performance prism identifies the reciprocal relationship between the stakeholders and the organisation. Also, performance prism gives due consideration to competitors and customers thus addressing the shortcomings of traditional performance measures in focusing on external factors and future performance (Kennerley and Bourne, 2003). However, Tangen (2004) argues that appropriate guidance for the selection of measures are lacking in the performance prism.

2.5.4.2.7 Strategy and success maps

By considering the transformation of company resources and stocks of these resources, success and strategy maps are developed. They show the causal relationship between the different perspectives and provide a good visual representation of the organisational objectives and their performance drivers. The strategy map is constructed by considering the four perspectives of Kaplan and Norton's BSC. It shows visually how the employees' jobs are linked to the overall objectives of the company (Kaplan and Norton, 2000). Thus, the strategy map can be considered as a strong communication tool that helps the organisation achieve its strategy. Furthermore, the strategy map demonstrates how the organisation can convert its resources (including the intangible resources such as employee knowledge) into tangible outcomes (Kaplan and Norton, 2000). However, Neely et al (2003) argue that if the strategy map is limited to the four perspectives of the BSC, they have the drawback of not addressing all the stakeholder groups of an organisation.

Success maps are developed by extending the five perspectives of the performance prism. Similar to the performance prism, success maps also take a broader view of the stakeholders of an organisation. In addition to the success map, Neely et al (2002) propose mapping the likely risks or failures for an organisation. By doing so, an organisation can identifies the critical failure points which can harm the organisation's performance (Neely et al, 2003). The PMSs developed over the past years are not limited to the above, but the researcher has discussed the most common PMSs that can be found in the literature. By addressing the requirements of various organisations, industries and disciplines, a number of other PMSs have been developed. Some have adopted the concepts of above PMSs and altered the performance measure to suit their requirements.

On the whole, the limitations associated with traditional performance measures direct the way to use new performance measures, which not only look into the financial aspects of the organisation, but also non financial aspects. It is evident from the above literature review that some of these PMSs blend the lagging indicators with the leading indicators (e.g.: BSC) i.e. measuring the results of the organisation's performance and the drivers of results (e.g.: EFQM model, Fitzgerald et al's framework). The concept behind the combination of lagging (results) and leading (enablers) indicators is to identify any failures before it damages the end result. For example, the leading indicators of BSC would identify the issues which will have an impact on the financial measures (i.e. the lagging indicator of the BSC), and provide information before the organisation is affected by the issue. Additionally, the lagging indicators monitor the past performance of the organisation, while the leading indicators assist in planning future activities. The importance of providing a balanced overview of organisational performance can be identified in most of PMSs. The use of multi-dimensional performance measures which capture different perspectives of the organisation such as shareholder value, customer satisfaction, financial perspective, capabilities of the employees, internal business processes etc. is evident in these PMSs. The need for linking the strategy of the organisation with the performance measures is emphasised in most PMSs. When the performance measures are aligned with the organisational strategy, the implementation of PM ensures the strategy implementation. In most PMSs, the measures are derived from the organisations' strategy. However, Neely and Adam's performance prism adopts a different view by deriving the company strategy to suite the requirements of the stakeholders.

The review shows that there are strengths and weaknesses in each PMS. It can be argued that factors like performance measures, frequency of measurement are heavily dependent upon the purpose of measurement, time available for measurement, availability of data, cost of measurement etc. Therefore, designing a single PMS to suit all the requirements and disciplines is not possible. It is up to the practitioner to evaluate the strengths and weaknesses, requirements, and commitments and decide on the most suitable PMS.

Having explored some of the commonly used PMSs, the following section elaborates on the applicability of the PM concept within the R&D settings.

2.6 Research and development performance measurement

2.6.1 Value of performance measurement to research and development

The impact of R&D on the business strategy was discussed in Section 2.2.2. This understanding of R&D as a strategic issue has resulted in changes of the management practices within organisations. Thus, it has been recognised that R&D cannot be treated in isolation, but has to be aligned and linked with the corporate strategy of the organisation (Pearson et al., 2000; Kerssens-van Drongelen and Bilderbeek, 1999; Roberts, 1988; Rogers, 1996; Roussel et al., 1991). With this understanding comes the question of implementing the R&D strategy leading to a better attainment of the organisational goals. This question is reflected in the study carried out by Bremser and Barsky (2004, p: 230) that states *"a firm can develop a seemingly brilliant R&D strategy designed to achieve competitive advantage and grow the firm, but implementing strategy is the management challenge"*. This question leads on to the following section which discusses the integration of PM with R&D strategy to enable its correct implementation. Further, other benefits of PM in R&D environments are also discussed.

2.6.2 Need for performance measurement in research and development work

Due to rising costs, time and other resource constraints, much attention is paid to the success of R&D work where managers are under pressure to monitor and improve the performance of such activities (Kerssens-van Drongelen et al, 2000). Further, attention of management is paid to identifying the contribution from R&D activities towards a competitive advantage for the organisation (Chiesa and Frattini, 2007; Germeraad, 2003). Karlsson et al (2004) assert that to gain the maximum outcome, the processes and factors which influence R&D work need be continuously evaluated. Accordingly, Karlsson et al, (2004, p: 185) argue that *"these processes, like everything else that has to be improved, have to be measured against some sort of data either historically or by expected output"*. This can be achieved by implementing PM applications within R&D work as it helps to measure the outcomes against the targets (Bremser and Barsky, 2004). Agreeing with this view Yawson et al (2006) claim that PM for R&D activities provide the basis to assess whether the organisation is progressing towards its goals, identifies the strengths and weaknesses, decides on the future actions needed for improvements and provides data to request additional resources.

The significance of positioning PM strategically has been well acknowledged in general PM literature as it directs and monitors the implementation of the strategy within the organisation (see Section 2.5.2). Similarly, a number of studies have revealed that PM of R&D plays a vital role by influencing and helping organisations to implement their strategies (Bremser and Barsky, 2004; Pearson et al, 2000; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen and Bilderbeek, 1999; Werner and Souder, 1997; Brown and Svenson, 1988) and motivating the employees towards achieving the predetermined goals (Kerssen van-Drongelen and Cook, 1997). Thus, the need to select strategic performance measures which focuses on processes, outputs, tangible and intangible assets is being emphasised for PM in R&D (Bremser and Barsky, 2004; Pearson et al, 2000). A shift from lagging financial measures towards forward looking strategic performance measures are also identified in the PM in R&D (Doukas and Switzer, 1992; Woolridge and Snow, 1990; Chan et al, 1990).

Investors in R&D play a vital role by providing necessary funds to undertake efficient and effective research. Thus, from the point of view of the investors, money spent on R&D work should be used to its maximum capacity. Consequently the argument which says financial restrictions negatively affect the freedom and the creativity of R&D activities (Roussel et al, 1991) has been challenged due to the need for efficient and effective results from R&D investment (Werner and Souder, 1997). Print (1999) recognises that some of the money spent on R&D activities is wasted and managers are unable to identify and locate the areas in which the money is wasted. Shareholders are also keen on recognising the contributions from R&D activities towards the development of the organisation (Institutional Shareholders' Committee, 1992). Such concerns from investors and shareholders of R&D spending have demanded identification of the actual contribution from R&D investments towards the organisational goals, thus increasing the accountability of the proper usage of R&D investments (Osawa and Yamasaki, 2005).Therefore, Pearson et al (2000) and Nixon (1998) state that management has been forced to find ways to measure the return on R&D expenditure and to evaluate the performance of such activities. In addition to the identification of utilisation of resources, PM in R&D could identify the proper resource allocation within organisations (Bremser and Barsky, 2004; Pearson et al., 2000; Kerssen-van Drongelen and Bilderbeek, 1999). Furthermore, PM in R&D improves communication and coordination of the activities (Bremser and Barsky, 2004; Loch and Tapper, 2002).

The above discussion shows the need for showing accountability of resources consumed on R&D activities, the need for increasing the efficiency and effectiveness of R&D activities, and the alignment of the R&D activities with the overall business strategy. Thus, this has raised the need for PM on R&D activities as such could evaluate the resource utilisation, assess the progress and success, motivate the employees towards the common goals, monitor and control the R&D activities. Research carried out in various industries indicates that long term competitive advantage depends on commitment to on going R&D work and the use of PM applications to evaluate its success (Osawa and Yamasaki, 2005; Pearson et al, 2000; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen and Bilderbeek, 1999; Werner and Souder, 1997; Tipping et al, 1995; Brown and Svenson, 1988). This justifies the advantages and competitiveness which organisations could obtain by implementing PM applications within R&D.

This section discussed the value of PM in R&D activities in general. The following section briefly explains the development of PM over the past decades to cater to the current needs of R&D work.

2.6.3 Development of research and development performance measures

Since few decades back, companies were adapting various mechanisms, mainly output and outcome based performance measures to measure certain aspects of R&D (Kerssens-van Drongelen et al, 2000; Robert, 1994). The performance measures related to R&D used during earlier days (1970s) focused mainly on three indicators (Robert, 1994):

- strictly technical products (patents, technical publications or citations to technical publications);
- financial benefits that emerge from R&D (profits, sales); and
- judgments about the success of individual R&D projects.

These measures were developed based on the output and outcome of R&D activities. Schainblatt (1982) asserts that these measures were widely used due to the ease of accountability. Further, the use of objective measures dominated the R&D PM during earlier stages (Keller and Holland, 1982). However, Moser (1985, p: 32) stated *"a major question in the use of such objective measures as indices of efficiency is whether they are truly representative of the context of the work settings"*.

Similar to the developments of performance measures discussed in general literature (see Section 2.5.3.1), PM in R&D has also undergone major changes over the last few decades. The use of financial measures as the only criterion of R&D PM has been challenged as they are lagging indicators and not connected with the operational activities (Loch and Tapper, 2002). Accordingly, the need to have non-financial measures for R&D PM has been arisen (Hart, 1993). According to Bremser and Barsky (2004), for the successful attainment of management strategies and aims and objectives, integrated PMSs are required as they capture the changes in financial and non-financial aspects of organisational performance. Technological advances and customer and profit-oriented markets also demanded R&D to facilitate broad areas of activities such as differentiations, time to market, value for money, service and economic production (Cooper, 1998; Smith and Reinertsen, 1998). The need to go beyond financial measures and consider customer and shareholder value, business processes, organisational learning and growth are identified and emphasised (Pearson et al, 2000). As a result, multiple and integrated performance measures that combine qualitative, quantitative, objective and subjective measures are identified as more effective ways to measure the performance of R&D work. In Section 2.5.3.1, it was revealed that the existence of multiple measures creates problems in properly integrating them to reflect the organisational performance. Similarly, Cooper and Kleinschmidt (2007) believe that having multiple performance measure on R&D activities could also confuse and make the implementation of PM more complex.

Accordingly, the need for integrated and strategically focused PM applications for R&D can be highlighted. Such PM applications align the processes of R&D work (R&D, production, marketing and other functional areas) with organisational strategy using lagging (outcome measures) and leading (performance drivers) measures. The section below discusses the currently available PMSs within R&D.

2.6.4 Performance measurement systems and performance measures used within research and development work

A number of performance measures and PMSs can be identified in the R&D PM area. According to Werner and Souder (1997) R&D performance measures can be broadly divided into macro and micro measures where macro level approaches concentrate on the impact of R&D on society as a whole and micro level approaches concentrate on the impact of R&D on the organisational level.

One of the earlier developed R&D PMS was by Brown's (1996) framework (see Figure 2.8). This framework was developed by considering the R&D laboratory as a system and considering input (people, ideas, and equipment), output (patents, products, publications) and outcome (cost reductions, sales improvements) based performance measures. In 1985, Moser carried out a survey and identified 14 categories of R&D performance measures. Most of the measures identified from this categorisation, are output based. Griffin and Page (1993) classify the measures into four groups: customer acceptance; financial; product level; and organisation level. The categorisation of R&D performance measures according to Kaplan and Norton's BSC i.e. according to financial, customer, internal business process and learning and growth perspectives (see Section 2.5.4.2.2) can be identified in number of instances (Yawson et al, 2006; Bremser and Barsky, 2004; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen, 1999; Kerssens-van Drongelen and Cook, 1997). The use of BSC provides an integrated PMS to implement the strategy while comprehensively and appropriately covering the vital areas of PM in the R&D environment (Yawson et al, 2006; Bremser and Barsky, 2004; Kerssens-van Drongelen et al, 2000). Godener and Soderquist (2004) identify three more classifications to measure performance, in addition to the four perspectives used in the BSC (see Section 2.5.4.2.2). They are strategic (strategic goal satisfaction), technology management (generation of new competitive products) and knowledge management (return on investment in terms of knowledge creation, knowledge transfer and knowledge exploitation). Coccia (2004) measures the performance of public research institutes using five measures (training, finance, national publications, teaching, international publications). In another study, the application of the EFQM model (see Section 2.5.4.2.4) for a research organisation can be identified by assigning performance measures for customer, people, social and business attributes (Weggeman and Groeneveld, 2005).

Section 2.6.2 identified the value gained by other industries in implementing PM within R&D activities while Section 2.6.3 and Section 2.6.4 respectively, discussed the development of R&D performance measures over time and common performance measures and PMSs used within R&D. Section 2.4.5 of this study explored the issues within construction R&D such as low level of investment, objectives of R&D activities not addressing the requirements of the parties' concerned, insufficient involvement of industrial partners, lack of evaluation mechanisms, lack of coordination and communication etc. The section below discusses whether these issues could be minimised and the success of construction R&D activities could be enhanced though the implementation of PM.

2.6.5 Performance measurement and construction research and development

To become involved in high quality research, construction R&D requires resources such as equipment, skilled personnel and funds (Seaden, 2002). As with any other investment, construction R&D investors expect reasonable returns from their investments (Seaden, 2002; Courtney, 1999). As discussed in section 2.4.5, a low level of investment can be identified for UK construction R&D when compared with countries like France, Japan and Scandinavia (Gann, 2000) and when compared with other sectors like manufacturing (Department for Business Enterprise and Regulatory Reform, 2007; Institute of Civil Engineers, 2006; DTI, 2006; DTI, 2005b; DTI, 2004; Dulaimi et al, 2002; Fairclough, 2002; Seaden and Manseau, 2001; Laing, 2001; Egan, 1998). One of the main reasons for low investment is *"improper reporting of R&D expenses"* (Seaden and Manseau, 2001, p: 186). Further, as discussed in section 2.3.3, people question the value of R&D when clear links between its benefits and the financial commitments are not established. Courtney (1999) argues that R&D returns should be *"more calculable"* by means of establishing certain and visible relationships between the investments and output of construction R&D activities. This can be done by implementing PM applications within construction R&D. By doing so, proper utilisation of investments and clear links between investments and potential benefits for the investors can be clearly identified.

Identifying new ways to access technical solutions and creating new and improved products in the construction industry requires not only sufficient investments, but also commitment and time of the employees (Building Research Establishment, 2005). Thus, time devoted to construction R&D should be justifiable. It is also important to show that the results obtained through construction R&D activities are correctly aligned with expected objectives. This has demanded proper controlling and monitoring mechanisms, and a way to assess goals against the outcomes. This can be achieved by implementing PM applications within construction R&D work as such applications continuously evaluate the success of the activities and identify gaps between the goals and expected outcomes (see Section 2.5.2).

As discussed in Section 2.4.5, construction R&D activities lack effective communication, feedback and validation procedures, and coordination between the parties involved in the process. For effective and efficient R&D work better management of aforementioned activities is important (Cohendet and Steinmuller, 2000; Steinmuller, 2000). Since, PM applications increase communication, coordination, feedback mechanisms and direct employees towards common goals (see Section 2.5.2) the implementation of PM within construction R&D would improve the internal capabilities and would generate successful results.

The need for training, participation in seminars, conferences, etc. is being identified as ways to increase the skills and knowledge of people involved in construction R&D activities, (Dulaimi et al, 2002). A properly designed PMS not only evaluates the objectives of the parties involved, but also identifies the supporting infrastructure needed for employees to carry out their work (see Section 2.5.4.1). Furthermore, PM helps to control, monitor and allocate the organisational resources (Melnyk et al, 2004; Love and Holt, 2000). By implementing PM applications within construction R&D, the resources can be properly handled thus increasing the accountability of the resources.

The evaluation of performance needs to ensure that the success criterion and the success factors of the R&D function are well achieved. Frattini et al (2006) state that the performance measures should be selected to reflect the Critical Success Factors (CSFs) of the area under consideration. Further, Thakkar et al, (2007) emphasise the importance of including correct performance measures within the PMS to gain the maximum benefits from PM. Thus, identification of the success factor has a major bearing on the evaluation of performance especially when designing targets or performance measures. Therefore, a greater insight into the factors, which lead to high performance of the R&D function, is needed for its success. Consequently, the following section discusses the success factors of R&D in general and the specific success factors of construction R&D.

2.7 Success factors of research and development

Chan et al (2002) define success as the degree to which project goals, objectives and expectations are met. Success could be viewed from different perspectives depending on the goals related to a variety of elements, including technical, financial, education, social, and professional issues (Lim and Mohamed, 1999). Lim and Mohamed (1999) distinguish success criteria and success factors, where the former refers to a set of standards or principles within which the success can be judged and the latter refers to the set of circumstances and factors, which could influence the attainment of the success criteria. Cooke-Davies (2002) also differentiates success criteria and success factors. According to him, success criteria is the measure that could be used to judge the success or failure of a project/business and success factors are the inputs to the management system that leads directly or indirectly to the success of the project/ business. Among these success factors, the most influential factors that are needed for the attainment of the overall goals can be defined as the critical success factors (CSFs).

For a new venture to be successful, it needs to be effectively moved forward through its life cycle from initiation to launch (see Section 2.2.3). This effective transference depends on a number of success factors. Cooper and Kleinschmidt (2007) assert a high quality, rigorous new product development process which consists of thorough upfront work, tough decision points, sharp early product definition and flexibility as the strongest drivers of the new product development (NPD) process. The need for human integrity in making discoveries, creating new products, processes and services is widely accepted highlighting the availability and ability of people as one of the crucial factors for successful R&D effort (Cooper and Kleinschmidt, 2007; Roberts, 2002). Other than the human resource, Cooper and Kleinschmidt (2007) identify the availability of financial resources as another factor, which significantly influences the NPD process. The management of R&D activities has become complex as it addresses the needs of various stakeholders thus requiring a contribution from multidisciplinary groups. Therefore, successful accomplishment of new ventures requires effective management of constraints of the stakeholders. Accordingly, the proper management of interdisciplinary team work (Sawhney and Prandelli, 2000), leadership styles and work environment (Shim and Lee, 2001) are also revealed as factors behind the success of R&D efforts.

A study carried out by Lester (1998) reveals 16 critical success factors, which centre on five main categories: senior management commitment; organisational structure and processes; attractive new product concept; forming the venture teams; and project management. These factors are derived from evaluating an early stage of NPD when there is a greater degree of uncertainty. The study carried out by Cooper (1999) considers the success factors needed at business unit level. After benchmarking factors that drive and obstruct effective NPD, they disclose 12 success factors and seven possible reasons that could hinder the effectiveness of NPD (see Appendix B). Sun and Wing (2005) linked the success factors with the life cycle of NPD and ranked them according to their importance. The study revealed that some of the CSFs were not sufficiently implemented in practice while the factors that are less important were well implemented. A summary of success factors from number of studies are given in Appendix B.

2.7.1 Success factors of construction research and development

In terms of the construction research base, Fairclough (2002, p: 17) raises the following questions; *"is the construction research base in a fit state to tackle the most critical issues of the 21st century? Does it have the right people, the right organisation, or the right vision? Does it have the right skills?"* Lack of skilled people in construction R&D organisations has resulted in inadequate support for ongoing R&D activities and a reduction in the absorption capacity to implement good practices developed in other organisations/disciplines. Similarly to Fairclough (2002), Conceicao and Heitor (2002) also assert the need of skilled employees to implement the good ideas. Skilled people therefore can be identified as one of the success factors for construction R&D. Further, supporting the researchers by providing facilities to attend seminars, conferences, and training activities to enhance their skills and knowledge are identified as important factors for effective construction R&D (Dulaimi et al, 2002).

The need for clear operational objectives, which are shared by the participants of the R&D work is identified by CRISP (2004) as another factor for construction R&D to be successful. They argue that clear objectives would not overwhelm the parties involved in R&D by giving unachievable expectations or inappropriate targets which cannot be met. Further, having clear timeframes for R&D work would determine and allocate adequate resources (CRISP, 2004). Innovation by its nature is highly risky. Thus, R&D, which leads to innovation can often fail or generate unexpected results. Therefore, for research work to be successful, creating a no blame culture and sharing the cost of failure of R&D work is emphasised (CRISP, 2004; Dulaimi et al, 2002). Fairclough (2002) asserts that lack of vision/strategy within construction research base as a factor that negatively affects R&D performance. A clearly defined and transparent R&D strategy communicates and guides employees towards achieving the common goals of the organisation. Moreover, as discussed in Section 2.4.4, creating proper links between academia and industrial partners is a factor, which positively influences construction R&D activities. Furthermore, securing long term funding has been identified as one of the main factors that contribute to the success of construction R&D activities (Hampson and Brandon, 2004). A study carried out by Gray and Davies (2007) revealed that measurement against targets, continuous improvement of the innovation, teamwork, selecting and generating new knowledge, innovation performance management, developing the right teams are important factors which influences the success of project based innovation in construction.

The studies carried out in other disciplines, such as manufacturing, suggested that there could be a gap between the factors that are important and those that are implemented (Sun and Wing, 2005). Not knowing the success factors could lead to not implementing them in practice. The success factors identified from the general literature review share a common view of what is necessary for the successful development of a new venture but they are not exactly the same for construction industry. In reality, it is difficult to generate a common set of success factors as they could vary depending on the industry, type of new venture and level of analysis (project level, process level). The unit of analysis of the majority of previous studies done in other disciplines was on the organisational level. However, there can be practical issues in the R&D function, which makes identification of the CSFs during the R&D function important. Though a number of studies have been carried out in other disciplines on the identification of success factors, within construction, such studies are rare.

As discussed in Section 2.5.2 and 2.6.1, PM has a number of advantages such as; evaluation of success or otherwise, motivating people, directing the employees towards the targets and acting as a communication tool etc. However, in order to achieve these benefits, it is important to set the correct targets for the measurement process as failure to do so would result in measuring something unimportant or irrelevant. On this premise the identification of the CSFs in the construction R&D function and aligning them with the performance measures can be elaborated. The identification of CSFs would help management to concentrate on the most significant and influential factors in the development of the new venture and linking them with the performance measures would ensure their proper implementation during the R&D function. Hence, this study intends to investigate the CSFs to integrate them with the life cycle of the new venture and thereby to develop the performance measure for the evaluation of performance of construction R&D activities.

This chapter discussed and synthesised the literature relating for the study. The section below presents the research questions developed through the literature review.

2.8 Research questions

In developing the main arguments for this study, the literature review lead to two different areas namely "r*esearch & development*" and "*performance measurement*". Through general and construction specific literature these two areas were integrated by establishing the need for PM within the construction R&D function. Hence, the need for further investigation of this significant yet under-researched area i.e. PM within construction R&D function was established. Accordingly, the following research questions were formulated from the literature review.

- what is the importance of R&D to the construction industry?
- what is the current position of construction R&D function?
- how can PM influence the performance improvement of construction R&D function?
- how can performance of construction R&D function be measured?
- what are the critical success factors of construction R&D function?

2.9 Summary and link

The significant contribution from the construction industry towards the built environment, society and the economy is unquestionable. Despite these contributions, the UK construction industry is being challenged to produce economically, socially and environmentally acceptable products to satisfy its stakeholders, which enhances the effectiveness and efficiency of the construction process and addresses resource constraints and sustainable goals. These challenges are forcing the construction industry to change its approach to design, construction, refurbishment, and maintenance and to set new targets, thus creating new scope for the designers, engineers, manufacturers, contractors, technologist, and researchers. In this context R&D acts as a key driver in helping to successfully address the challenges placed upon the construction industry. However, it was revealed that there are number of issues in construction R&D. Nevertheless, PM could bring about solutions to the issues within construction R&D function and could enhance its success. However, identifying the focal point of PM in construction R&D function is important and it was established that the evaluation of performance needs to ensure the achievement of the success factors. Not knowing the success factors could lead to repercussions of paying insufficient attention on them and/or focusing on factors which are less important for the success of construction R&D function. Thus, through the literature review the need for investigating the CSFs of construction R&D function and incorporating them within the PM applications for their effective implementation was established.

This chapter identified the value gained by other industries in implementing PM within R&D activities (Section 2.6.2). Further, the need for PM in construction R&D was also identified (Section 2.6.5). Fairclough's (2002) and Egan's (1998) reports suggested that the construction industry needs to learn and adopt research practices such as technology transfer and management of processes from other industries. Therefore, to develop theory related to PM in construction R&D, different theories can be brought in theories of PM in general; and PM in R&D used in other disciplines. Nevertheless, there could be certain misfits of the aforementioned theories and their applications within construction R&D settings, as each discipline has their own characteristics, which are different from one to another. Hence, for the development of PM theory within construction R&D, first it needs to identify the characteristics of the construction R&D (see Section 2.4) and ascertain the applicability of theories and concepts from other disciplines within the construction R&D. Thus, concepts and theories were used from other disciplines when developing the theory for this study and they were empirically evaluated to identify their applicability and validity within construction R&D. On this premise, this study can be considered a valuable contribution to the PM within construction R&D as it is not purely restricted to the application of the theories and concepts identified in other disciplines. Having established the *"what"* component of this study, the next chapter looks at the *"how"* component by presenting the research methodology pertaining to the study.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

The previous chapter provided a comprehensive literature review to address the main research issues of the study. This chapter discusses the research methodological design of the study. Accordingly, the chapter is structured as follows:

- First, the steps adopted when designing the research problem of this study are discussed.
- Second, identification of the research philosophy and approach of this study is presented. This is followed by a discussion on case study design.
- Third, the data analysing techniques and the use of computer aided software for data analysis are discussed.
- Fourth, the case study design applicability of this study is presented.
- Finally, as a summary of the entire research process followed by the study, the research methodological framework is presented.

3.2 Establishment of the research problem

Saunders et al (2007) view the proper establishment of the research problem as the most difficult yet the most important element of the research. The research problem of this study was established via the initial impetus of the researcher, literature review and expert opinion. The sections below discuss these three steps.

3.2.1 Initial impetus

A research area with a particular interest to the researcher and which suits his/her capabilities is identified as an important factor to be considered when initiating a study (Saunders et al, 2007; Remenyi et al, 1998). Saunders et al (2007) argue that such a research area ensures that the researcher's heart as well as head is engaged in the research project. Adding to that Gill and Johnson (2002) assert that accessibility, time availability, importance of the potential outcome, researcher's interest, financial support and the value and scope of the research area are important aspects when deciding on a research topic. Accordingly, the initial impetus for this PhD came from the past experience and interests of the researcher, who thus, chose the subject area as *"Performance Measurement in construction industry"*. The section below explains how the initial impetus was supported with the literature review to arrive at the research problem relevant to the study.

3.2.2 Literature review

A literature review helps a researcher to grasp the existing knowledge from other scholars regarding a particular subject area. Therefore, Alexander (1996) identifies it as a *"building block"* to build up successful research work. Agreeing with this view Eisenhardt and Graebner (2007) identify a strong literature review as the basis for sound empirical research to identify the research gap and to suggest research questions which address the gap. A literature review ensures that the researcher's knowledge is up to date in the selected subject area and most importantly that the researcher is not reinventing the same issues that have been previously explored. Metcalfe (2003) views literature reviews as a *"court room process"* where the existing articles in the subject area are the potential experts or witnesses, which support or oppose the main arguments. Furthermore, Alexander (1996) perceives literature review as a *"lens"* which facilitates to narrow down the research area and as a *"sign post"* which shows new directions for the research. Further, Gill and Johnson (2002) claim that a critical literature review would identify the limitations of a study and shows how new research would fit within the wider context. As a consequence, a literature review helps the researcher to enhance their knowledge of the subject area, and to clarify the research questions.

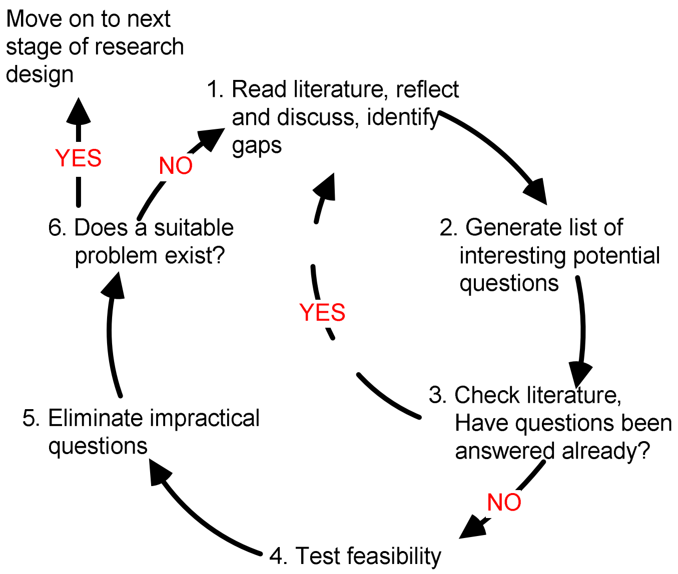


Figure 3.1: Procedure for identifying a research problem (source: Collis and Hussey, 2003)

Collis and Hussey (2003) illustrate the iterative process of establishing the research problem through the literature review as shown in Figure 3.1. Accordingly, a researcher has to revise the initial ideas and undergo a number of cycles of literature reviews before establishing the potential research problem, which could lead to a researchable project.

As mentioned in Section 3.2.1, *"Performance Measurement in construction industry"* was selected as the broad area of this study. First, a *"general literature review"* was carried out to narrow down the research area. In addition to the construction specific literature, the researcher reviewed literature related to Performance Measurement (PM) applications in other industries (see Figure 3.2). Through this initial literature review, the researcher was able to identify gaps in PM applications within construction industry and the areas which are well explored in other industries yet not adequately within the construction industry. After identifying the subject areas which could be researched, the next step involved reading the reports such as Respect for People (Constructing Excellence, 2004); Accelerating Change (The Strategic Forum for Construction, 2002), Better Public Buildings (DCMS, 2002), Rethinking Construction Innovation and Research (Fairclough, 2002), Building Down Barriers (Holti et al, 1999), Rethinking Construction (Egan, 1998) and Constructing the Team (Latham, 1994) etc. The intention of reading the aforementioned reports was to identify whether there is a specific need for the identified research areas to be further investigated. This process ensured the selected subject areas are not only under investigated, but also has a current need to investigate. Finally, the areas narrowed down were evaluated with the supervisory team to choose the most appropriate one to suit the scope of the PhD by considering the limitations such as scope, time and accessibility (see Figure 3.2). After the general literature review and consideration of the limitations of the study, PM in construction Research and Development (R&D) was identified as the most potential and researchable theme. Having identified this, the researcher carried out a "*specific literature review*" focusing on the points below:

- construction R&D (its importance, main stakeholders, issues which hinder effective R&D within the construction sector); and
- performance measurement (the development of PM over the past decades, performance measurement systems (PMSs), benefits and drawbacks of PM).

Following the specific literature review, the aim, objectives and research questions pertaining to the study were formulated and the conceptual framework (see Figure 4.2) was developed.

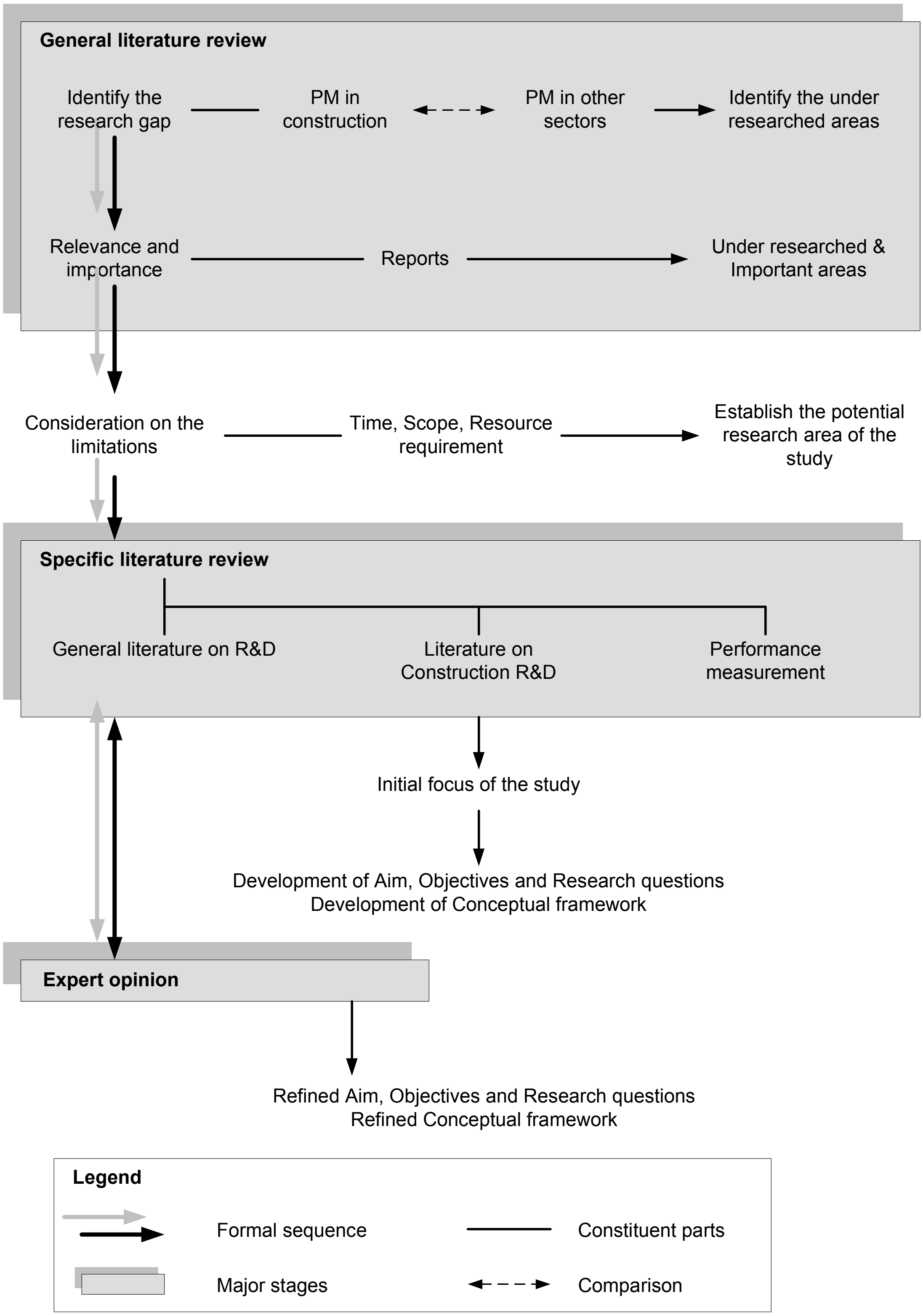


Figure 3.2: Identification of the focus of the study

Having discussed the process of the literature review, the following section details the expert opinions gathered to further strengthen the selected subject area.

3.2.3 Expert opinion

Having arrived at the research problem through the literature review, the next step for the researcher was to carry out a series of expert interviews to fulfil the following requirements:

- to gather the views in relation to the importance and influence of PM in construction R&D;
- to critically review the key areas extracted from the literature review (issues and success factors of the construction R&D, stakeholder contribution towards construction R&D, role of PM in construction R&D); and
- to identify any other areas which could be investigated and addressed when developing the study.

Unstructured interviews were carried out with two professors of construction management, who are extensively involved in construction R&D activities. Via the expert interviews the aim, objectives and research questions were refined as shown in Section 3.2.4. In addition, the conceptual framework was also refined to reflect the expert opinion (see Chapter 4 for more details for the development of the conceptual framework).

3.2.4 Research problem

As explained in Chapter 2, the aim of the study is to explore the influence of performance measurement on the construction R&D function. To achieve this aim, the specific objectives were formulated as follows:

Objectives:

- identify the importance of R&D in the construction industry
- identify the current position of construction R&D
- evaluate the importance of performance measurement in construction R&D function
- explore how the performance of the construction R&D function is measured
- determine the critical success factors of construction R&D function
- develop a performance measurement system that enables management to assess the success of the R&D function.

Merely having a research aim and objectives will not direct the researcher to *"what needs to be looked for"* and *"where to look for it"*. Therefore, to achieve greater focus for the study, the researcher established a number of research questions as shown below.

Research questions:

- what is the importance of R&D to the construction industry?
- what is the current position of construction R&D activities?
- how can performance measurement influence the performance improvement of construction R&D function?
- how can performance of construction R&D function be measured?
- what are the critical success factors of construction R&D function?

The Sections 3.2.1, 3.2.2 and 3.2.3 showed the progressive development towards the establishment of the research problem for the study. The next section describes how the research methodology was designed to cater to the established research problem.

3.3 Research methodological design

The main intention of any research is to add value to the accumulated knowledge through the means of identifying, investigating and producing solutions to an unsolved problem (Remenyi et al, 1998). The process of finding solutions to the research problem is *"not a clear cut sequence of procedures followed by a neat pattern, but a messy interaction between the conceptual and empirical world"* (Gill and Johnson, 2002, p: 3). Booth et al (2003, p: 5) also agree with this view and state that *"research follows crooked paths, taking unexpected turns even looping back itself"*. Even though the research process is uncertain and risky, the appropriate research design would minimise the possibilities of any failures by identifying and forecasting problems and pitfalls that the researcher may come across. Furthermore, a research design follows a procedure of work, which determines the approaches and techniques that could be adopted during a study. In addition to that, research design looks into the philosophical aspects of the research which in turn helps to identify the overall research strategy (collecting, analysis, interpretation of data and drawing conclusions); evaluate various research methods and identify their limitations;

increase the compatibility of research approaches and research techniques (Easterby-Smith et al, 2002).

This study used Kagioglu et al's (2000) hierarchical model, which nest the research philosophy, approach and techniques (Figure 3.3). Within this *"nested"* model, research philosophy which is at the outer ring guides the research approaches and research techniques while ensuring that the chosen research philosophy, approach, and techniques are compatible with each other (Kagioglou et al, 2000). The following sections further describe in detail the research philosophy, research approach and research techniques pertaining to this study.

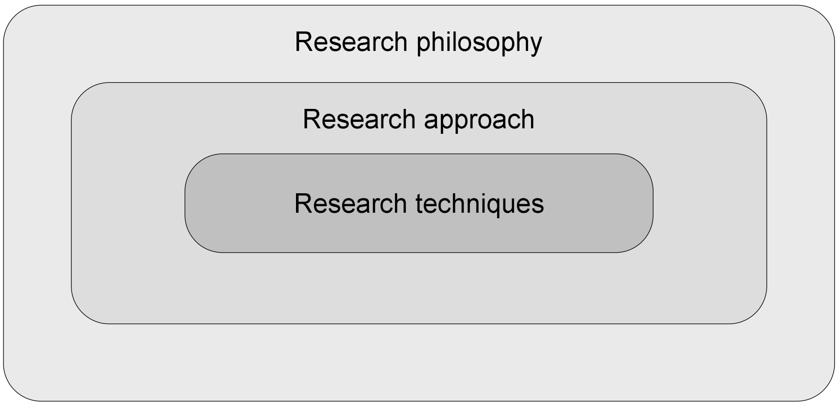


Figure 3.3: Nested approach (Kagioglou et al, 2000)

3.3.1 Research philosophy

Gill and Johnson (2002) stipulate that there is no one best approach to research but that it is a compromise between the options based on the philosophical understanding or the basic beliefs about the world. Agreeing with this view, Easterby-Smith et al (2002) also recognise research philosophies as the basis for effective research design and argue that failure to adhere to philosophical issues can negatively affect the quality of the research. Not limiting the importance of understanding philosophical issues for effective research design, Collis and Hussey (2003) claim that it could also govern the way you write your thesis.

There are two main research philosophies namely Positivism and Interpretivism (social constructionism) which can be placed at two extreme ends of a continuum where one end is interpretivism and the other end is positivism (Easterby-Smith et al, 2002). There are a number of assumptions within these philosophical stances as

Ontology, Epistemology and Axiology. Ontology seeks to identify the nature of the reality; Epistemology shows how we acquire and accept knowledge about the world and Axiology is the nature of the values the researcher place on the study (Sexton, 2003; Collis and Hussey, 2003; Easterby-Smith et al, 2002).

3.3.1.1 Positivism

Positivism has the ontological assumption of reality is having a pre determined nature and structure. This is known as *"realism"* (Johnson and Duberly, 2000) or *"objectivism"* (Saunders et al, 2007). Further, the positivist is allied to the epistemological assumption that the properties of reality need to be measured through objective measures rather than subjectively through sensation, reflection or intuition (Easterby-Smith et al, 2002). Moreover, the positivist believes that the process of research is value free in terms of the axiological assumption (Saunders et al, 2007; Collis and Hussey, 2003). Thus, the researcher would detach from the research environment and take the role of an independent observer without interfering with the research environment and would not allow the values and bias to distort the research results. In addition to that, positivist searches for causal explanations and fundamental laws and use the deductive approach for the research (Collis and Hussey, 2003; Easterby-Smith et al 2002; Gill and Johnson, 2002; Remenyi et al, 1998).

3.3.1.2 Interpretivism

The positivistic approach which was originally used to study natural science was criticised when applied to social science as the latter deals with human behaviours. It is argued that humans cannot be treated as objects and theories which lead to definite laws as humans are influenced by feelings and perceptions. Thus, conversely to positivistic studies, interpretivism is based on the ontological assumption that the external world does not have a pre determined nature or structure but is created by the perceptions and consequences of humans. This is known as "*idealism"* (Gummesson, 1991) or *"subjectivism"* (Saunders et al, 2007). Further, interpretivism is with the epistemological assumption that the properties of reality can be measured through subjective measures and determined by examining the perceptions of people (Collis and Hussey, 2003; Easterby-Smith et al, 2002). Thus, rather than searching for casual explanations or for external factors, Interpretivist admire the different views that people place on their experiences. This enables the researcher to have closer interactions with the research environment unlike in the positivist studies. Due to this close interaction, the Interpretivist believes that the research is value laden, thus choice of what to study and how to study is determined by human beliefs and interests (Collis and Hussey, 2003; Easterby-Smith et al, 2002). Table 3.1 differentiates between the characteristics of Positivism and Interpretivism research philosophies.

Table 3.1: Contrasting implications of positivism and interpretivism (Easterby-Smith et al, 2002)

	Positivism	Interpretivism
The observer	Must be independent	Is part of what is being observed
Human Interest	Should be irrelevant	Are the main drivers of the science
Explanations	Must demonstrate causality	Aim to increase general understanding of the situation
Research progress through	Hypotheses and deduction	Gathering rich data from which ideas are induced
Concepts	Need to be operationalised so that they can be measured	Should incorporate stakeholder perspectives
Units of analysis	Should be reduced to the simplest terms	May include the complexity of 'whole' situation
Generalisation through	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

For many reasons, interpretivism can be identified as the most appropriate research philosophy for this study. As set out in the aim and objectives, the study expected to identify the different views of respondents regarding the importance of R&D within the construction sector, factors which are needed for the successful attainment of R&D work, suitable PM measures and methods for R&D activities. Further, the study needed to understand the appropriate context and the process of R&D work. Thus, the study valued and encouraged the free flow of ideas, opinions and perceptions of people based on their experience within the research environment and considered human interaction as the main drivers of the study as in interpretivist philosophy. Hence, the study takes the ontological assumption that reality is not pre determined, but socially constructed and the epistemological assumption that knowledge is gathered by examining the views of the people. Moreover, the research environment was not expected to be controlled and simplified with assumptions and hypothesis as in the deductive research approach used in positivistic studies. In opposition, an inductive research approach is used with the intention of generating rich data to build up theories rather than to test theories. Further, the research requires in-depth analysis by selecting a small number of samples to gather detailed facts about the research environment. The characteristics of positivism and interpretivism and the philosophical stance pertaining to this study (shown with a red circle) are illustrated in Figure 3.4.

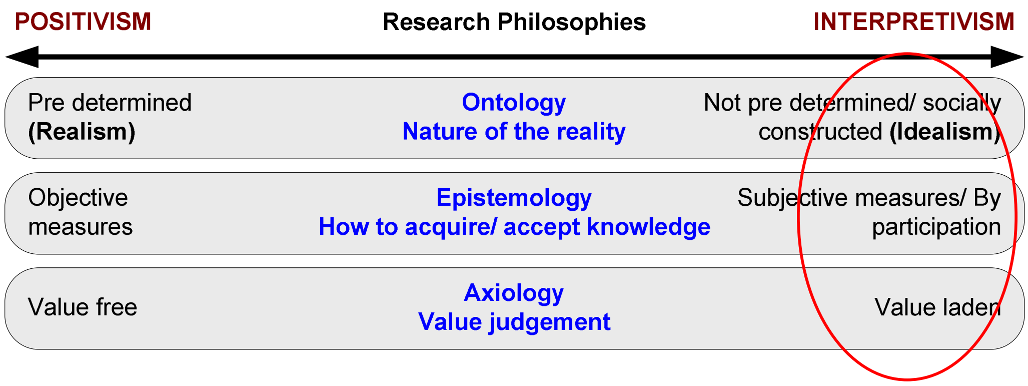


Figure 3.4: The philosophical stance pertaining to the study against the research philosophical continuum

Having identified the philosophical stance, the next section looks into the research approach pertaining to the study.

3.3.2 Research approach

There are number of research approaches where ones research can be based upon such as experiments, surveys, case studies, action research, and ethnographical studies. Some research approaches are likely to harmonise better with one particular research philosophy than the others, therefore, the selection of the research approach needs to reflect the philosophical stance of the study.

Experiments are mostly conducted in a laboratory setting under controlled environments where the phenomena and the context are separated (Yin, 2003). Since the parameters are controlled and simplified with hypothesis, experiments are mostly associated with the deductive approach. Saunders et al (2007) identify experiments as a form that favours natural sciences. Experiments allow identification of casual relationships by observing the effect of the dependent variable by controlling the independent variable. Similarly with experiments, surveys are also related to the deductive approach (Saunders et al, 2007). Surveys facilitate collection of large amounts of data in an economical way. They are undertaken by selecting a sample by which the whole population can be judged.

Yin (2003, p: 13), describes case studies as *"an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident"*. Due to the open-ended inquiry used in case studies, it is suitable for building theory and generating hypothesis (Amaratunga et al, 2002). In opposition to experiments and surveys, ethnographical studies are rooted within the inductive approach (Saunders et al, 2007). In the ethnographical research approach, the researcher uses socially acquired and shared knowledge to understand and interpret human activities (Collis and Hussey, 2003) and is appropriate for investigating the characteristics of people, their societies and customs. Ethnography research covers a considerable time period (Burns, 2000; Van Maanen, 1982) where the researcher becomes a member of the research environment being studied and the data is collected through participant observation. Action research is based on the assumption that the social world is constantly changing and the researcher and the research are also part of that change (Collis and Hussey, 2003). Therefore, the researcher being a part of the environment under study, will try to solve practical problems (Waser and Johns, 2003; McNiff and Whitehead, 2002; Robson, 2002), and try to influence and change the attitudes and behaviour of the participants (Waser and Johns, 2003).

Gill and Johnson (2002) assert that the aforementioned research approaches can be differentiated and placed along the philosophical continuum depending on their emphasis on deduction or induction, degree of the structure and type of data they generate. Table 3.2 shows how this differentiation can be done based on their characteristics.

Table 3.2: The comparison of nomothetic and ideographic methods (source: Gill and Johnson, 2002)

	Nomothetic	Ideographic
1	Deduction	Induction
2	Explanation via analysis of causal relationships	Explanation of subject meaning systems and explanation by understanding
3	Generation and use of quantitative data	Generation and use of qualitative data
4	Use of various controls, physical or statistical, so as to allow the testing of hypothesis	Commitment to research in everyday settings, to allow access to and minimise reactivity among subjects of research
5	Highly structured research methodologies to ensure replicability of above 1,2,3 and 4	Minimise structure to ensure above 2,3 and 4

Accordingly by evaluating the characteristics of research approaches, they can be plotted in the research philosophical continuum as shown in Figure 3.5.

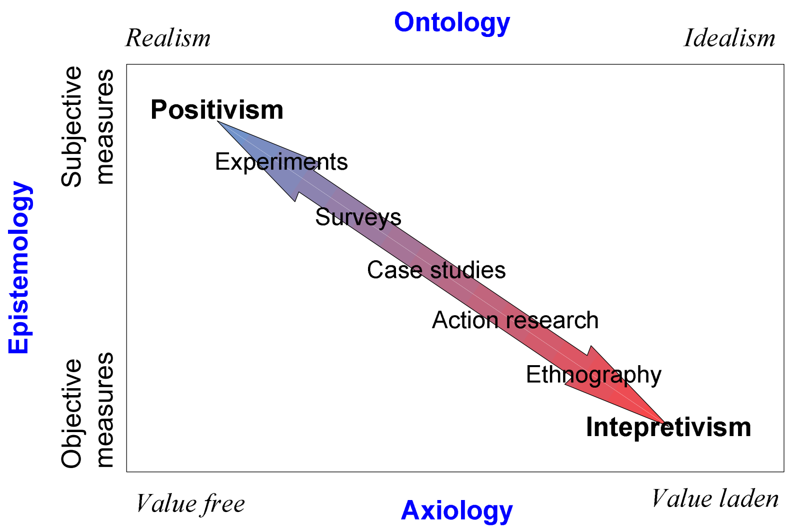


Figure 3.5: Research approaches within the philosophical continuum

Figure 3.5 highlights that experiments and surveys are more towards positivism research philosophy while case studies, action research and ethnography are more towards interpretivism philosophy. Since this study uses interpretivism with regard to the philosophical stances, the use of experiments and surveys are unjustifiable. Accordingly, the researcher has to make a choice between ethnography, action research, and case studies. The research under consideration does not intend to influence or change the attitudes or procedures of the participants or the environment as does in action research. Further, it does not intend to study behavioural patterns or physiology of the participants as in the case of ethnographical studies. Hence, in this study a case study research approach is preferred for exploring the PM applications within construction R&D.

In addition to the philosophical stance, the research questions in a study influence the selection of a research approach. Yin (2003) argues that *"how" "why"* questions favour explanatory studies and the use of *"what"* questions are suitable for the exploratory type of research. Therefore, by addressing the research questions of this study, case studies can provide more insight, firstly by exploring and secondly by explaining the phenomenon under investigation.

The above section justifies the selection of case studies by considering the philosophical stance, nature of the study and the research questions posted. The following section further justifies the selection of case study research approach by elaborating on the added benefits of case studies.

3.3.3 Case study design

Having identified why experiments, surveys, action research and ethnographical research approaches are not suitable for this study (see Section 3.3.2), the section below looks into the use of case studies as a research approach and how it could enhance the quality of this study. As per the aim, objectives and research questions given in the Section 3.2.4, this study requires exploration of the PM concept within collaborative construction research activities. It will identify different views of individuals regarding the critical success factors (CSFs) of R&D, suitable R&D performance measures and measurement techniques and the influence of PM towards construction R&D. Thus, a research approach which facilitates an in-depth analysis and gathering of professional opinions is required. According to Gerring (2007) case studies offer in-depth analysis of the phenomenon under consideration. Further, case studies are carried out in a way that they incorporate the views of the *"actors"* of the case under consideration (Zonabend, 1992). Further, case studies can be used not only to explore existing theory but also to challenge an existing theory (Saunders et al, 2007; Yin, 2003). A similar comment is given by Patton and Appelbaum (2003, p:

67), who identify the ultimate goal of case studies as *"to uncover patterns, determine meanings, construct conclusions and build theory"*.

Despite the fact that case studies have the above advantages, they are criticised for biasn, use of incomplete evidence and for being time consuming and expensive (Remenyi et al, 1998). Yet it can be argued that, if not properly designed the bias can be included in surveys and experiments. Even though case studies are time consuming and expensive, careful design of the case studies can minimise the time and budget. In addition to this, case studies have a number of advantages which compensate many drawbacks. The case study research approach embraces a variety of evidence such as document reviews, interviews, and observations (Saunders et al, 2007; Yin, 2003) which is considered a strength of case studies. This increases the richness of the collected data whilst creating the prospects for data triangulation.

The following characteristics are noted as being the key points behind the selection of the case study research approach for this study:

- facilitates an in-depth study to identify the links between the R&D and PM;
- allows multiple sources of evidence to be used to increase the validity of the collected data;
- does not control/ manipulate the environment under examination (as in the case of experiments, surveys);
- does not interfere with the attitudes, perceptions or the procedures of the environment (as in the case of action research);
- analyses a contemporary event; and
- the research questions posed favour case studies.

Having chosen case studies as the research approach, the next section explains the compromise made between the use of single and multiple case studies.

3.3.3.1 Single vs. multiple case studies

As stipulated by Yin (2003), case studies can be broadly divided into multiple and single and then, depending on the number of units of analysis, embedded (more than one unit of analysis) or holistic (one unit of analysis). Thus, four types of case study designs exist (see Figure 3.6).

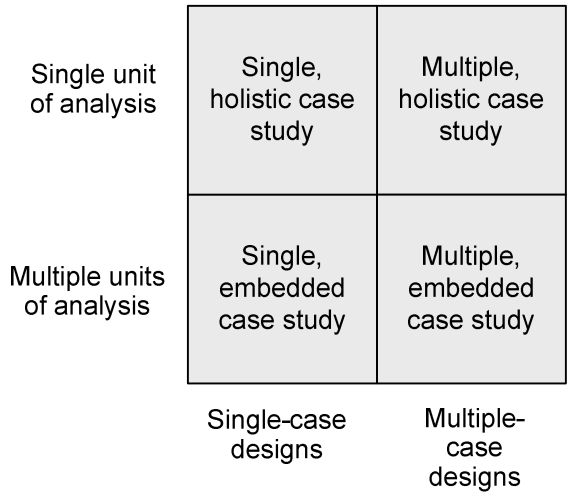


Figure 3.6: Types of case studies based on the number and units

A single case study approach is suitable when investigating critical, unique, representative, revelatory or a longitudinal study (Yin, 2003). A critical case can be used to challenge, confirm or extend a theory whilst the unique case represents a rare situation. As opposed to a unique case, a representative case captures a common situation or a *"typical"* project, thus, studying one case is sufficient to get an understanding about the other cases. A revelatory case can be used to study a phenomenon which was inaccessible earlier. From a longitudinal case, the phenomenon will be studied over a period of time. The study under consideration fell under the critical case as it sought to develop and refine a theory on the influence of PM towards construction R&D. The researcher argues that to develop a valid theory, it is critical or important to apply it to the existing situation and refine it. Thus, by taking the critical view, the abstracted concepts will be assessed based on the views of experts involved in the construction R&D activities. Through this, the abstracted concepts can be refined whilst developing valid theory which contributes to knowledge.

Furthermore, this study takes a longitudinal approach as the phenomenon under consideration i.e. application of PM within construction R&D function as a dynamic process. One of the objectives of the study is to develop a Performance Measurement System (PMS) which could be used to identify the influence of PM on the construction R&D function. To identify the actual impact of PM in construction R&D function, the PMS developed through the study needs to be tested on a R&D project, over a period of time. However, testing the PMS on a R&D project is not practical due to the life span of R&D projects in relation to the life span of a PhD.

This was considered as a limitation of this study. As an alternative, the developed PMS was presented to a group of experts via semi structured interviews (see Appendix C) during the refinement stage of the case study (see Section 5.6), and thereby the impact of PMS towards the construction R&D function was assessed. With such practical limitations a similar refinement and identification of the impact of Key Performance Indicator's (KPI) on a Knowledge Management environment was done by Pathirage (2007). In his study, a structured survey was used during the refinement stage to obtain the views regarding the impact of KPIs. Accordingly, by taking the longitudinal view, this study explored the current situation within the construction R&D function, designed and proposed solutions to enhance the effectiveness of R&D activities and finally obtained the views of expertise on the anticipated benefits PMS.

The third rationale for the selection of single case study was based on the depth of coverage from this study. Generally by using multiple case studies, a researcher can increase the breadth of a study. However, the single case study provides the opportunity to explore the phenomenon in detail. Though single case studies are often criticised for not generalising conclusions, many authors argue that the number does not matter providing the case study addresses its stipulated objectives (Flyvbjerg, 2006; Yin, 2003). Consequently, if it is designed and conducted appropriately, a single case study would be able to contribute as much to the knowledge than poorly designed multiple case studies. By taking forward this argument, the researcher also believes that what matters is not the quantity of case studies (as the quantity cannot substantiate the quality of the research work), but designing the case study to suit its scenario governed by the aim of the study. Since this study expected the continuous development and refinement of theory, the researcher needed to carry out an in-depth study by compromising between the breadth and depth of the study. The depth of coverage using multiple data collection methods and considering multiple perspectives are further discussed in Section 3.3.3.4.

To summarise, this study used the single case study approach due to the criticality of the theory development and refinement of the phenomenon, the longitudinal view of the study and the depth of coverage from the study.

Accordingly, this section has discussed the rationale behind the selection of single case study for the study. The section below looks into the unit of analysis pertaining to this study.

3.3.3.2 Unit of analysis

As asserted by Miles and Huberman (1994, p: 25), the unit of analysis of a study is a *"phenomenon of some sort of occurring in a bounded context"*. According to Collis and Hussey (2003) it is the focal point where the variables, phenomena and the research problem refer to and about which the data is collected and analysed. Because of its importance, Miles and Huberman (1994) identify the unit of analysis as the *"heart"* of the study. Remenyi et al (1998) state that the decision of the unit of analysis is governed by the research questions of the study. The unit of analysis of a case study can be ranged from an individual, a group of people, to a process or relationship (Yin, 2003; Remenyi et al, 1998; Kervin, 1992). It is advisable to establish a unit of analysis similar to a previous study by considering the literature in the subject area rather than establishing it arbitrarily (Yin, 2003; Remenyi et al, 1998). Accordingly, by considering the research questions posed for the study (see section 3.2.4) and by considering the previous literature (Kerssens-van Drongelen and Cook, 1997) *R&D function* was selected as the unit of analysis for the study. R&D function was defined as the *"set of activities necessary to effectively and efficiently initiate, co-ordinate and accomplish the product and process development activities of a company"* (Kerssens-van Drongelen and Cook, 1997). Thus, R&D function is the set of resources and competencies that carry out the R&D process (Fisscher and Weerd-Nederhof, 2000): which can be defined as the conversion of the inputs to outputs (Zairi, 1997). Accordingly, the study was designed with a single unit of analysis (the R&D function), thus taking the nature of "*single holistic* case study" (see Figure 3.6).

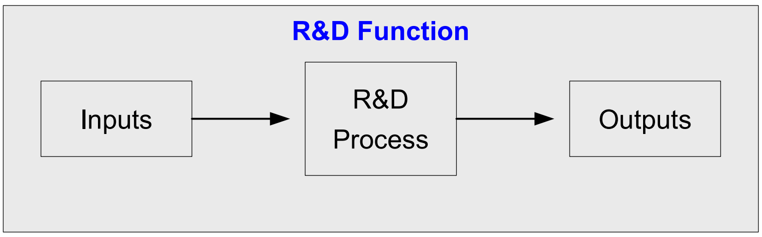


Figure 3.7: Unit of analysis of the study: R&D function

After establishing the unit of analysis, the next step was to define the boundary of the study. Deciding the boundary helps the researcher to identify the scope of the study, for example to determine the limits of the data collection (Yin, 2003). As discussed in Section 2.4.2 construction R&D activities can take the form of academic research, industrial research or collaborative research between academia and industry and as was discussed collaborative research work is preferred as it delivers a number of positive impacts over and above pure academic based or industry based research (see Section 2.4.4). After going through the case study selection and screening process based on theoretical and purposive sampling (see Section 3.3.3.3), it was decided to consider the scope of this study as collaborative R&D initiated by universities. Thus, the unit of analysis was extended outwards to represent multiple organisations namely universities and construction organisations which fall within the scope of the study. Accordingly, the data was gathered from individuals (academic members and industrial partners) employed in multiple organisations (universities and construction organisations) and R&D projects were taken as the base to study the R&D function (see Figure 3.8).

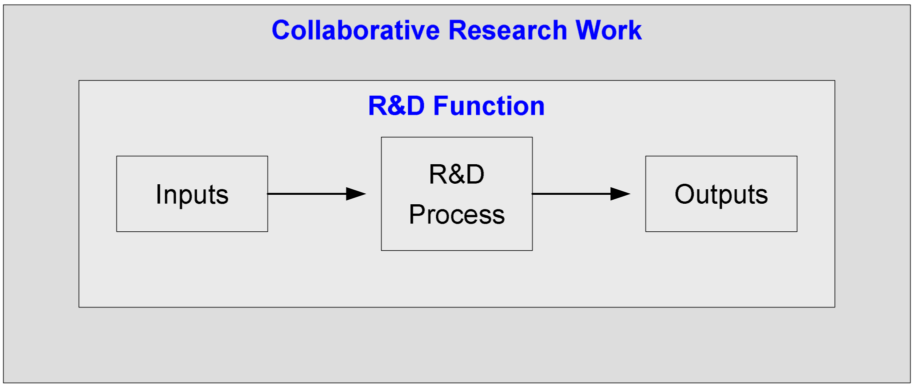


Figure 3.8: Unit of analysis inbuilt within the scope of the study

3.3.3.3 Case study selection

The primary objective of case screening is to ensure the researcher selects the most suitable case study for the data collection which satisfies the requirements of the study. Within the case study, the identification of the participants who can best inform about the phenomenon is essential. Further, the types of data sources to be investigated and accessibility required need to be sorted out during the case study selection and screening (Yin, 2003). Case study selection based on probabilistic sampling (i.e. drawing a sample by using a statistical procedure to represent the whole population and generalising the findings to the population) is unusual because the researcher does not expect to generalise the findings to the whole population, but to gain a deeper understanding about the phenomenon being studied, to develop theories and to generalise to the theoretical propositions.

Accordingly, instead of probabilistic sampling, *"purposive"* and/or *"theoretical"* sampling can be used to select the case studies. Purposive sampling selects the cases when it illustrates features or processes that the researcher is interested in (Silverman, 2001). However, Silverman (2001, p 251) claims that *"there is only a slight difference between purposive and theoretical sampling where former selects the cases without theoretical grounds and owing to the practicality of the study where as the latter with a theoretical grounds"*. Accordingly, the researcher used theoretical sampling and purposive sampling to choose a suitable case study and thereby to develop theory.

Eisenhardt (1989) emphasises the need for deriving a population to select suitable cases for a study. Through the literature review (see Section 2.4.4), it was established that collaborative research activities yield more benefits than the work purely based within universities, independent research organisations or construction organisations. This was further supported by the expert interviews (see Section 4.4.3). Thus, collaborative research work was identified as the population within which the case study could be selected. Having decided on the population, a theoretical background or an operational criteria (as described by Yin, 2003) was established to qualify the case. The study wanted to address the applicability of the PM concept within the construction research activities. Therefore, one of the major requirements was to base the study within an organisation which has engaged heavily in collaborative construction research activities. In this manner, the quality as well as the quantity of research work was assessed. To do this screening, a list of organisations (universities, construction organisations and research institutions) who were involved in collaborative research work was prepared in consultation with the supervisors. By considering the experience of the researchers, Research Assessment Exercise (RAE) ratings, profiles of current and past research work (via web pages) it was decided to select the collaborative research work initiated by universities or research institutions.

Next, the accessibility to carry out the case study was established. With regard to accessibility, the study required an in depth, longitudinal approach to explore the PM in construction R&D. Thus, the researcher needed the accessibility during different stages of the study; firstly to conduct semi structured interviews, secondly to administer a questionnaire survey and finally to do another series of semi structured interviews (see Figure 3.10). Within the selected university based research institutions, except for one, accessibility was denied due to the Research Assessment Exercise 2008 (RAE is an assessment carried out within research institutions in the UK Universities. This years' assessment is based on the following criteria: staff details; research output; research students and studentships; research income; and research environment and esteem). Thus, the final selection was made between university based research institution and the independent research institution based on purposive sampling. As the number of respondents was high in the university based research institution, it was selected as appropriate for the case study.

3.3.3.4 Case study process for theory building

As discussed in Section 3.3.3.1, the single case study approach was selected for this study. Accordingly, the researcher explored and recognised the PM concept within the construction R&D function, without controlling the variables but rather taking into account the variables applicable and studying the inter relationships between R&D and PM. As noted by Strauss and Glaser (1967), theory building requires the on going comparison of data and theory. Adding to that, Lynham (2000) asserts continuous refinement between theory and practice is also needed for effective theory building. This section describes the case study process used for theory building and refinement with particular reference to the stages and objectives of the case study.

As noted by Gill and Johnson (2002), the deductive approach starts by conceptualising the phenomenon followed by empirical observation to test it. Conversely, inductive approach begins with empirical observation to develop theory. However, Eisenhardt (1989) highlights the importance of having an initial definition of the research question prior to beginning theory building. She states that, otherwise, the researcher can become overwhelmed by the amount of data gathered. Similarly, Yin (2003) asserts the need of pre establishing a theory or conceptualising the phenomenon prior to data collection and analysis process. Thus, Eisenhardt (1989) states that case study research begins with a deductive approach and moves on to an inductive approach to build the theory.

Accordingly, before starting the case study approach, the researcher conceptualised the PM in construction R&D through a comprehensive literature review and expert opinion (see Section 3.2.2 and 3.2.3). Thereafter, during the case study design and preparatory stage (see Figure 3.9), a suitable case study was selected after the case screening (see Section 3.3.3.3) and the data collection protocols were prepared and piloted. With this, the researcher started the actual data collection within the case study.

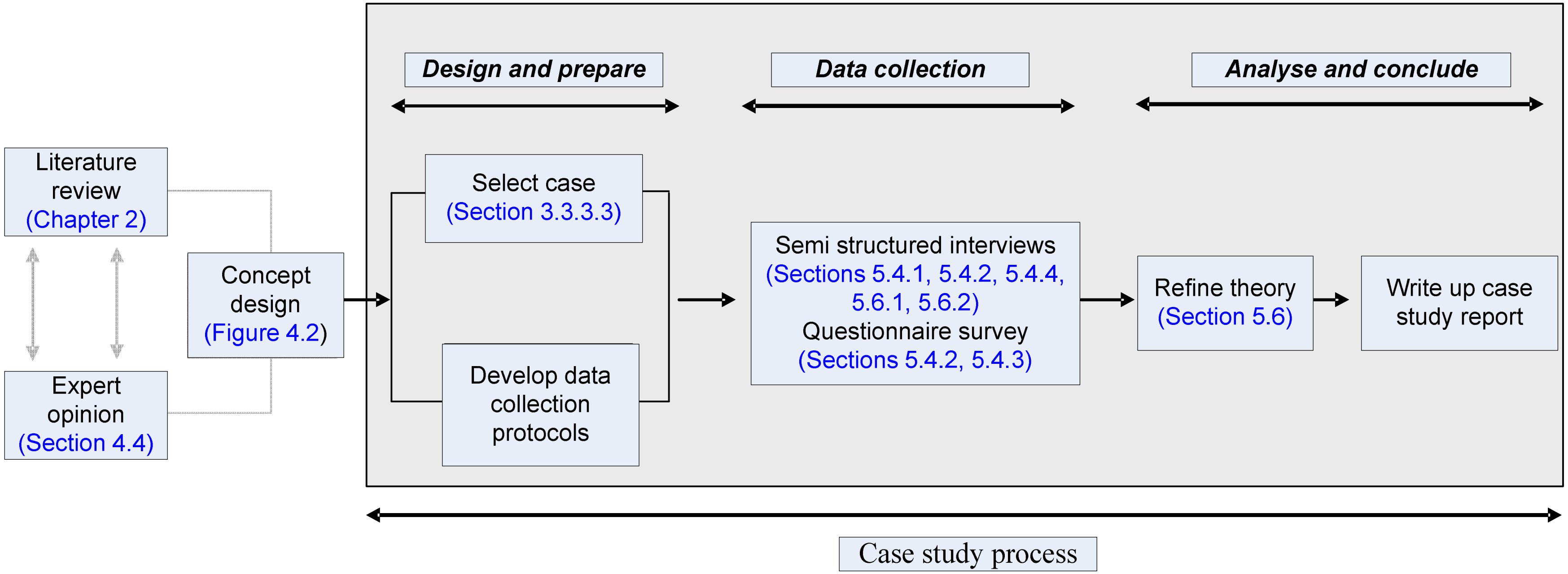


Figure 3.9: Case study process

The case study consisted of three stages of data collection (see Figure 3.10). As indicated in Figure 3.10, during the exploratory stage, a series of semi structured interviews and a questionnaire survey was carried out within the case study. Through this, the component of the conceptual framework (issues, CSF of R&D function, and the need of PM in construction R&D function) developed through the literature review and expert interviews were established. At the development stage, a PMS was developed to measure the performance of construction R&D function. During the explanatory stage, the PMS was refined via a series of semi structured interviews.

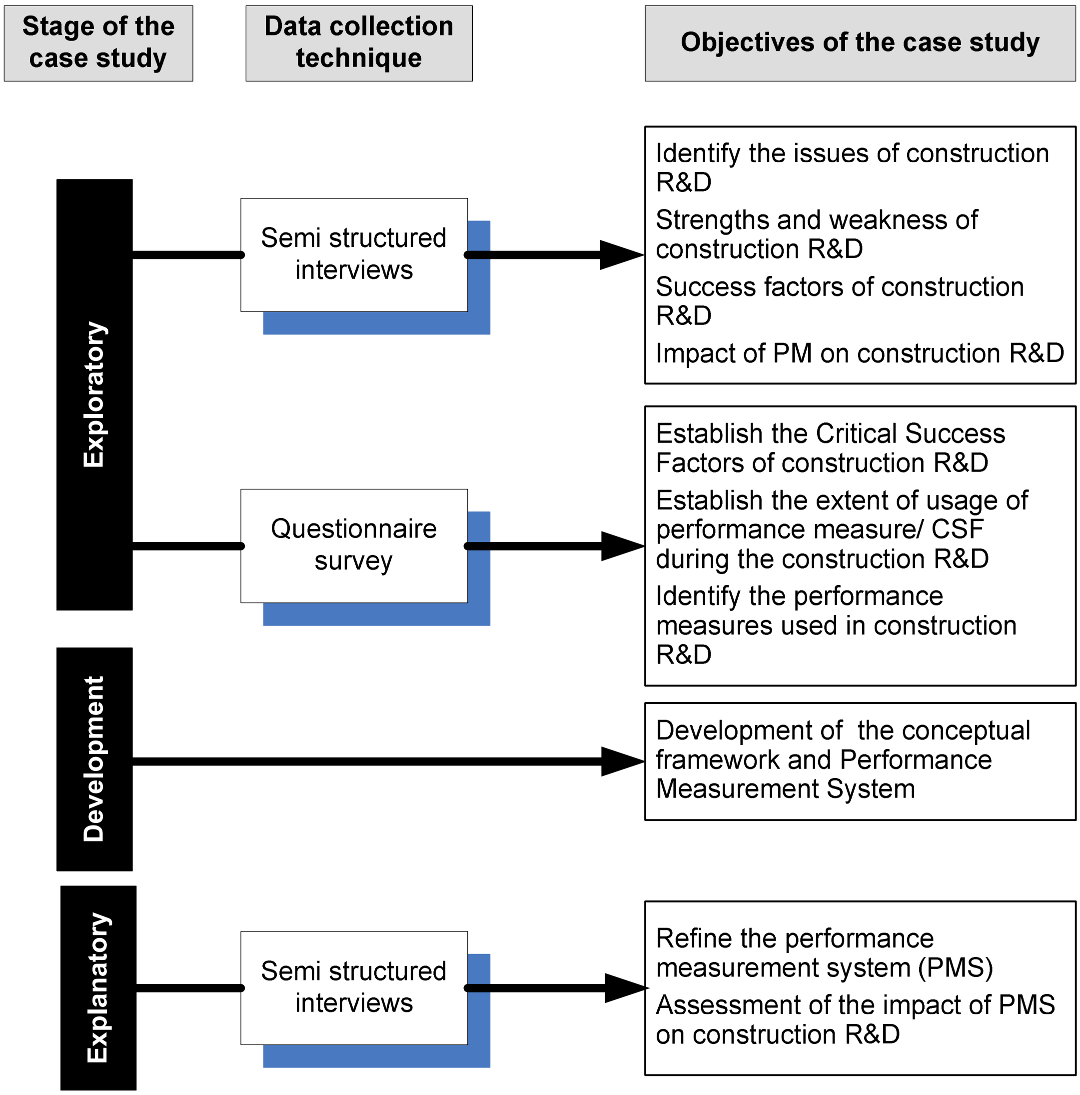


Figure 3.10: Data collection stages of the case study

During the case study, the researcher adhered to the five characteristics proposed by Remenyi et al (1998) on making an exemplary case study (see Table 3.3).

Table 3.3: Characteristics of an exemplarily case

Character	Description	How it was addressed	Reference
Significant	Case study of interest to the relevant stakeholders	Establish the importance of the study and research gap Through the literature and expert opinion the need of PM within R&D function was established. Further, paucity of research in this area created the need of further research.	Section 3.2.2, 3.2.3
Complete	Clear definition of research problem, identification of the boundaries of the case study	Establish the research problem through a comprehensive literature review and refinement of the same through the expert opinion. Through the research questions the study was focused and identified the areas to be explored. Identification of unit of analysis, scope of the case study ensured the proper establishment of boundary of the study.	Section 3.2.4 Section 3.3.3.2
Consider alternative perspectives	Collecting the relevant evidence from different perspective and triangulation of evidence	The evidence was gathered form principal investigators, researchers and industrial partners to corroborate the same issues. Triangulation of evidence in terms of source, methodology.	Section 3.5
Display sufficient evidence	Present compelling and convincing evidence	Through the data analysis, the initial research questions and thereby the aim and objectives of the study was addressed. Creating links between the literature and empirical evidence, consideration of the different perspectives corroborate the evidence.	Chapter 6
Composed in an engaged manner	Ensuring the validity and reliability of the study	Number of good practices were adapted to ensure the reliability and validity of the study	Section 3.6

The above sections discussed the case study approach relevant to the study. The sections below focus on the research techniques used during the study.

3.3.4 Research techniques

According to the nested model (see Figure 3.3), the inner most ring refers to the research techniques, which represent the data collection and analysing techniques.

The following section first examines the data collection techniques in general and with particular reference to this study.

3.3.4.1 Data collection techniques

There are number of research techniques available for data collection such as; document reviews, observations, questionnaire surveys, interviews. Observation allows collection of data on human behaviours from the research environment directly rather than relying on another persons interpretation (Sapsford and Jupp, 2006). Hence, observations facilitate direct information gathering which cannot be explained by the participants and collection of data from the people who cannot take part in surveys or interviews (Sapsford and Jupp, 2006). However, observations are time consuming and the closeness of the research environment tends to increase the observer biasness of the collected data (Saunders et al, 2007; Sapsford and Jupp, 2006). Thus, people under observation can consciously or unconsciously change their behavioural patterns when they know that are under observation.

Document reviews can provide either primary source of data: when they are written by the people who are directly involved in the period of study or secondary source of data: if the documents are about an interpretation or judgement on the primary data (Sapsford and Jupp, 2006). In the former situation, the document can be considered as original / raw material for the researcher whilst in the latter, careful interpretation is needed as they could have been prepared for a particular purpose or for a group audience. Document reviews are a useful source for data collection within a case study research approach to corroborate or argue against the data collected from other sources (Yin, 2003).

Questionnaire surveys provide an efficient way of collecting data from a large sample as the respondents are asked to answer the same set of questions (Saunders et al, 2007). They can be closed ended (structured) or open ended (unstructured). The coding can be done easily in closed ended questionnaire surveys. However, similar to semi structured or unstructured interviews, open ended surveys also have the disadvantage of difficulty of reducing to codes and standardisation (Jackson and Trochim, 2002). One of the disadvantages of surveys is that they do not enable the researcher follow-up questions immediately to improve the understanding of a particular answer. In contrast, some respondents find surveys enable them to express their answers more easily.

Interviews can be structured, semi structured or unstructured. Unstructured and semi structured interviews are time consuming during the data collection and analysing. Nevertheless, they permit the researcher to follow up questions to clarify the issues thus allowing a deeper exploration of the subject area (Burns, 2000). As noted by Silverman (2001, p: 87) the interviews in social science strive *"…to generate data which give an authentic insight into people's experience"*. Further, a good rapport can be built up between the respondent and the interviewer and is preferred when extensive, in depth data collection is required (Burns, 2000). In contrast to these advantages, interviews can only be used with a limited number of people due to its time consumption.

As discussed above, the aforementioned data collection methods have their own advantages and disadvantages when used in isolation. To increase the richness of the collected data these methods can be combined so that the weaknesses of one method could be minimised by the strengths of the other methods. Therefore, the deployment of multi-methods is encouraged by many authors (Saunders et al, 2007; Yin, 2003; Collis and Hussay, 2003; Miles and Huberman, 1994). Saunders et al (2007) and Yin (2003) point out two main situations where the multi-method approach can be used within a study. Firstly, it allows the researcher to use different methods to assist different purposes of the study. This facilitates the capture of holistic view of the phenomenon being studied and further increases the depth and breadth of the study. For instance, a questionnaire survey can be used to identify critical issues of a study followed by in-depth interviews to explore more into the identified factors. Secondly, the use of multi-methods facilitates the methodological triangulation (see Section 3.5), i.e. supporting the facts or events of the phenomenon being studied through different sources of evidence. The second approach: the methodological triangulation increases the construct validity of the study (see Section 3.6).

By appraising above data collection techniques in terms of their appropriateness, strengths and limitations, interviews were selected as the main mode of data collection for this study due to their ability for examination of issues in detail. Unstructured interviews were used to gather the data from experts (see Section 3.2.3) whilst semi structured interviews were used within the exploratory and explanatory stages of the case study (see Figure 3.10). Further, a questionnaire survey was also administered during the exploratory stage of the case study (see Figure 3.10). In addition to the interviews and questionnaire survey, document reviews were used as a substitute data collection method. Detailed descriptions about the data collection techniques relevant to this study are given in the below section.

3.3.4.2 Unstructured interviews

To identify the critical issues which need to be addressed from the study and to refine the conceptual framework developed through the literature review, expert opinion was gathered from two unstructured interviews (see Section 4.4). Due to the nature of the unstructured interviews the researcher was able to capture the respondents' perceptions regarding the broader area of PM in construction R&D. This facilitated the researcher in refining the aim and objectives and identifying further improvement areas for the study.

3.3.4.3 Semi structured interviews

For this study, semi structured interviews were used at the exploratory and explanatory stage of the case study. The below section first describes the semi structured interview used during the exploratory stage of the case study.

3.3.4.3.1 Semi structured interviews at the exploratory stage of the case study

As stipulated in Section 3.2.4, the primary aim of this study was to explore the influence of performance measurement on the construction R&D function. To fulfil this aim, the exploratory stage of the case study was mainly targeted on identifying the different views of the respondent's regarding the success factors of construction R&D and the degree of importance the respondents are attaching to PM in construction R&D activities (see Figure 3.10 for the objectives of semi structured interviews at the exploratory stage). Therefore, it was necessary to select a data collection medium, which would facilitate in-depth insight into the R&D environment, and to gather the different views and opinions of the respondents. To facilitate the aforementioned requirements, the researcher selected an open-ended nature of inquiry. However, the researcher also devised a structure/ direction to prevent the respondents deviating from the scope of the study and to keep them focused on the main issues. Thus, semi structured interviews were identified as the most suitable data collection technique during the exploratory stage of the case study. The use of semi structured interviews helped the researcher to gather the data in a flexible and conversational manner but with a focus towards the study. The interviews during the exploratory stage were terminated when the researcher found no more new data regarding the area being studied.

3.3.4.3.2 Semi structured interviews at the explanatory stage of the case study

Similar to the exploratory stage, the explanatory stage also used semi structured interviews owing to their characteristics as explained in Section 3.3.4.3.1: in-depth investigation with open ended nature of inquiry; and focus towards the main issues of investigation. Accordingly, six semi structured interviews were carried out with the intention of refining the PMS based on the findings of the exploratory stage and to assess the impact of the PMS on the performance improvement of the construction R&D function (see Figure 3.10 for the objectives of semi structured interviews at the explanatory stage).

3.3.4.3.3 Structure of the semi structured interviews

As Yin (2003) states, for the data collection to be effective, precise communication to the participants is needed regarding the purpose of the case study. Thus, a study brief explaining the overall objectives, benefits to the respondents, commitment from the respondents and how confidentiality would be dealt with during the exploratory stage was prepared (see Appendix D). Along with the study brief, interview guideline containing the main questions pertaining to the exploratory stage of the case study (see Appendix E) was distributed among the respondents.

The interview guidelines were piloted and revised prior to distribution among the respondents. Saunders et al (2007) assert that the preliminary analysis of the pilot test data is important as it ensures the researcher acquires the required answers. Therefore, the responses from the pilot interviews were analysed to check whether the interviews generated the required data to satisfy the objectives of the exploratory stage of the case study.

During the explanatory stage, interviews guidelines (see Appendix C), PMS diagram, and the table showing the performance measures were given to the interviewees prior to the interview similar to the practices adopted during the exploratory stage of the case study.

With the consent of the interviewees, the interviews during the exploratory and explanatory stages were tape recorded using a digital voice recorder. As noted by Saunders et al (2007), recording the interviews sometimes prevents the interviewee from revealing confidential matters. Nevertheless, tape recording interviews provides a number of benefits such as being able to transcribe the interviews accurately, allowing the interviewer to fully concentrate on the questions during the interview, use of direct quotations from the interviewee when presenting the findings and thus, increases the reliability and validity of the study (see Section 3.6). The duration of the interviews for exploratory stage was in the range of 60-90 minutes whereas the interviews at the explanatory stage about 45 -60 minutes.

As described by one of the interviewees of the study *"in a semi structured interview….. the interviewee does not behave properly and starts answering questions which will be coming later on"*. Thus, the questions did not follow the exact sequence of the interview guideline. After carrying out the interviews, they were transcribed (see Appendix F for an interview transcript) and sent back to the interviewees for confirmation. In order to become familiar with the data, the researcher chose to select the manual transcribing process rather than relying on software. The details of the semi structured interviews at exploratory and explanatory stages are given in Table 3.4.

Table 3.4: Details of the semi structured interviews at the exploratory and explanatory stages of the case study

Category	Description	Exploratory stage		Explanatory stage	
		Assigned code	Number of interviews	Assigned code	Number of interviews
Principal Investigators	Principal investigators represent the university and manage and lead the R&D project	S1-PI	5	S2-PI	4
Researchers	Researchers represent the University and carries out the research work related to the project (e.g.: data collection, analysis etc.)	S1-R	5	S2-R	2
Industrial Partners	Industrial partners are the representatives from construction organisations who contributes to the R&D project	S1-InP	3		

3.3.4.4 Questionnaire survey

A questionnaire survey was conducted as part of the case study during the exploratory stage of the study (see Figure 3.10). According to Dillman (2000), three types of data variables can be gathered from questionnaires; opinions, behaviour and attributes. An opinion variable discloses what the respondents believe to be true or false or their feelings about a subject; a behaviour variable records the experience of the respondents regarding a subject; and the attribute variable reveals the characteristics of the respondents such as age, education (Dillman, 2000). From the questionnaire survey, the researcher wanted to gather the attitudes of the respondents regarding the importance of the success factors of construction R&D projects (see Figure 3.10 for the objectives of the questionnaire survey). Further, the researcher sought to discover the actual implementation and/or consideration of the success factors during the R&D project (see Section 2 Questionnaire in Appendix G). This was carried out to identify whether there was a discrepancy between the importance and implementation/consideration of success factors, as it was noted that sometimes the success factors that are important are seldom implemented whilst unimportant factors are often implemented (see Section 2.7). Accordingly, the questionnaire survey was designed to mainly gather opinion and behavioural variables. A Likert scale was used to capture the opinions and behavioural variables; the opinion Likert scale to represent five scales of *"importance"* (unimportant, of the little important, moderately important, important and very important) and the behavioural Likert scale to represent five scales of *"frequency"* (never, rarely, sometimes, very often and always). Further, for both the scales, a *"no opinion/ not applicable"* column was added so that the tendency for giving an inaccurate answer when the respondents lacks knowledge or opinion for a particular question was minimised (see Krosnick, 2002). Table 3.5 shows the values assigned for the Likert scale.

Table 3.5: Values assigned for the Likert scale

Scale	Unimportant	Of the little important	Moderately important	Important	Very important	No opinion/ N/A
Scale	Never	Rarely	Sometimes	Very often	Always	No opinion/ N/A
Value	1	2	3	4	5	99

Further, the questionnaire survey was used to identify the use and types of performance measures evident during the construction R&D function (see Section 3 of the Questionnaire in Appendix G). In addition to the above, the respondent's background information such as experience and designation was gathered to show the selected sample of the respondents represents the total population.

Similar to the semi structured interviews, the structured questionnaire was piloted and a preliminary analysis was carried out for the pilot data. Next the self administered questionnaires were distributed among the respondents. In addition to a hard copy, the questionnaire was prepared electronically and emailed to the respondents. Duration of two weeks was given to the respondents to complete the questionnaire and at the end of the two weeks a reminder was sent with one week extension. However, due to low response, the deadline for the industrial partners was further extended to three weeks.

3.3.4.5 Selection of respondents for the questionnaire survey

To select the respondents, a sample needs to be established. When selecting a sample there are number of steps which need to be followed, namely, identifying a suitable sampling frame (to represent the population), deciding on the sample size, establishing the sample technique and checking the sample is a representation of the population. As the sampling frame for the principal investigators and researchers, the research institution's web site was used. A stratified sampling technique was used to derive the sample from the sampling frame. This ensured the principal investigators and researchers are adequately represented thus increasing the level of accuracy of data. To select the industrial representatives, snow ball sampling was used. Accordingly, the researcher approached the principal investigators and researchers within the research institution and obtained details of the industrial partners with whom they have worked. Table 3.6 shows the profile of the respondents who participated in the questionnaire survey.

Table 3.6: Response rate for the questionnaire survey

Category	Number of questionnaires sent	Number of responses received	Response rate
Principal Investigators and Researchers	55	34	62%
Industrial Partners	74	26	35%

The link between the semi structured interviews, questionnaire survey, research questions and the literature section is given in Table 3.7.

Table 3.7: Link between the research questions, semi structured interviews, survey questions, and the literature section

Research question	Literature section	Section of the semi structured interview: exploratory stage	Section of the questionnaire	Section of the semi structured interview: explanatory stage
How can PM influence the performance improvement of construction R&D function?	Section 2.6.2 and 2.6.5	Question 6		Section 2
How performance of construction R&D function is measured?	Section 2.6.4	Question 6	Section 3	
What are the critical success factors of construction R&D function?	Section 2.7	Questions 1-5	Section 2	

3.3.4.6 Documents reviews

Document reviews were used for this study mainly to understand the details of the case study organisation, to obtain the details of the participants for interviews and the questionnaire survey. Further, policy documents of the funding bodies linked with the case study were also reviewed.

3.3.5 Objectives of the study and how they are addressed through the data collection methods

The table below shows how the objectives are addressed through the data collection methods (see Table 3.8)

Table 3.8 - Objective of the study and the mode of investigation

Objective	Method of investigation				
			Case study		
	Literature review	Expert opinion	Semi structured interviews: Exploratory stage	Questionnaire survey	Semi structured interview: Explanatory stage
Identify the importance of R&D in the construction industry	x				
Identify the current position of construction R&D	x	x			
Evaluate the importance of performance measurement in construction R&D function	x	x	x		x
Explore how the performance of the R&D function is measured	x		x	x	x
Determine the critical success factors of construction R&D function	x		x	x	x
Develop a performance measurement system that enable management to assess the successfulness of the R&D function	x	x	x	x	x

After discussing the data collection techniques, the next section focuses on the data analysis techniques.

3.4 Data analysis and write up

The data analysis of a research project is one of the significant parts of any research as it helps to investigate the collected data and to draw up conclusions based on them. According to Jorgenson (1989, p: 107) data analysis starts with *"…breaking up, separating, or disassembling of research materials into pieces, parts, elements,* *or units"*. Thereafter, the researcher sorts them and looks for types, sequences, patterns and even combines quantitative and qualitative data to seek evidence to address the initial propositions of the study (Yin, 2003). The aim of this process is to assemble or reconstruct the data in a meaningful way (Jorgenson, 1989). As stated by Hartley (2004) data analysis helps to generate theories which are grounded in the empirical evidence.

As discussed in section 3.3.4.1, this study gathered qualitative data from unstructured and semi structured interviews and quantitative data from a questionnaire survey. First, this section describes the analysing techniques used for the qualitative data (Section 3.4.1) and next the quantitative data analysis (Section 3.4.2).

3.4.1 Analysis of the semi structured interviews

Due to the use of unstructured and semi structured interviews, the researcher obtained free flowing text as qualitative data. Ryan and Bernard (2003) classify the methods available for analysis of free flowing text into two broad approaches.

- by considering the codes as units of analysis (code based)
- by considering the words as units of analysis (word based)

3.4.1.1 Code based analysis

The code based analysis of text creates links between theory and empirical data and allows conclusions to be drawn while facilitating a rigorous and transparent analysis of the data (Ryan and Bernard, 2003). Grounded theory, content analysis and schema analysis are classified under the code based analysis. Often, the results from code based analysis are displayed in frequency tables and cross tabulations, thus resulting in poor data displays (Miles and Huberman, 1994). Under the code based analysis, the portions of data will be linked with researcher derived codes or prior established codes. Identification of researcher driven classifications from the text is recognised as a limitation of code based analysis as it could increase the bias of the data (Jackson and Trochim, 2002). On the other hand, prior identification of codes has the limitation of categorising the responses forcefully under pre established categories.

3.4.1.2 Word based analysis

Word based analysis takes into account the natural meanings embedded in free flowing text to generate the meaning in text (Carley and Palmquist, 1992). Some of the examples include keywords in context [KWIC], semantic networks, and cognitive maps. The focus of word based analysis is to look for semantic or meaningful relationships (Colorado State University, 2006). Accordingly, they consider the words created by the respondents and capture the relationships in the form of maps within a respondent's statement and even between different respondents (Carley, 1997). Thus, this allows relationships to emerge from the respondents' statements, rather than the researcher forcefully identifying the relationships. Thus, word based analysis produces less bias results than code based analysis. Further, the possibility of representing relationships between concepts is considered as an advantage of word based analysis over code based analysis. However, word based analysis can only represent the concepts, actions and the direction of actions, but drawing up the conclusions about the context is up to the researcher. Since the initial identification of concepts is done by the researcher, Ryan and Bernard (2000) claim that the researchers' judgment can influence the selection or cut off the concepts from the free flowing text. Thus, if the analysis is solely done using a word based analysis, it could have the disadvantage of not showing the transparency when identifying the concepts.

As discussed above, the code based and word based methods, have strengths and weaknesses. Thus, for this study, both the code based and word based methods were used to minimise the weakness of using a sole method of data analysis for free flowing text. Accordingly, a code based approach was used to derive the main concepts/themes from the free flowing text rather than using a word based approach to directly obtain the codes. This process increased the transparency of the identified main concepts/ themes and codes (see Section 3.4.1.3). On the other hand, since the code based approach is poor in presenting the data, word based approach was used to identify the relationships between the main concepts/ themes (see Section 3.4.1.7). As the code based approach, content analysis and as the word based approach, cognitive mapping were used.

Having differentiated the code and word based methods, the next section explains the use of content analysis within this study to analyse the interview data.

3.4.1.3 Content analysis

The earlier definitions of content analysis had the component of *"quantification"* associated with it. Within this context, content analysis can be used to quantify words, concepts or themes and characters in a text. However, in the later definitions, the focus of content analysis has moved on to *"inference", "objectivity"* and *"systematisation"* (Franzosi, 2004). Accordingly Holsti (1969, p: 14) defines content analysis as *"… a technique for making inferences by objectively and systematically identifying specified characteristics of messages"*. The Bureau of Justice Assistance (2006) also provides a similar definition by identifying content analysis as a set of procedures for collecting and organising non-structured information into a standardised format, which helps to make inferences about the characteristics and meaning of written or recorded material. Krippendorff (2004) one of the seminal authors in the area of content analysis defines it as a research technique to make replicable and valid inferences from text to a context of their use.

3.4.1.3.1 Types of content analysis

In the literature review various authors categorise content analysis in different ways. According to Krippendorf (2004) content analysis can range from the simplest form of word count to thematic analysis or conceptual analysis. The word based analysis involves counting the frequency of words in the text. The underlying assumption behind word counting is that the words mentioned most often indicate the important concerns. However, there are several constraints associated with the mere word count of text. For example, the use of synonyms may underestimate the importance of concepts (Weber, 1990). Furthermore, multiple meanings may mislead the researchers when carrying out word counts in content analysis (Stemler, 2001). In conceptual content analysis the text is scrutinised to check the existence and frequency of a concept/ theme (Colorado State University, 2006; Krippendorf, 2004). In this method, dominant concepts/themes in the text are categorised into codes (Franzosi, 2004). Instead of counting the frequency of word usage as used in word based content analysis, this approach attempts to find similar cognitions under the same concept (Swan, 1997). Thus, the underlying principle is to identify the occurrence of selected terms within the text. These terms can be implicitly or explicitly related to the concepts/ themes under consideration (Colorado State University, 2006).

From this study, the researcher intended to explore the respondents' views about the PM concept within the construction R&D settings. Thus, the opinions and attitudes regarding the PM practices in R&D setting, strengths and weaknesses of the current system were investigated. Further, the respondents' views about the successful criterion of construction R&D were explored. Within this scenario, the mere word counting would not lead the researcher to achieve the ultimate goals by deriving major concepts/themes from the study. Thus, conceptual content analysis was identified as the most suitable method.

3.4.1.3.2 Coding in content analysis

Stemler (2001) claims the use of codes and categorisation in content analysis makes this tool rich and meaningful. Ryan & Bernard (2000, p: 780) reinforce this statement by saying *"coding is the heart and soul of whole text analysis"*. According to Weber (1990, p: 37), *"category is a group of words with similar meanings or connotations"*. Categories have to be mutually exclusive and exhaustive where former refers when no unit comes in between two data sets and the latter refers when the data represent a comprehensive set of units (General Accounting Office, 1996).

One of the core questions rose when dealing with content analysis is regarding the development and definition of categories and codes. Literature reviews, researchers own experiences with the study are good sources to identify concepts and thereby to develop categories and codes. In addition to that, the text itself can generate concepts, categories and codes. Therefore, codes can be identified before, during and after the data collection (Ryan and Bernards, 2003; Ryan and Bernards, 2000). *"Coding is data reduction not proliferation"* states Bernard (2000, p: 446). It is important to have a manageable and reasonable number of codes for the data analysing process depending on the extent and requirement of the study. While too many codes can make the study cumbersome, too few codes also can produce unreliable and invalid conclusions (Palmquist, 2006). It is recommended that the categories and codes are developed as close as possible to the original text by using actual phrases, words from the text (Corbin, 1990). This is known as in-vivo coding (Bernard, 2000).

There are two main approaches for coding known as Inductive and Deductive coding (Krippendorf, 2004; Bernard, 2000; Marying, 2000) sometimes also known as Emergent and Priori coding (Stemler, 2001).

3.4.1.3.2.1 Deductive Coding

Deductive coding commences with prior establishment of categories and codes based upon a theory and bringing them in connection with the text (Stemler, 2001; Mayring, 2000; Bernard, 2000). This approach is suitable for the confirmatory stage of research (Mayring, 2000; Bernard, 2000). The use of pre-established categories and codes leads to the delivery of well organised data analysis. Nevertheless, this approach can neglect concepts and categories which do not fall under the pre-established categories.

3.4.1.3.2.2 Inductive coding

Inductive coding allows categories and codes to emerge from the text itself. This approach is suitable for the exploratory or discovery phase of research (Mayring, 2000; Bernard, 2000) and is used extensively in grounded theory. However, Miles and Huberman (1994) suggest the use of coding which lies in between the deductive and inductive approaches. Accordingly, some categories can be pre-established from the literature review and can add more as you go along the text. For this study the aforementioned approach was used by pre defining some of the codes through the theoretical background whilst allowing new codes to emerge from the text itself.

The section below describes the word based approach used to analyse interview data within the study.

3.4.1.4 Cognitive mapping

Cognitive mapping can be viewed as a technique to structure ideas and to identify relationships between them. The founders of cognitive mapping technique Collin Eden and Fran Ackermann identify it as a tool which can be used to structure messy or complex data (Eden and Ackerman, 1998). Agreeing with that, Mc Donald et al (2004) and Brightmen (2004) recognise cognitive mapping as a technique which allows analysis of disordered, difficult and interlinked issues or ideas and the factors that surround them. Simultaneous representation of conflicting viewpoints is noted as a strength of cognitive mapping (Mc Donald et al, 2004). In addition to that, the structure of cognitive mapping eases decision making, reasoning, arriving at judgments, and making predictions about future events (Daniels and Henry, 1998).

By using cognitive mapping, the issues/ideas can be structured into a hierarchical network. Thereafter, the relationships surrounding and supporting information behind the issues/ideas can be exploited and can be made explicit. Thus, it can be argued that cognitive mapping is a technique which helps to bridge the gap between raw data and theory building.

3.4.1.5 Use of computer aided software

A variety of computer software applications have been developed over past years to facilitate data analysis process from making notes to data displaying and theory building (Weitzman, 2003). However, Weitzman and Miles (1995) argue that software will not build theory for the researcher; rather it would support the researcher's intellectual efforts. Silverman (2005) also favours the above arguments and states that computer aided software needs to be used with caution as they have both strengths and limitations. One of the main advantages of computer aided software is their ability to handle large volumes of data. Further, by using computer aided software, text can be easily manipulated and displayed in a number of ways (Robson, 2002). In addition to that, computer aided software provides a single location for storing materials ranging from interview transcripts, category definitions, interpretations, comments etc. (Robson, 2002; Mayring, 2000). This makes the data analysing process more comprehensive, transparent and replicable thus increasing the reliability and validity of the data analysis. On the down side, the use of computer aided software can make the researcher mechanistic and damage the creativity. Adding to that Weitzman (2003) asserts that computer aided software would influence the researcher to take *"short cuts"* rather than learning the correct procedures. The researcher argues that it is at his/her discretion to allow computers to take the control of the study and to make it mechanistic. If the computer aided software is used with care to assist the tedious tasks of data handling while keeping the intellectual part with the researcher, such tools can be used to enhance the data analysing process.

3.4.1.6 Selecting an appropriate software for data analysis

There are a number of software packages available for the analysis of data such as ATLAS.ti, HyperRESEARCH, MAXQDA, MAXQDA2, NVivo, Decision explorer, QSR N6. When selecting software for data analysis, a number of factors need to be considered (see Saunders et al, 2007; Lewins and Silver, 2006): the amount of data to be analysed; time availability; availability of support to learn to use the package; operating system of the computer and the memory it has; the analysing approach, whether it is deductive or inductive; the research methodology of the study etc. However, Lewins and Silver (2006) assert that deciding on a software package for data analysis is a subjective decision governed by the aforementioned factors.

As argued in Section 3.4.1.5, the researcher intended to use software packages for this study to assist with the data handling process, rather than allowing the software to dominate the data analysis process. Accordingly, the researcher decided to use three types of software to support the data analysis for the study, namely NVivo (version 2) and Decision Explorer (version 3.1.2) to carry out the content analysis and cognitive mapping respectively and SPSS (version 13) for the analysis of the questionnaire survey. When evaluating the features of the selected software packages, it was noted that they satisfy the researcher's data analysing requirements. Further, the decision to use these software packages were influenced by the availability of the software and literature, training and support received for the researcher in carrying out the analysis. The section below discusses the processes adopted when using NVivo and Decision explorer.

3.4.1.6.1 NVivo

NVivo is a software package designed to help management, organisation and to support qualitative research. It is developed by QSR International who earlier developed NUD*IST to facilitate code based data analysis. The NVivo software package has a number of features which assist the data analysis process. The NVivo (version 2) was used at the exploratory stage of this study for the following reasons:

- the number of interviews were too large to deal manually;

- NVivo permits a rigorous and comprehensive data analysis process;
- increased transparency and replicability of the analysis;
- facilitates the use of memos to record important information related to the interviews;
- easy accessibility to the complete lists of codes which makes revisions much easier;
- easy retrieval of codes, thus the consistency of coding is maintained while avoiding duplication.

The next section describes the data analysis steps followed by using the NVivo software.

3.4.1.6.2 Data analysis steps in NVivo

This section discusses the steps followed when analysing the semi structured interviews using NVivo software. As the first step, new projects were created by using the launch pad (see Figure 3.11). Separate projects were created to analyse the influence of PM in construction R&D and for the evaluation of the CSFs of construction R&D. After creating the projects, the semi structured interviews which were tape recorded and transcribed by using MS word were changed to rich text format (RTF) to upload onto the NVivo software (see Figure 3.11).

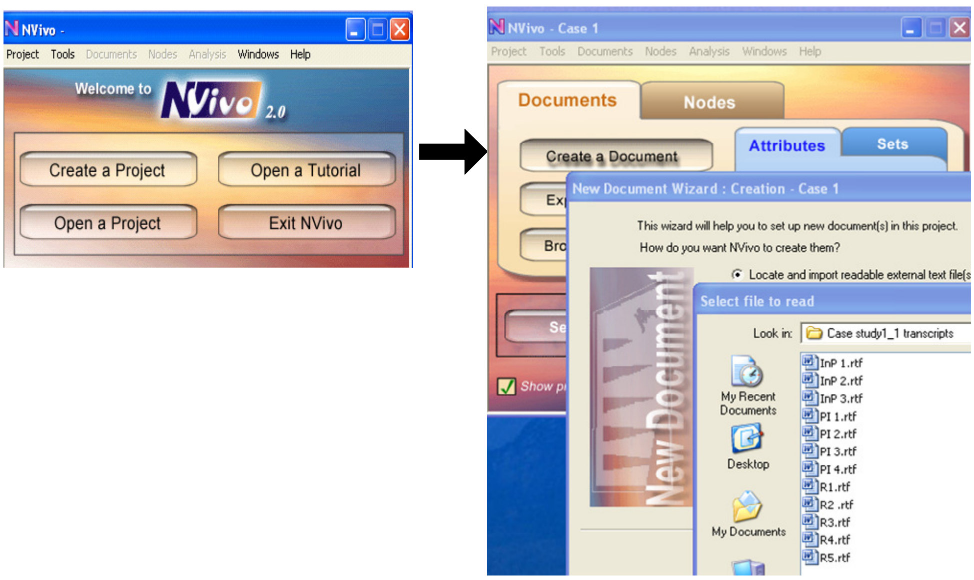


Figure 3.11: Creating and uploading the transcripts onto NVivo software

After uploading the transcripts, they were carefully scrutinised with the aim of identifying concepts. For example, the semi structured interviews were scrutinised to identify the main concepts related to the objectives of the exploratory stage of the case study (see Figure 3.10 for objectives of the exploratory stage). Whilst going through the transcripts, they were broken down into meaningful content categories which related to a particular concept. The next step was to assign a code for each concept identified from the transcripts. As mentioned in Section 3.4.1.3.2, the researcher used the characteristics of both deductive and inductive coding approaches. When a concept was identified, a code was assigned from the provisional list of codes developed through theory or assigned a new code. This process was carried out in repetitive cycles until no new concept was identified. This process helped the researcher to become more familiar with the interview transcripts and to generate new concepts from the text. The coding was done by using descriptive key words where the key words were chosen from the original words and phrases used in the transcripts (Figure 3.12).

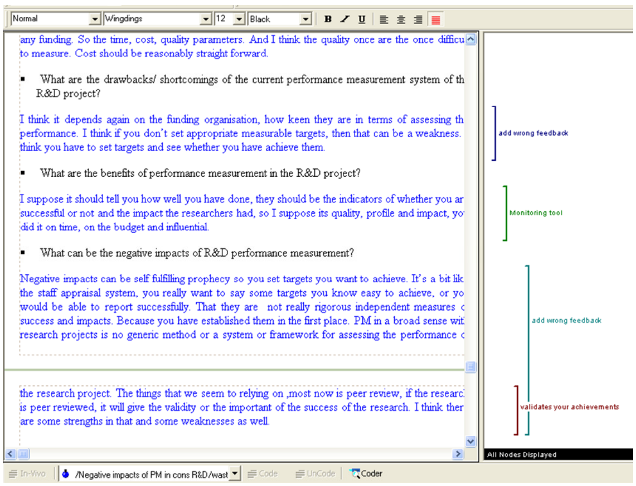


Figure 3.12: Coding the transcripts

3.4.1.6.2.1 Linking with the tree nodes

The codes created from the above process were listed as *"free nodes"* (nodes in a flat structure) in the NVivo software. Thereafter, the next task was to link these codes (which were listed as free nodes in NVivo) with the objectives of the exploratory stage (see Figure 3.10) to build up arguments and to arrive at conclusions. To do this, NVivo software identifies another type of node which is called a *"tree node"*. Because of the hierarchical nature of tree nodes, free nodes can be transferred into them and arranged and structured in an appropriate way. Accordingly, each research question was broken down into sub themes and these sub themes were used as the tree nodes for this study (Figure 3.13).

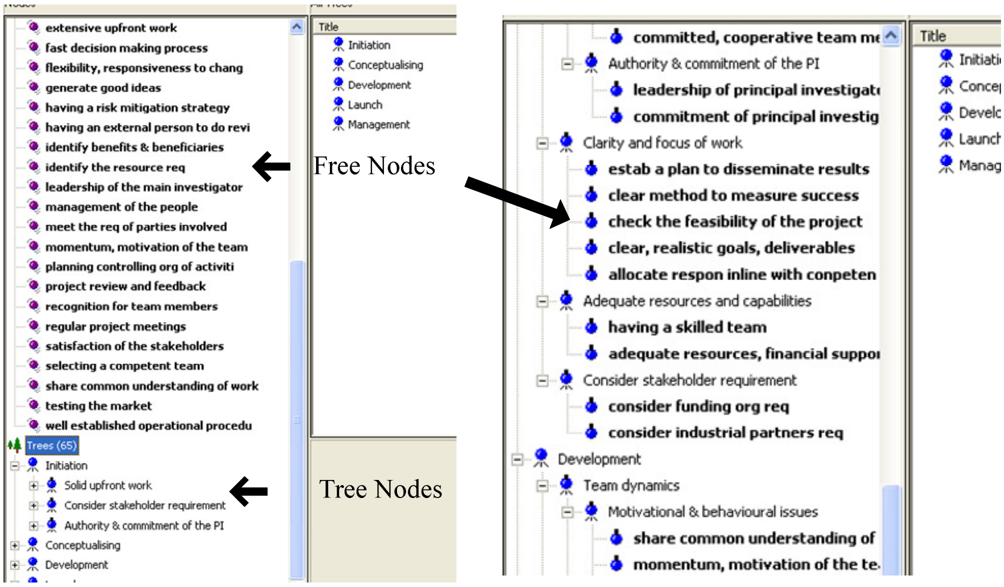


Figure 3.13: Linking the free nodes with the tree nodes

Figure 3.14 illustrates the synthesis other data analysis process used in NVivo.

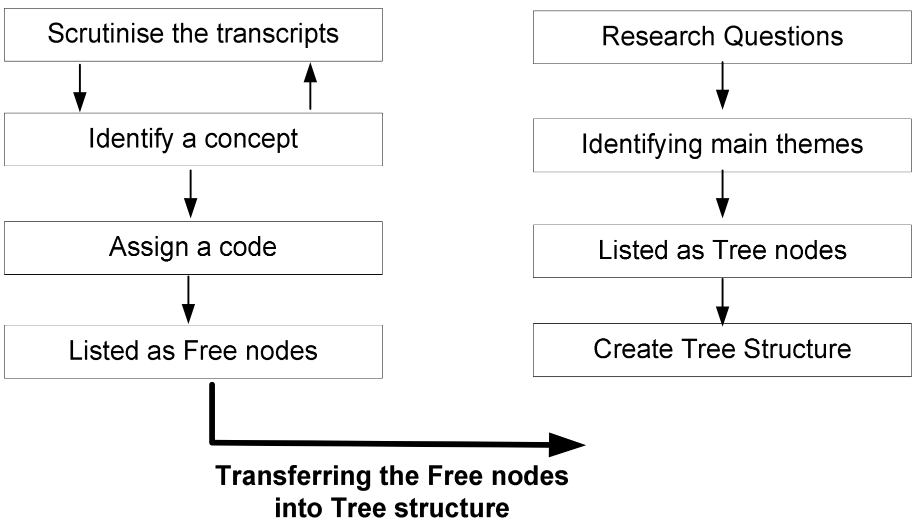


Figure 3.14: Synthesis of the data analysis process using NVivo

Having discussed the steps used in NVivo, the following section discusses the application of Decision Explorer software within the study.

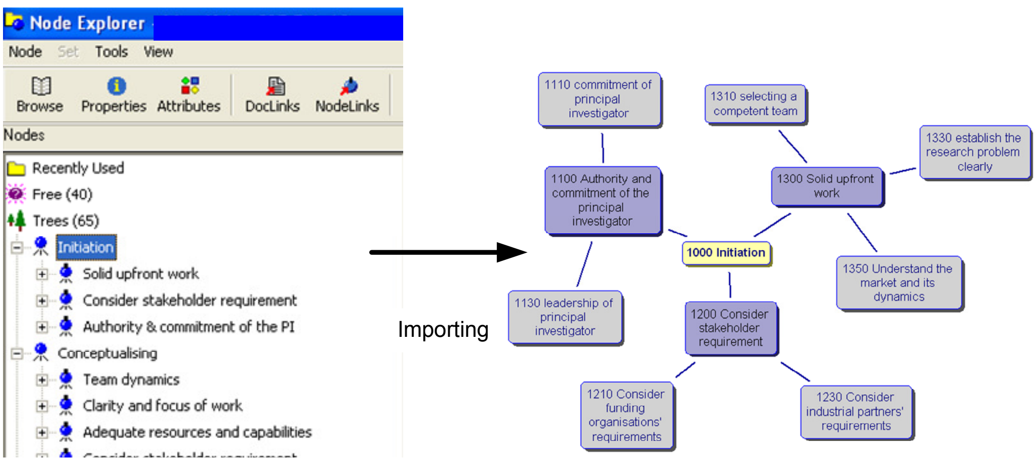
3.4.1.7 Decision explorer

The Decision Explorer software (version 3.1.2) was used to draw the cognitive maps related to this study. It is a software package published by BANXIA software Ltd. Decision Explorer software helps to organise the opinions of the interviewees and identify the relationships between them. Accordingly, the opinions of the respondents can be entered in the form of "*concepts*" and different concepts can be linked to show their relationships and interdependencies. Decision Explorer software helps to create different types of links (e.g.: cause and effect, temporal) between the concepts and illustrates negative and positive relationships. Further, the software provides the opportunity to customise the links and concepts according to the requirements of the researcher. Thus, the maps drawn by Decision Explorer software are easily understandable and attractive. Further, attaching notes in the form of memos helps the researcher in lessening the number of notes required for further analysis and the possibility of creating sub maps using the main map make the Decision Explorer software user friendly and less time consuming.

The section below explains how the Decision Explorer software was used to develop the cognitive maps.

3.4.1.8 Data analysing steps in Decision Explorer

First, the coding structure developed with NVivo (the tree structure) was imported into the decision explorer software to create the basic map as shown in Figure 3.15.



Nvivo Tree structure

Decision explorer map

Figure 3.15: Importing the NVivo tree nodes to Decision Explorer

The codes within the basic cognitive map were supported with the concepts extracted from the interviews transcripts (see Figure 3.16). The concepts were entered in the form of short phrases and relationships were created between the concepts and codes.

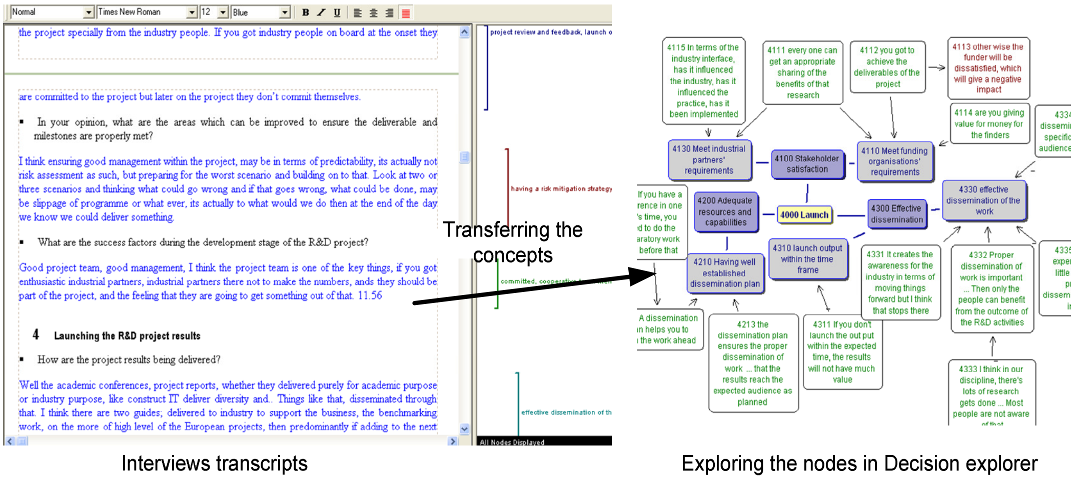


Figure 3.16: Transferring the concepts from transcripts to decision explorer map

As shown in Figure 3.17, for this study, two types of relationships were used within the map namely; the causal (A leads to B or A explains B) and hierarchical (A belongs to B).

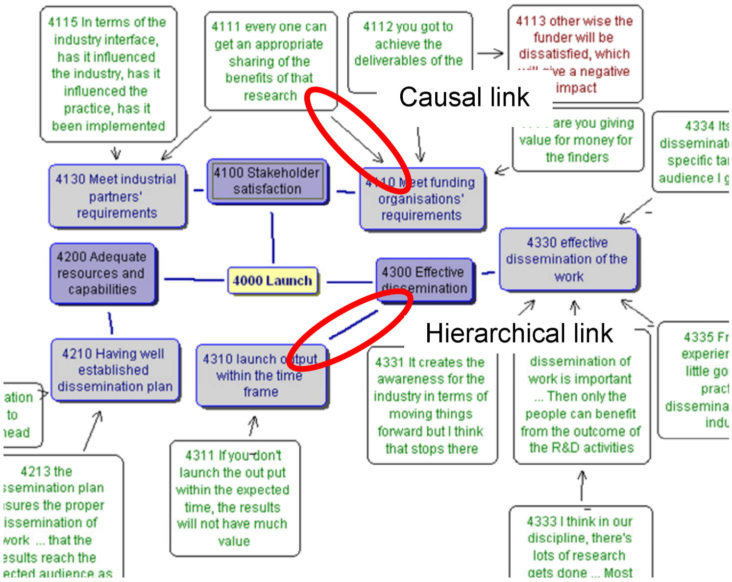


Figure 3.17: Links used in Decision explorer diagrams

Within the causal relationships positive and negative relationships were identified. Accordingly, the negative relationships were denoted with a minus sign (see Figure 3.18).

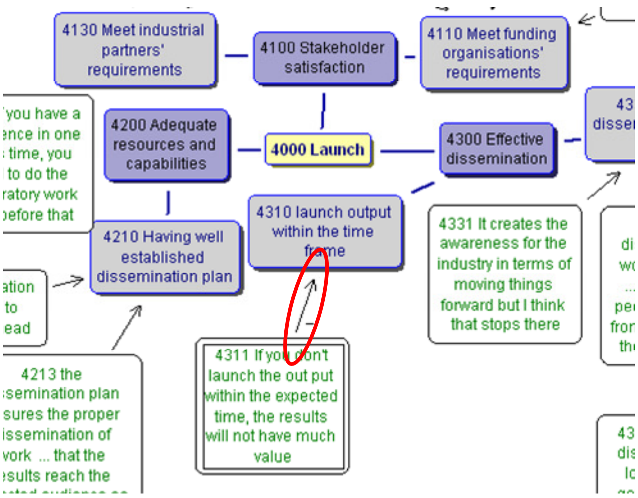


Figure 3.18: The use of negative links

3.4.2 Analysis of the questionnaire surveys

The analysis of the questionnaire survey consisted of two parts:

- analysis of the importance and implementation/consideration of success factors; and
- obtain an understanding of the use and types of performance measures.

As explained in Section 3.3.4.4, a Likert scale was used to gather data on the importance and implementation/consideration of success factors during the construction R&D function. The data gathered from the academic members and industrial partners was first entered into spread sheets using MS excel software. To minimise the errors of manual data entering, the *"speech"* facility of MS Excel was used so that the researcher was assured of the entering of correct value. However, the data set was further proof read to avoid any errors. Thereafter, the data sheets were transferred to SPSS software (version 13). The analysis of the data on the CSFs and performance measures was done in two separate SPSS projects. After transferring the data to the SPSS software, the variables were defined according to the specified fields of SPSS (e.g.: name, type, label, values, and measure).

3.4.2.1 Measurement scales

Before proceeding with the analysis, it is important to identify the level of measurements; whether it is nominal, ordinal, interval or ratio. Nominal data has no order thus the assignment of values (numbers) to the data is purely arbitrary (e.g.: male=1, female=2). Since, the assigned values are considered as *"labels"* to the data, they cannot be used for mathematical calculations (Garson, 2007). A data set is said to be ordinal when the values assigned can be ranked. However, the intervals between the values may not necessarily be equal or represent actual quantities (Naoum, 1998). For statistical calculations of ordinal scale, median is suggested. The data set representing the degree of satisfaction can be considered as an ordinal data set. The interval scale has order as well as equal intervals i.e. the distance between to two adjacent points are equal. An interval scale with an absolute zero point is called as a ratio scale (e.g. income).

When constructing the first section of the questionnaire for this study, nominal scale was used to label the academic members and industrial partners responses (academic member= 1, industrial partner= 2) and ordinal scale was used in the form of a Likert scale to represent the degree of importance and implementation/ consideration of success factors during the construction R&D function. When analysing ordinal scales, Bendixen and Sandler (1995) asserted that the ordinal scale can be considered as an interval scale provided that the distance (intervals) between the adjacent points of the scale is equal and when the scale has at least 5 or 7 categories (Garson, 2007). Accordingly, the Likert scale used for this study was considered as an interval scale on the assumption that the distance between the values is equal and since the scale has five points. Hence, the central tendency of a Likert scale was calculated by using the Mean values of the data. For the second section of the questionnaire survey which is on the identification of use and types of performance measures during the construction R&D function, the positive responses (Yes) were assigned number 1 whilst the negative responses (No) were assigned number 2.

The data gathered regarding the use and types of performance measures was also first entered into a spread sheet and transferred to SPSS for further analysis.

3.4.2.2 Dealing with missing data

As the first step of analysing the questionnaire survey, the researcher dealt with the missing data from the questionnaire. Often in questionnaires, missing data can exist for the following legitimate reasons: the respondents refused to answer the questions (a non response), the respondent did not know the answer or did not have an opinion (no opinion), mistakenly omitting the question (Barr, 2004; deVaus, 2002). It is important to give due consideration to the patterns of missing value as the existence of a higher number of missing values can affect the precision of the results. When coding the missing data, it is important to differentiate between the user missing data (which occurs due to the aforementioned factors) and the system missing data (which occurs when the data is not entered in the cell by the researcher) (Bryman and Cramer, 2005; Barr, 2004). Since the data set of this study was checked for errors system missing data was not found. However, two types of user missing data were found. Firstly the questionnaire had a separate column to indicate *"no opinion/ not applicable"* (see Appendix G). Secondly, some of the respondents had not recorded their responses for some reason. When handling the missing data, Saunders (2007) and Barr (2004) say that missing data should be coded differently if it needs to be distinguished based on the reason for the respondent's omission. However, for this study, it was not necessary to distinguish the above two types of missing data, thus a common code was used. Accordingly, the missing data was assigned with the value 99 to avoid any confusion with the values assigned for the other scales (see Table 3.5).

To identify whether data is missing completely at random (MCAR), the missing value analysis was used. To check whether data is missing at random, the missing value analysis supports the Little's MCAR chi-square test. When the Little's MCAR result is not significant, the missing values in the data set are considered MCAR. Accordingly, when performing the missing value analysis, it was identified data is missing randomly without any patterns.

3.4.2.3 Analysing techniques used

To identify the main features of the data set descriptive statistics were used whilst inferential statistics were used to uncover the relationships of the sample (Pallant, 2001). For the descriptive statistical methods, calculation of the mean values and frequencies and under the inferential statistical methods, Wilcoxon Signed Rank test and Mann-Whitney U test were used with a significance level of 0.05.

3.4.2.3.1 Comparison of the mean values

To assess the importance and the extent of implementation/consideration of success factors during the construction R&D function, the mean values i.e. the average value of the data sets were calculated. Accordingly, separate mean values for academic members' and industrial partners' responses as well as the overall mean values were calculated.

3.4.2.3.2 Wilcoxon signed rank test

After identifying the importance of the success factors, it was further required to filter the success factors based on their criticality to the construction R&D function. Therefore, it was necessary to identify the demarcation point between the differences of opinion of the respondents regarding two consecutive success factors. Accordingly, the Wilcoxon signed rank test was used to identify the demarcation point of the views on difference in opinion. The Wilcoxon signed rank test is a non parametric method to test the differences in two related variables when the subject (dependant category) is measured on two occasions or under different conditions (Hill and Lewicki, 2007; Pallant, 2001). For the output of the study, the associated significant level given as *Asymptotic Significance* (Asymp. Sig) needs to be considered. When the Asymptotic significance is less than 0.05, the difference between the dependent variables is considered statistically significant i.e. the data distribution is considered as unequal between the two samples.

3.4.2.3.3 Mann-Whitney U test

Mann-Whitney U test is used to identify the difference between two independent categories, for example in this study the academic members and the industrial partners. Similar to the Wilcoxon signed rank test, the *Asymptotic significance* (Asymp. Sig.) was considered to identify the statistical significance. Accordingly, an *Asymptotic Significance* of less than 0.05 was taken as statistically significant for this study. Mann-Whitney U test was used to recognise the difference of opinions of the academic members and industrial partners regarding the importance of success factors during the construction R&D function.

3.4.2.3.4 Calculation of frequency

The frequency was calculated for academic members' and industrial partners' usage of the performance measures during the construction R&D function. Based on the overall frequency values, the data set was ranked.

Table 3.9: Summary of the data analysing methods used

Data collection mode	Analysing method	Analysing technique/ test	Software
Semi structured interviews	Code based analysis	Content analysis	NVivo (version 2)
	Word based analysis	Cognitive maps	Decision explorer (version 3.1.2)
Questionnaire survey	Descriptive statistics	Comparison of mean Calculation of frequency	SPSS (version 13)
	Inferential statistics	Wilcoxon Signed Rank test Mann-Whitney U test	SPSS (version 13)

3.5 Triangulation

The idea behind triangulation is to obtain more agreement from different data sources, researchers, methods, etc. regarding a particular issue. Thus, triangulation makes the findings reliable and valid. However, Collis and Hussay (2003) argue that triangulation cannot rectify a poor research design, but can enhance a good research design. There are number of triangulation methods which could be incorporated in a research study. Table 3.10 shows the triangulation methods used within this study (Saunders et al, 2007; Yin, 2003; Collis and Hussay, 2003; Love and Holt, 2002).

Table 3.10: Triangulation methods

Name	Description	Methods used
Source triangulation	By time source	Data was collected over at different time period owing to the nature of the longitudinal case study
	By origin/perspectives	Data was collected from Principal Investigators, Researchers and Industrial Partners involved in construction R&D activities
Methodological triangulation	By data collection method	Use of unstructured and semi structured interviews, questionnaire survey and document reviews
	By data analysing method	Code based (content analysis) and word based (cognitive mapping) techniques
Discipline triangulation		Comparison of general literature on R&D, performance measurement with empirical evidence

The above sections discussed and justified the research methodological design, data collection and analysing techniques.

3.5.1 Write up

According to the research process, the final stage is to write up the PhD thesis. This was initiated by building a comprehensive chapter breakdown. The writing of the thesis was done during the progressive development of the study rather than at the end of the data analysis. As indicated in the research methodological framework, the continuous write up helped the researcher to identify any gap, to reflect on and refine the research process.

3.6 Case study design acceptability

It is important to increase the readers' confidence about a particular researcher's findings, thus emphasis is placed on judging the quality, and showing the appropriateness of the methods used during a research study. Irrespective of ones philosophical stance, reliability and validity issues need to be addressed (Easterby-smith, 2002; Remenyi et al, 1998). Since interpretivist studies involve reflections or interpretations made by the researchers on social views and lived experience of human beings, it is important to show the genuineness and the credibility of the findings. As Silverman (2001, p: 221) asserts *"…it simply will not do to accept any account just on the basis of researcher's political credential… and the qualitative researchers must make different claims if we are to take their work seriously"*. Thus, appraising the quality of the interpretivist research is much in debate and various criteria are being proposed by different authors to incorporate and adhere to throughout the research process and reporting.

Remenyi et al (1998) stipulate that criteria used to assess the quality of positivist studies (such as internal validity, external validity, reliability and objectivity) should not be directly transposes when judging non-positivist studies. Agreeing with this view, Mays and Pope (2000) and Fade (2003) state that a common language should not be used to judge the quality of research in positivist and interpretivist studies. Rather than using statistical methods to judge the quality of the study, the interpretivist needs to demonstrate the consistency and integrity of the study (Fade, 2003; Remenyi et al, 1998). Through clearly demonstrating the procedures followed during the study and honest representation of the experience of the respondents and their influences, rather than twisting the evidence to fit the researcher's own theories and even exposing and discussing the biases of the study, are being acknowledged as better ways of enhancing the quality of interpretivist studies (Fade, 2003; Remenyi et al, 1998). Accordingly, a number of criteria are being proposed to assess the quality of the interpretivist research (Easterby-Smith et al, 2002; Yin, 2003; Silverman, 2001; Mays and Pope, 2000; Remenyi et al, 1998; Whittemore et al, 2001). Some of the authors prefer to proceed with the criteria or terminology used in positivist studies whilst some are suggesting alternatives (see Appendix H). However, some argue that the alternative criteria have just re-labeled the positivist criteria to show greater appropriateness to interpretivist research. As a consequence, correct reading of the positivist criteria is needed when used within the interpretivist studies. Supporting this view, Easterby-Smith et al (2002) also claim that the meanings of the terms used to judge the quality of research varies considerably depending on the philosophical stance.

The researcher has compared some of the common quality criteria used to evaluate interpretivist studies (see Appendix H). The aforementioned fact, i.e. the use of different terminology to generate similar meanings can be identified in Appendix H.

By evaluating the quality criteria, the study followed the criteria below to appraise the quality of this study.

- Construct validity: Establishing correct operational measures for the concepts being studied
- Internal validity: Establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinct from spurious relationships
- External validity: Establishing a domain to which the study's finding can be generalised
- Reliability: Demonstrating the transparency of the study.
- Credibility: Demonstrating the research findings are credible and believable from the perspective of the participants of the research.

Reliability in positivist studies is based on demonstrating the replicability or repeatability i.e. ensuring the measures of the study would yield the same results on other occasions (Easterby-smith et al, 2002). However, when it comes to the interpretivist studies, where the study is carried out in a social environment without controlling the environment, the conditions under which the study was carried out would be difficult to reproduce (Reyemin et al, 1998). Thus, demonstrating the transparency of the study through good practice guidelines (Easterby-smith et al, 2002; Reyemin et al, 1998), ensuring the respondents would understand the questions in the same way (Silverman, 2001) were asserted to increase the reliability of the interpretivist research.

It is argued that in interpretivist studies the credibility of the researcher plays a major role. Fade (2003, p: 141) states that *"…researchers interpret what study participants do and say and often ask further probing questions based on the information they receive. They also interpret the data and allocate codes to phrases or phenomena as part of the analytical process"*. Thus, it is important to show how the interpretations are arrived at and the contribution from the researcher, exposing the bias and personnel perspectives and demonstrating how they have been taken into consideration during the analysis. This is also known as reflexivity. By taking this into account, the researcher used credibility as another criterion to appraise the study under consideration. As discussed under axiology (see Section 3.3.1), this study takes the value judgement stance with the belief that the researcher's judgements will have an impact on the study. Thus, the use of credibility for this study needs to be highlighted.

Figure 3.19 illustrates how the quality of this study is maintained during the different stages of the study. Further, various techniques used to evaluate the quality criteria within this study are also illustrated. The research direction and the focus of the study were achieved by a comprehensive literature review and expert interviews. Through this iterative process, the research gap, and the importance of the subject areas were established and aim, objectives and research questions of the study were explicitly identified and refined. The methodological design of the study was done in such a way that it suited the phenomenon under investigation while ensuring the compatibility of research philosophy, approach and techniques. Accordingly, through the progressive development of the study, links were created between research gap and its importance; aims, objectives, and research questions; methodological design achieving the internal validity of the study.

During the data collection, theoretical sampling, purposive sampling and stratified sampling were used to identify the appropriate respondents and data sources for the study under consideration. This ensured the construct validity of the study by following correct operational measures. In addition to aforementioned sampling, triangulation by data collection and analysing methods, origin, time and discipline secured the construct validity (see Section 3.5). Further, due to the use of triangulation, the credibility of the study was increased when the findings are corroborated from different perspectives and methods. Tape recording the interviews, checking the transcripts by the respondents and creation of a data base with materials used during the case study enhanced the transparency of the study thus ensuring the reliability as discussed above. Further, piloting the semi structured interviews and the structured questionnaire and the use of consistent interview guidelines assured that the respondents would understand the questions in the same way and enhance the consistency of the coding.

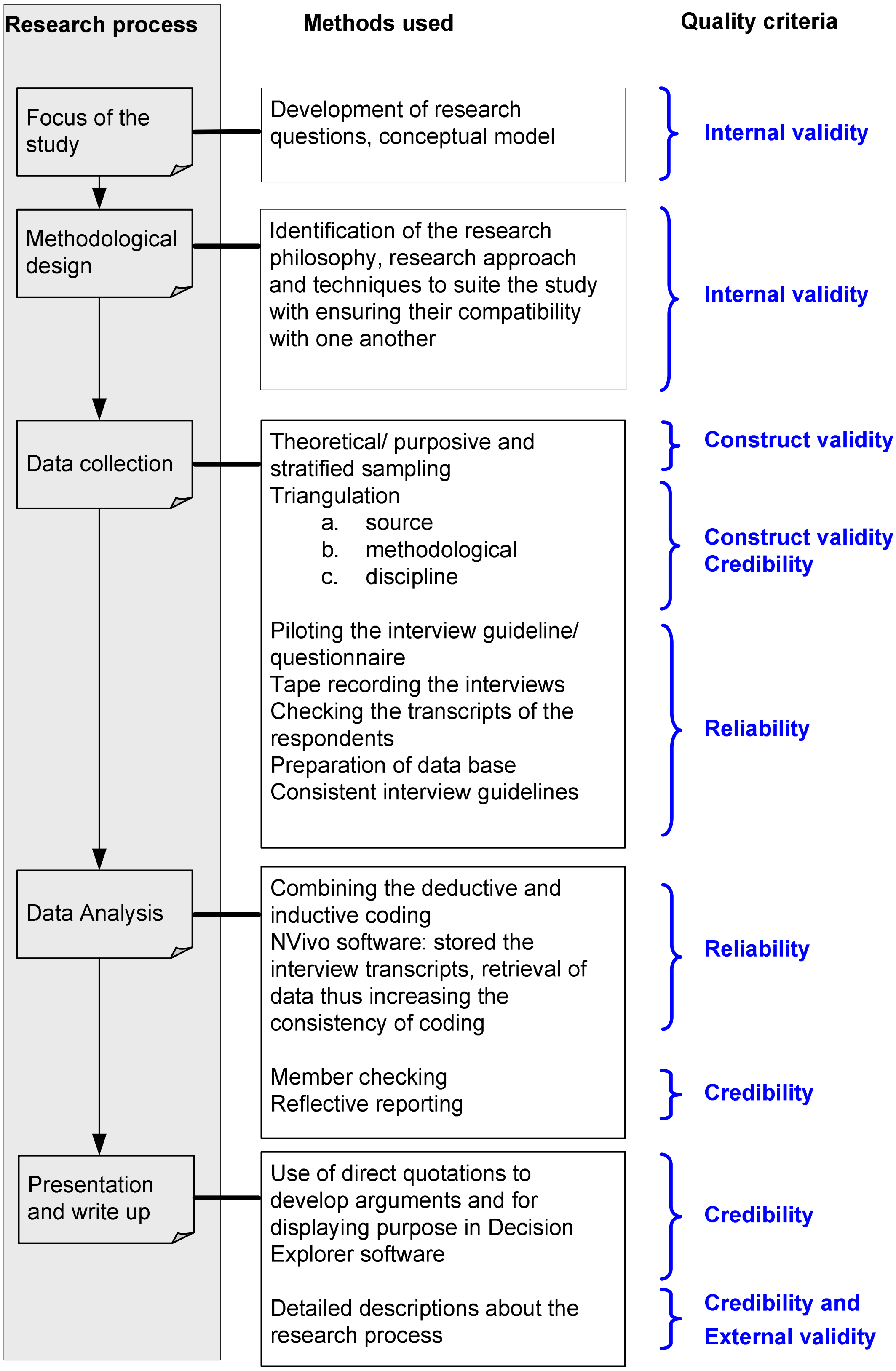


Figure 3.19: The quality criteria used within the study

During the data analysis stage, the use of both deductive and inductive coding approaches ensured a comprehensive identification of the main concepts from the study (see Sections 3.4.1.3.2.1 and 3.4.1.3.2.2). This can be considered as the use of correct operational measures to increase the construct validity. Further, the use of NVivo software (see Section 3.4.1.6.2) assisted in the storage of the interview transcripts, kept records on the respondents thus, performing the role of a central data base. Moreover, the consistency of the coding was maintained through the use of NVivo software due to its data retrieval facility. Therefore, the use of NVivo software increased the reliability of the study. During the refinement of the PMS the involvement of the respondents to read, check and comment on the findings ensured the data analysis process is congruent with the participant's experience. This evaluated the researcher's logical approach to data analysis and decision making based on the gathered data thus on the accuracy of researcher's thinking. This process enhanced the credibility of the study. Further, the supervisors scrutinised the whole research process increasing the credibility of the findings.

The researcher used direct quotations of the respondents when presenting the arguments. Further, the Decision Explorer software used during the study displayed the respondents experience as it is. Such activities assured the reliability of the study at the presentation and write up of the study. Further, detailed or thick descriptions were used throughout the research process to give the reader a better understanding of the underlying conditions behind the phenomenon and the activities that had taken place. Through these detailed descriptions, the credibility of the study was shown. In addition to this the detailed descriptions about the phenomenon being studied, the nature of the unit of analysis considered (the R&D function within a collaborative research work), and the type of participants involved, the researcher constructed a domain or circumstances within which this study's findings can be generalised.

Having discussed the case study design acceptability for the study, the section below graphically illustrates and summarises the entire research process discussed within this chapter.

3.7 Research methodological framework

This chapter discussed and justified the research methodology adopted for this study in addressing the aim and objectives of the study. Accordingly, by summarising the steps used for the study, this section presents the research methodological framework of the study (see Figure 3.20). The framework consists of three main stages namely the establishment of the research problem, research methodological design and the data analysis and write up. The framework illustrates the logical approach followed during the study, beginning from the researcher's initial impetus up to the writing up of the PhD thesis. The solid black arrows in Figure 3.20 indicate the formal sequence of the study. As Remenyi et al (1998, p: 79) assert, *"research is almost always complex for each step to follow from the previous step in the planned and desired way the first time it is attempted"*. Thus, the dotted lines in Figure 3.20 represent the retracing of the previous steps, by the researcher, in order to do revisions based on reflections made during the progress of the study.

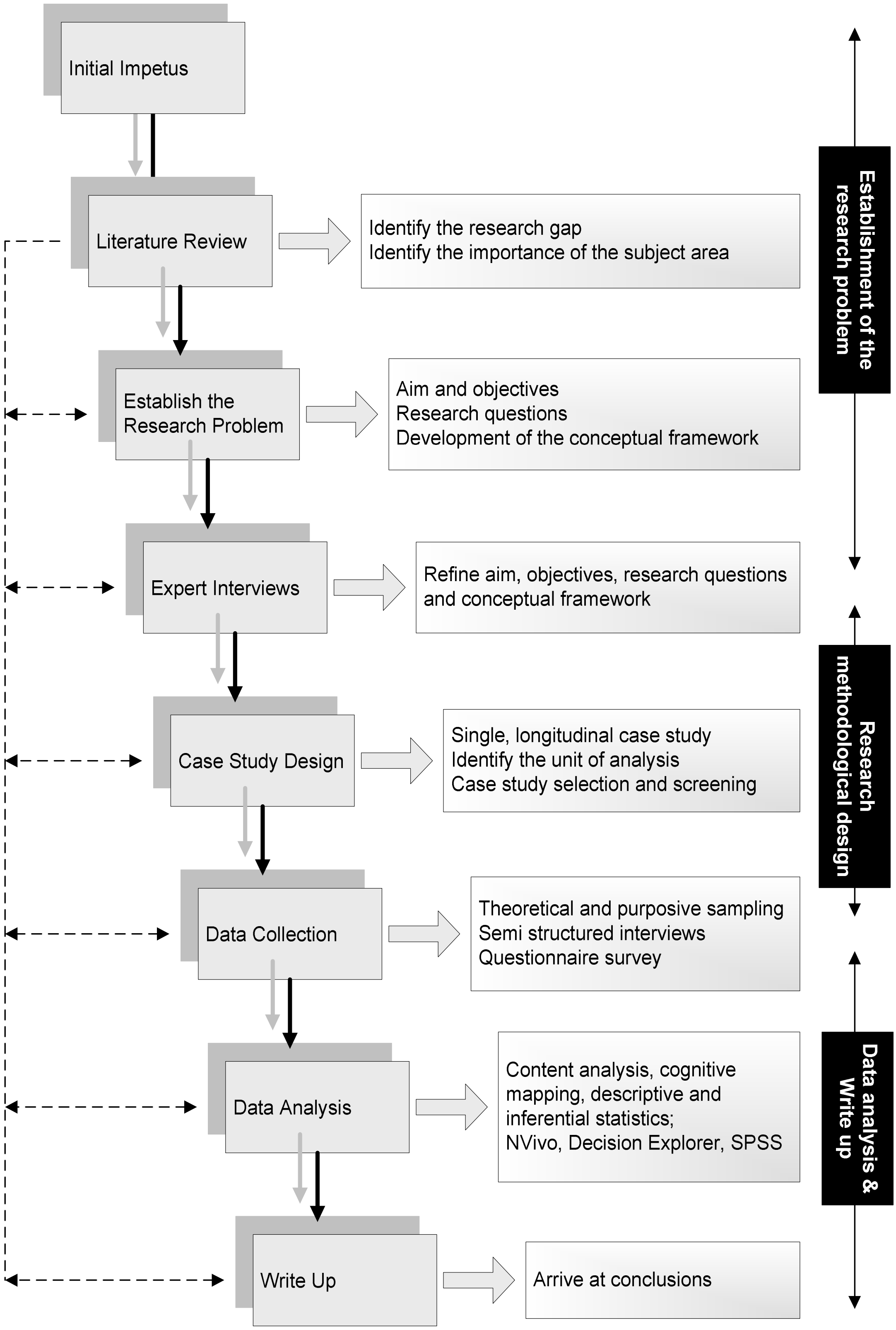


Figure 3.20: Research methodological framework

3.8 Summary and link

This chapter presented and justified the research methodology adhered from the establishment of the research problem to the writing up of the Thesis. The chapter discussed how the research philosophy, approach and techniques were positioned to address the research problem of the study. Further, the design of a single case study and the measures taken to ensure the acceptability of the research findings are also discussed. The next chapter presents the development of the conceptual framework for this study.

CHAPTER 4 CONCEPTUAL FRAMEWORK

4.1 Introduction

Following the research methodology discussed in the previous chapter, this chapter is about the development of the conceptual framework pertaining to the study. The chapter is structured as follows:

- First, it discusses the importance of identifying a conceptual framework.
- Second, the key factors extracted from literature review are discussed. This is followed by the experts opining.
- Third, the development of the conceptual framework is explained.

4.2 Importance of developing a conceptual framework

Section 3.3.3.4 of the research methodology highlighted the importance of conceptualising the phenomenon under consideration or pre establishing an initial theory prior to starting the data collection and analysis. Eisenhardt (1989) and Eisenhardt and Graebner (2007) see it as moving from deductive to inductive research approach when doing case studies. By conceptualising the phenomenon under consideration, the researcher can illustrate the main concepts pertaining to the study, how the concepts are interrelated and the circumstances within which the concepts and inter relationships are said to be true (Yin, 2003). Hence, according to Miles and Huberman (1994: p. 18) a conceptual framework *"explains, either graphically or in narrative form, the main things to be studied- the key factors, constructs or variables- and the presumed relationships among them"*. Similarly, Millennium Ecosystem Assessment (2003) views a conceptual framework as a way of addressing the core questions developed through literature and/or through users indicating the issues to be addressed within the study and their interrelationships. Therefore, the conceptual framework helps to identify a coherent set of ideas or main areas which need to be considered during the progress of the study, the routes researcher takes when developing the study and focuses on the subject area through the identification of the scope/ boundary of the study. From the aforementioned discussion, the constituent parts of a conceptual framework can be noted as the main concepts, their interrelationships and the presence of a boundary within which the concepts and their interrelationships are applicable.

Accordingly, Figure 4.1 shows how the constituent parts (i.e. main concepts, their interrelationships and the presence of a boundary) derived from theory were combined with the expert opinion to develop the conceptual framework pertaining for this study.

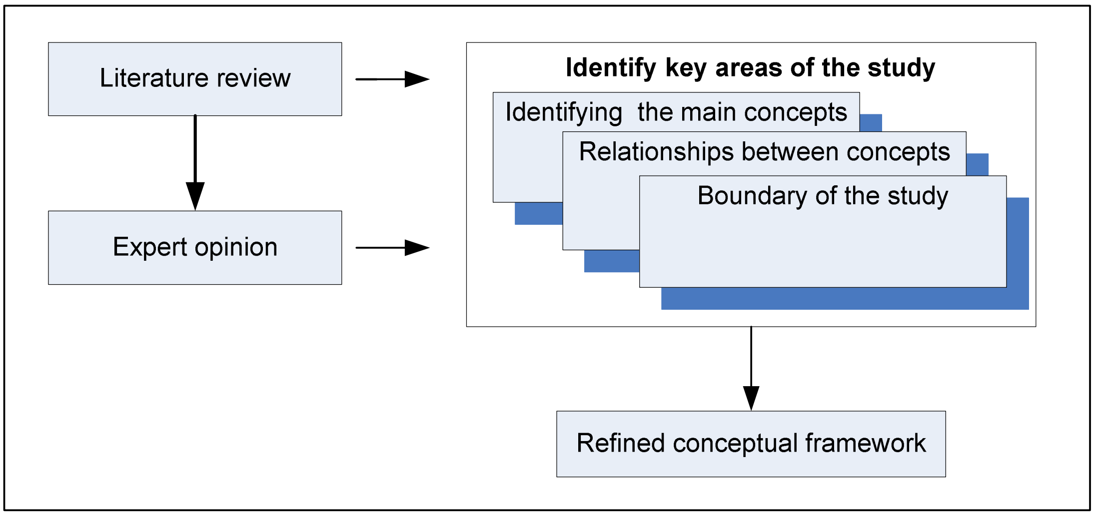


Figure 4.1: Development of the conceptual framework

4.3 Key issues identified from the literature

4.3.1 Importance of research and development for the construction industry

The UK construction industry is being challenged to produce economically, socially and environmentally acceptable products to satisfy its stakeholders, to enhance the effectiveness and efficiency of construction processes and to address resource constraints and sustainable goals. These challenges are forcing the construction industry to change its approaches to design, construction, refurbishment, maintenance and to set new targets, thus widening the scope of work for the designers, engineers, manufacturers, contractors, and researchers (Fairclough, 2002). In this context R&D activities play an imperative role by addressing the challenges placed upon the construction industry (see Section 2.3.3). The development of advanced and new construction materials, processes and management methodologies help the construction industry to successfully address its stakeholder needs.

Furthermore, R&D activities facilitate the exploration and creation of new knowledge and capabilities within organisations to help them compete successfully in the marketplace. Hence, the need of prioritising R&D activities, increasing the R&D investments, creating long term research partnerships are identified as key factors which enables the growth of the construction industry (Barrette, 2007; Fox and Skitmore, 2007; Hampson and Brandon, 2004; Fairclough, 2002).

4.3.2 Issues within construction research and development

Despite the benefits, a number of issues have hindered R&D activities within the construction industry (see Section 2.4.5). Identifying the actual contributions from R&D activities, justifying and showing the accountability of resources, ensuring the outputs are aligned with expected goals have become important owing to increased expenditure, time and resource constraints of construction R&D activities. Further, inadequate mechanisms to evaluate the success and the effective usage of funds have negatively affected the construction R&D activities. Furthermore, the complexity of R&D activities has been increased due to the engagement of different stakeholders and the presence of a wide range of activities. Moreover, lack of communication and coordination between the stakeholders and a lack of clear objectives to address their requirements are evident within construction R&D (see Section 2.4.5). Consequently, these issues have lowered the investments for construction R&D and resulted in producing research results with low applicability. It was evident that these issues are interrelated with one another and was argued that the cause of the majority of issues in construction R&D is directly or indirectly rooted in the lack of evaluation mechanisms (see Section 2.4.5).

4.3.3 Need of performance measurement for effective research and development

The issues within construction R&D (see Section 2.4.5 and Section 4.3.2) show a need for control and monitoring mechanisms within construction R&D, thus this study argues that by implementing PM the solutions can bring about to the issues. For instance, the implementation of PM increases the transparency of work (see Section 2.5.2) thus, the contribution of the parties involved within the R&D activities can be identified and the utilisation of resources can be shown (see Section 2.6.5).

Since PM evaluates the achievements of goals against the targets (see Section 2.5.2), through the implementation of PM, the output can be aligned with the objectives of R&D activities. Furthermore, PM could increase the communication and coordination of the parties involved in the R&D activities. Moreover, it was established from the literature review that the utilisation of PM within the construction R&D would generate benefits such as evaluating the success of R&D activities; identifying future improvement areas and required support for such activities; and directing the employees towards the common goals (see Section 2.6.5).

4.3.4 Targeting performance measurement on critical success factors

The evaluation of performance needs to ensure that the success criterion of the R&D function is achieved. Within the R&D function there are various success factors which could influence the accomplishment of the success criterion (see Section 2.7). However, it is revealed from the studies carried out in other industries that whilst the factors that are less important are successfully implemented those that are important are not implemented (Sun and Wing, 2005). Thus, to improve the performance of the construction R&D function, a greater insight is needed into the factors that could generate success (see Section 2.7.1). Accordingly, coupling the success factors with PM could ensure the vital factors that influence the successful R&D function are properly implemented.

As discussed above the key areas of the study: the importance of R&D in construction industry (see Section 4.3.1); issues within construction R&D (see Section 4.3.2); need of PM for effective construction R&D (see Section 4.3.3); and focusing PM on the CSFs of construction R&D (see Section 4.3.4) was established through a comprehensive literature review. Thereafter, by incorporating the aforementioned key areas, the conceptual framework pertaining to the study was drafted. Next, two expert interviews were carried out to further refine the conceptual framework. The section below discusses the views of the experts regarding the subject area under consideration for this study and on the drafted conceptual framework.

4.4 Expert opinion

The study carried out two expert interviews to identify critical issues which need to be investigated from this study. Further, the conceptual framework developed through the literature review was refined through the expert interviews (see Section 3.2.3).

4.4.1 Importance of performance measurement for construction research & development

The interviewees acknowledged the importance of PM within construction R&D function. One of the interviewees suggested the use of PM as a means of showing the value for money of the construction R&D activities. *"I think it (PM) is needed, because it does provide the focus"* stated another interviewee. However, he highlighted the importance of getting the *"philosophy of PM"* clear and understandable. *"… If you are to look at performance, you can adopt a number of philosophies; you can measure the process, the output or combine the process with the output"*. Rather than concentrating purely on the output of R&D activities, he emphasised the need of measuring the whole process. *"If you are trying to measure outcomes, then you are driving the behaviour, you are driving the system to behave in a way that would generate the outcomes. In academic terms you are looking at papers, everybody can generate papers, so what! However, if you start measuring the process itself, then you are more likely to influence a better outcome. Not in quantity terms, but in quality terms."*

4.4.2 Establishing correct targets for measurement

As much as the importance of PM within construction R&D, setting up correct targets for measurement was equally highlighted by the interviewees. "*There is a role for measurement; rather it's a tool for managing…you need to define what is success for your project. Therefore, getting the right targets is very important"* commented one of the interviewees. They believed that failure to set up correct targets could end up in directing the R&D activities towards unnecessary areas and de-motivating the people when the desired targets are not achieved. One of the interviewees explained this *"Sometimes when the targets are not met, the capabilities of the team are actually developing in a very good way. So you cannot* *say, well I didn't meet one target, therefore I failed... and there have been other instances, where the targets are being over achieved, but you feel that you are not developing the capabilities. So you need to set out the targets in a very contextual manner"*.

4.4.3 Collaborative research work

The interviewees differentiated the views and capabilities of university and industry oriented research. *"…the universities are very effective in formulating ideas and proposals. The practitioner community knows about issues, knows about problems. It doesn't necessarily know how to address those in effective ways that can shape up the research activity"* stated one interviewee. Similarly, another interviewee stated that industrialist tends to be more tasks driven but lacks skills which academia tends to have. As a whole, the interviewees acknowledged the importance of collaborative research work. *"There are two aspects of research I think. The theoretical aspect as well as the practical aspect…some people might say innovation should come from outside the industry, from academia because industry is too busy doing things. Some people might say innovation should come from industry because they know what there requirements are and what they need*" commented one interviewee noting down the different drivers for research activities. Thus, he believed that the partnership between university and industry could yield many benefits as such partnerships could combine theory with practical knowledge.

4.4.4 Research and development process

In addition to the importance of PM, identifying the correct targets for the measurement, the construction research base and the importance of collaborative research work, the interviewees commented on the drafted conceptual framework. However, when questioned about the sequential approach of the R&D process in the draft conceptual framework, one of the interviewees commented *"in the traditional approach, we have the phases like initialisation, conceptualising, development and launch. What we normally found with that is we have to go back anyway and have lots of iterations. That refinement is very useful for the success… So we tend to adopt a more flexible approach, something like a flexible stage gate approach"*. However, the presence of the phases was acknowledged by the interviewees. *"I think the gates* *(phases) still provide the focus in terms of what's being delivered…but the way in that's being achieved need to be more flexible"* stated one of the interviewees.

From this section, the expert opinion was gathered and the following factors were elaborated: the importance of PM in construction R&D; the need of measuring the performance of the construction R&D; the need of establishing correct targets for PM; benefits of research partnerships between universities and construction industry partners; and the iterative process of R&D activities. The section below discusses the amalgamation of the key areas extracted from the literature review and expert opinion to develop and refine the conceptual framework of this study.

4.5 Development of the conceptual framework

As discussed in Section 4.2, a conceptual framework comprises of three main components as follows:

- the main concepts;
- their inter relationships and;
- the boundary.

This section details the inclusion of key areas elicited from literature and expert interviews to construct the constituent parts and thereby develop the conceptual framework pertaining to this study.

4.5.1 Main concepts

As derived from literature, the need of PM was further acknowledged by the interviewees in minimising the inherent issues within construction R&D activities and to improve the effectiveness and efficiency of R&D activities. The interviewees supported the measurement of performance by considering the R&D process rather than the outcome as such measurement implementations would be able to identify how a better process could lead to better outcomes. Further, if PM is focused only on the R&D output, it will utilise lagging indicators and would enclose the drawbacks associated with the lagging performance indicators as discussed in Section 2.5.3. However, PM focusing on the output and the process leading to the output would utilise both lagging and leading indicators. Accordingly, the leading indicators would depict any shortcomings of the R&D process and indicate any negative impacts, which could affect success of R&D the outcome.

Moreover, the importance of identifying the correct targets for PM was highlighted from the literature as well as from the expert opinion. It was revealed that failure to identify the correct targets could lead to either measuring unimportant aspects of performance or delivering incorrect information to the system which in turn could result in deviating from the original objectives of the project, non achievement of the deliverables, poor quality of the work and de-motivating the team members. Though it is good to have separate phases for ease of referencing and to understand the activities involved at each phase (see Section 2.2.3), the interviewees believed that the R&D process should be a flexible one to accommodate new developments and reflections, which could encounter during the ongoing process. The iterative process of R&D activities could refine, revise, identify potential improvement areas, thus ultimately develop the successfulness of R&D activities. Furthermore, it was identified from literature the important role played by the stakeholders of construction R&D activities (see Section 2.4.5) and how the dissatisfaction of the stakeholders has negatively impacted upon the construction R&D activities such as lack of contribution from the industrial partners, low level of investments from the funding bodies, lack of applicability of the research results etc.

Based on the above synthesis the main concepts of the conceptual framework was identified as: the R&D function (see Section 3.3.3.2); issues within construction R&D; CSFs; PM; and stakeholder involvement. In the initially drafted conceptual framework, the management activities needed for the R&D activities were inbuilt within the four phases of the R&D function namely; initiation, conceptualising, development and launch. However, to reflect the iterative process of the construction R&D activities (such as continuous reviews, monitoring, controlling, communication, feedback etc.), the project management activities were added separately.

Having identified the main concepts of the conceptual framework, the section below explains the relationships between these concepts.

4.5.2 Relationships between the concepts

As the second step of the development of the conceptual framework, the relationships between the concepts were identified. The conceptual framework highlights the contribution from the stakeholders involved within the R&D function for the new venture to be successful. Further, the framework identifies the issues and CSF governing the new venture during its lifecycle. Next, the model denotes the implementation of PM within the R&D function targeting the CSFs, which would in turn improve the efficiency and effectiveness of the R&D activities, minimise the issues while improving the satisfaction of the stakeholders involved in.

4.5.3 Boundary/scope of the study

The next step of the development of the conceptual framework was to identify the scope or the boundary within which the concepts and their inter relationships are true. It was revealed from literature review that collaborative research work has the benefits such as increased applicability of the research results to the industry, knowledge transfers and sharing of good practices within the collaboration, creation of long-term research partnerships, which could result in more investments for R&D activities etc (see Section 2.4.4). Similarly, the experts highlighted the benefits of collaborative research work between universities and industry as such could merge the theoretical aspects of research with practice (see Section 4.4.3). Accordingly, collaborative research work was identified as the boundary of this study.

By incorporating the main concepts (see Section 4.5.1), their inter relationships (see Section 4.5.2) and the boundary of the study (see Section 4.5.3), the conceptual framework was drafted and refined to reflect the expert opinion as shown in Figure 4.2.

4.6 Conceptual framework

Figure 4.2 depicts the conceptual framework developed and refined through the literature review and expert opinions. The core of the framework represents the unit of analysis of the study: the R&D function. Black arrows indicate the stakeholder contribution towards the construction R&D function whilst the red arrows indicate the performance improvements of the R&D function. Blue and green arrows denote the issues and CSFs the R&D function respectively. The framework highlights the contribution from the stakeholders involved within the R&D function for a new venture to be successful (from the black arrows). Further, it identifies issues (from blue arrows) and critical success factors (from green arrows) governing the new venture during its lifecycle. Next, the framework illustrates the implementation of PM within the R&D function focusing on the critical success factors. Finally, the conceptual framework indicates the influence of PM towards successful construction R&D activities (from the red arrows). It indicates the communication of information regarding the R&D function (e.g.: the progress of R&D activities, allocation and utilisation of resources, commitment of the parties involved and achievement of the milestones, deliverables etc.) to the stakeholders involved in the R&D function. In addition, feedback provides on the success/failure of R&D function is also illustrated.

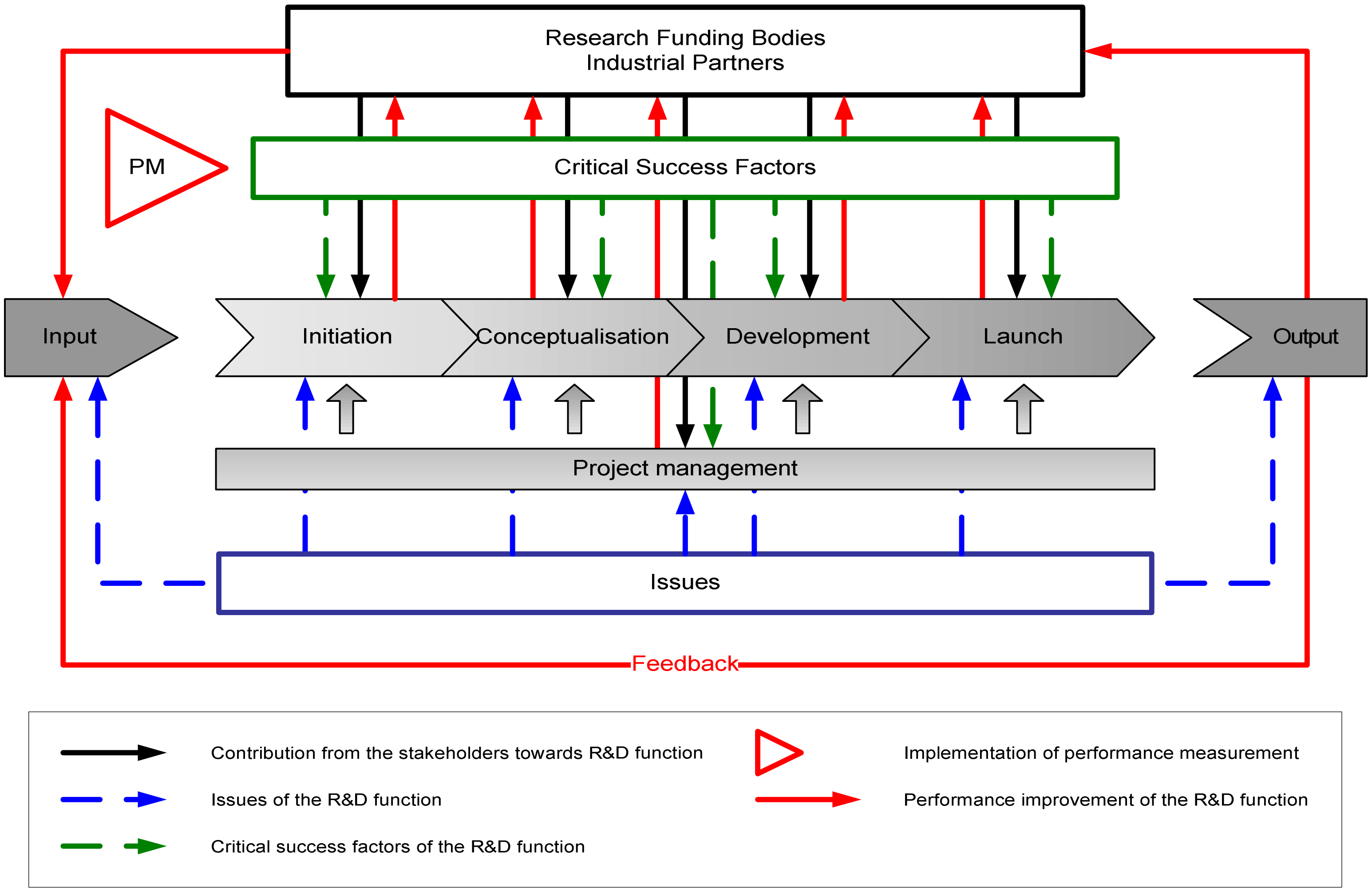


Figure 4.2: The conceptual framework

4.7 Summary and link

This chapter discussed the procedure adopted to develop the conceptual framework of this study by identifying the main concepts, their inter relationships and the boundary of the subject area under consideration. The components of the conceptual framework were extracted from the literature review and were supported with expert opinions. The conceptual framework illustrates the influence of PM within construction R&D function to enhance the success of construction R&D activities while satisfying the stakeholders. Further, it denotes the main areas which will be empirically investigated during the case study. Having developed the conceptual framework of the study, the next chapter presents the data analysis and synthesis and the findings of the empirical investigation using the single case study research approach.

CHAPTER 5 DATA ANALYSIS AND RESEARCH FINDINGS

5.1 Introduction

Chapter 4 discussed the development of the conceptual framework pertaining to the study. This chapter presents the data analysis and findings of the case study. The chapter is structured as follows:

- First, the background information about the case study is given, followed by the main stages and key activities of the case study.
- Second, analysis and the research findings of the exploratory stage are presented. Accordingly, the influence of Performance Measurement (PM), Critical Success Factors (CSFs), and existing performance evaluation methods of the construction R&D project when it follows the R&D function are explored and summarised.
- Third, the development of the Performance Measurement System (PMS) to measure the performance of construction Research and Development (R&D) function is presented.
- Fourth, the refinement of the PMS through a series of semi structured interviews is presented.

5.2 Background information in relation to the case study

UNRI is a UK university based research institution in the field of the built environment. In 1996 and 2001, UNRI was awarded a 5* rating at the Research Assessment Exercise (RAE). Since 2001, UNRI has been recognised as a 6* rated research institute. The institute is internationally recognised for its research activities and has national and international partners from both industry and academia. UNRI has three main research themes namely: Information and Communication Technology which focuses on improving capabilities through technological innovations; Management which focuses on optimising organisational performance; and Environment which focuses on enhancing quality of life and governance. UNRI comprises nine research centres which carry out research in the areas of healthcare; acoustics; learning and teaching in the built environment including construction, surveying and real estate; physical geography and environmental science;

information technology in construction; management; sustainable urban and regional futures; accessibility and disability; and urban quality.

One of the major assets of UNRI is its post graduate research community. The post graduate researchers of UNRI are offered a number of programmes such as PhD, MSc and MPhil which can be studied on a full time, part time and split-site basis. The areas of study of the UNRI's post graduate community vary from fundamental theory to applied research. Currently, there are about 170 PhD students and 116 academic staff within UNRI. The researchers and staff of UNRI have produced more than 300 journal articles, 600 conference papers, 50 major project reports and have supported approximately 200 research events over the past years. The funding sources for UNRI are from government bodies, research councils, and industry.

The vision of UNRI is to play a leading role in setting the built environment research agenda both nationally and internationally through innovative, fundamental and real-world research. In this respect, knowledge creations of the parties involved in research activities and delivering research output that is applicable to the wider community, including the industrial needs is significant.

Having, briefly identified the details of the university based research institute which leads the collaborative research work related to the case study, the section below discusses the stages and key activities involved within the case study.

5.3 Stages and key activities of the case study

The case study research approach pertaining to this study consisted of three main stages namely; exploratory; development of the PMS; and explanatory (see Figure 3.10). Throughout the case study, two series of semi structured interviews: firstly, at the exploratory stage and secondly, at the explanatory stage, were carried out. Further, a questionnaire survey was distributed at the exploratory stage of the case study. The objectives of the different stages of the case study are illustrated in Figure 3.10.

5.4 Exploratory stage

This section provides the data analysis and findings of the exploratory stage based on the data collected through semi structured interviews and the questionnaire survey. This consists of four sub sections: identification of the influence of PM on construction the R&D project which follows the R&D function (see Section 5.4.1); identification of CSFs of the construction R&D function (see Section 5.4.2); the implementation of CSFs at the R&D function (see Section 5.4.3); and status of the application of PM, performance indicators and measures (see Section 5.4.4).

Thirteen semi structured interviews were carried out during the exploratory stage of the case study and Principal Investigators' (S1- PI), Researchers' (S1-R) and Industrial Partners' (S1-InP) views were gathered (see Table 3.4 for the descriptions and codes of the interview participants).

5.4.1 Influence of performance measurement on construction research and development

Within this section, the academic members' and industrial partners' views regarding the influence of PM in construction R&D projects are discussed. The data collection medium used was semi structured interviews (see Appendix F for an interview transcript). For each section, the coding structures obtained from NVivo software and the cognitive map obtained from decision explorer software are provided. Following them are the descriptions pertaining to each section. Finally, the empirical data is synthesised.

5.4.1.1 Positive influences of performance measurement on construction research and development: academic members' perspective

This section discusses the academic members' perspective regarding the benefits that could be obtained from PM within construction R&D projects. Figure 5.1 and Figure 5.2 present the coding structure and the cognitive map related for this.

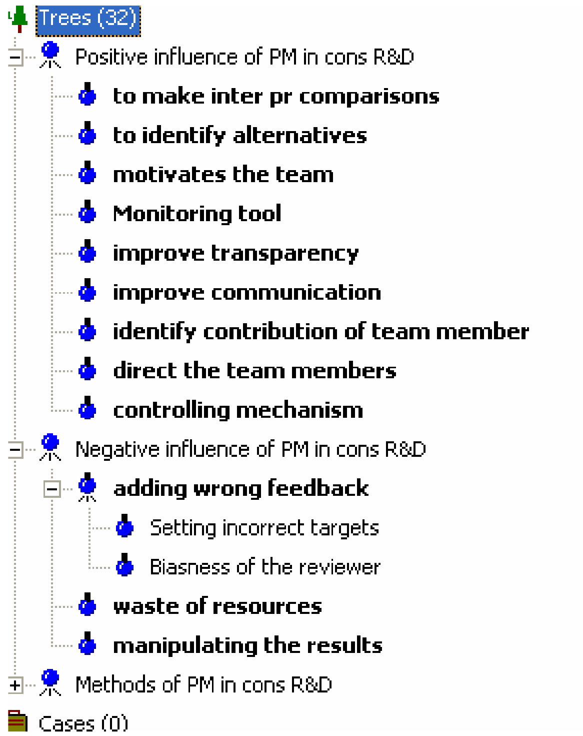


Figure 5.1: Coding structure on the academic members' view on the influence of performance measurement in construction research and development

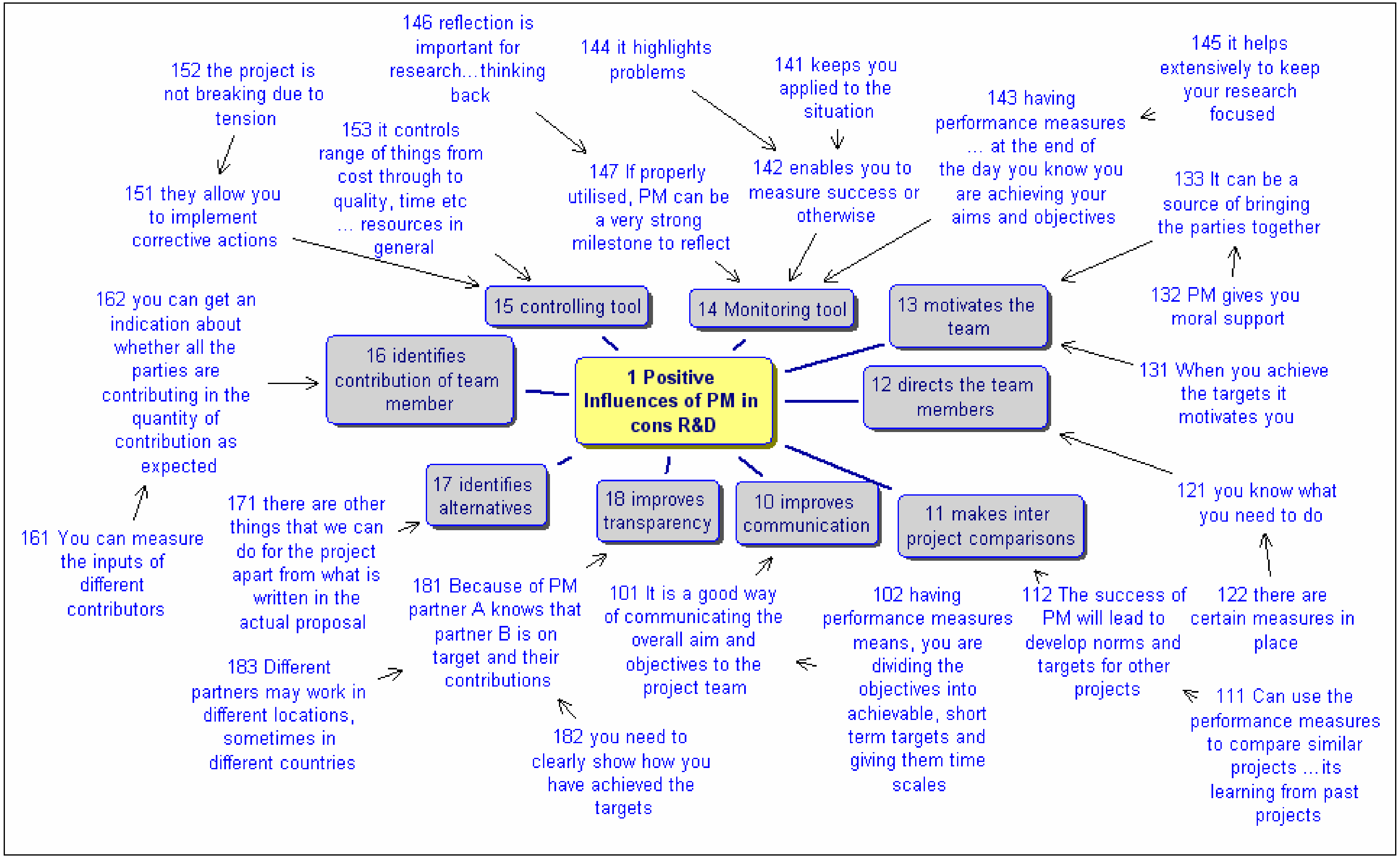


Figure 5.2: Cognitive map on the academic members' view on the positive influences of performance measurement in construction research and development

As shown in Figure 5.2, S1-R1 stated that PM keeps the R&D project in focus without deviating from the overall aim and objectives (145 and 141). Further, when the performance measures are in place, they reveal whether or not the project has achieved its target and highlight any lagging areas in comparison with the set targets (144, 142, 143). Thus, S1-PI3 pointed out*"… it (PM) keeps you applied to the situation, it enables you to measure success or otherwise" (141, 142).* Further, PM helps to identify the lagging areas of the R&D project in terms of achieving its aims and objectives stated S1-PI3 (144). Thereafter, corrective actions can be taken for the R&D project. S1-PI1 stated *"Obviously it (PM) allows you to implement corrective actions that are needed to make sure the project is not breaking due to tension*" (152). S1-PI3 also agreed with this view and added that PM can control the resources such as time, cost and quality (153).

S1-R1 saw PM as a means to identify future improvement areas required for a project (171). He stated *"In order to achieve the performance measures, there may be so many other things outside the proposal that you can do towards the success of the project. The measures itself gives us the indication apart from the activities written down in the document, these things could lead to a better project"*. Similarly, S1-R2 suggested that PM helps to think back and make reflections on the successful achievement of the targets (147, 146). Identification of the contribution from the different team members was revealed as another benefit of PM within the construction R&D project (161, 162). As observed by S1-PI1 *"You can measure the inputs of different contributors and …at least you can get an indication about whether all the parties are contributing in the quantity of contribution as expected" (162)*. S1-PI4 stated that within a particular R&D project, there can be partners from different locations and even from different countries (183) and only at certain deliverable stages will all the partners get together. S1-PI4 claimed that as a result of PM, the partners get to know what the others have contributed towards the project and whether the project is progressing as planned (181, 182).

S1-R2 commented *"… there are certain measures that are in place, you know what you need to do to achieve those measures"*, thus viewed PM as a way of guiding the team members towards the objectives of the project. Agreeing with this view, S1-PI5 identified PM as a means of communicating the overall aim and objectives to the project team (101, 102). He added "… *having performance measures means, you are dividing the objectives into achievable, short term targets and giving them time scales" (102).* Adding to the above, S1-R2 viewed the achievement of performance measures as a motivational factor for the team. He said *"when you achieve the targets, it (PM) motivates you, it gets the lazy man going" (131).* S1-PI5 also had similar views on PM. He mentioned *"PM gives you the moral support especially, when the performance is good…it (PM) motivates you and can be a source of bringing the people together" (132, 133).* S1-PI4 identified PM as a valuable source for making inter project comparisons (111). Further, S1-PI4 added that *"success of PM will lead to develop norms and targets for other projects*" (112).

Having identified the academic members' perspectives on the benefits of PM, the succeeding section looks into the industrial partners' perspectives.

5.4.1.2 Positive influences of performance measurement in construction research and development: industrial partners' perspective

Similar to the academic members' view about the contribution of PM towards motivating the research team members, industrial partners too recognised PM as motivational tool (see Figure 5.3 and Figure 5.4). S1-InP2 suggested that *"If used properly they (PM) should always be an encouragement, because good knowledge tells you where you are and it allows you to adjust your efforts accordingly. So good performance measures should encourage success, celebrate success and should lift the moral"(321).* Acknowledging the monitoring and controlling mechanisms of PM, S1-InP2 added that PM helps to modify and adjust the future plans based on the actual and current state of the R&D project (343, 342, 341). Supporting this view, S1-InP1 stated *"I suppose it (PM) will tell you how well you have done, they should be the indicators of whether you are successful or not and the impact the researchers had…and ultimately PM will show you are on time, to the budget and the influence the project has made" (311, 312).*

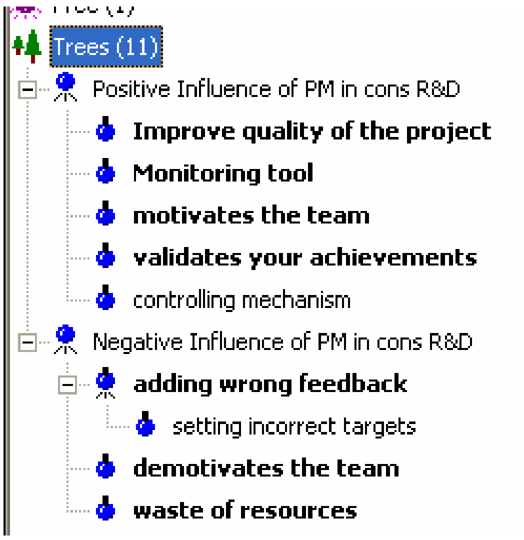


Figure 5.3: Coding structure on the industrial partners view on the influence of performance measurement in construction research and development

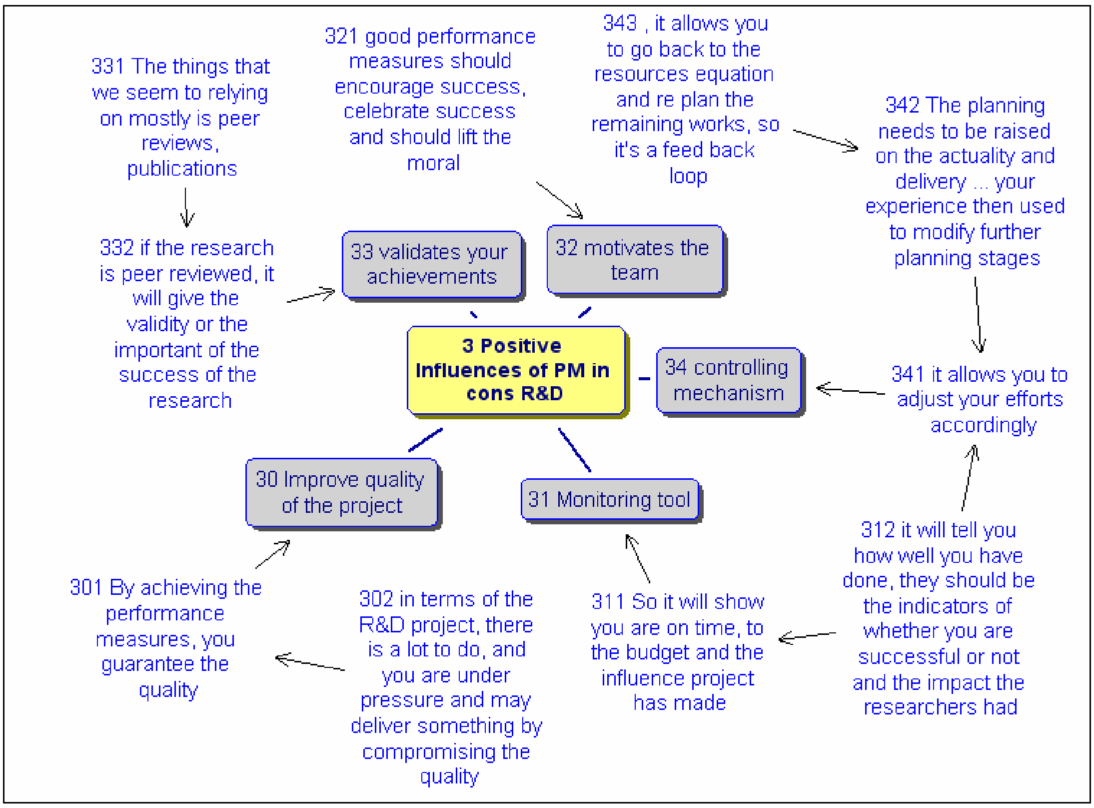


Figure 5.4: Cognitive map on the industrial partners' view on the positive influences of performance measurement in construction research and development

S1-InP3 asserted that, within R&D projects, there are number of activities which need to be done. Thus, within the busy schedules and various activities, the quality of the project could be neglected (302). But, when the performance measures are in place, by achieving them, the expected quality of the project is delivered (301). As asserted by S1-InP1, peer reviews and publications are common performance measures used in construction R&D work (332, 331) which again, ensure the achievement of required standards for the project.

Having revealed the industrial partners' perspective regarding the benefits of PM, the following section discusses the negative influences of PM in construction R&D project.

5.4.1.3 Negative influences of performance measurement in construction research and development: academic members' perspective

Although there are a number of benefits of PM within construction R&D it also revealed several negative influences (see Figure 5.5). One such negative influence of PM is associated with the bias of the reviewer (203). S1-PI3 stated the method of interpretation, writing of reports and arriving at conclusions can vary depending on personnel views (202).

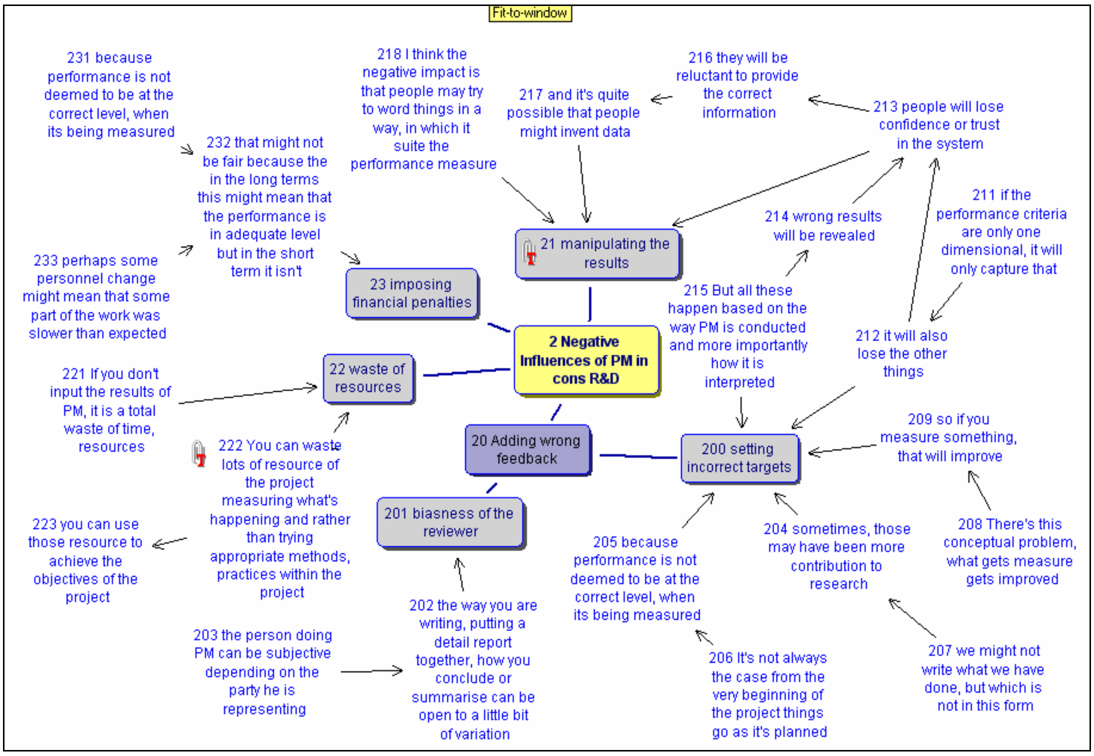


Figure 5.5: Cognitive map on the academic members' view on the negative influence of performance measurement in construction research and development

Some academic members' noted that PM could waste resources, especially if it is only used to measure what's happening in the project rather than trying to use appropriate methods and practices to address the objectives of the project (222). Further, S1-PI5 pointed out that the resources used for PM could be used elsewhere to address the aims and objectives of the project (223). Thus, he added *"…So you have got to strike a balance between implementing the right performance measures, which need to be efficient in themselves, you don't need them to consume too many resources and energy in measuring what's going on rather than applying"*. According to S1-PI5, if the results of PM are not used for the R&D project, i.e. when there is no feedback from PM to the R&D project, the whole process of PM could become a waste of resources (221).

S1-R2 identifies that using incorrect targets within PM could result in adding wrong feedback to the system (211, 212, 208, 209) and could overlook other important contributions for the research (207, 204). He asserted *"But all these (benefits of PM) happen based on the way PM is conducted and most importantly how it is interpreted"*. He goes on to say "*you see what you want to see. If you are looking for a particular thing, if the performance criteria are one dimensional, it will capture only that. But it will also lose the other things" (211, 212).* Furthermore, during certain periods of time, S1-PI4 stated that the performance of the R&D project could be lagging (231, 206). But, in the long run, the project could recover and perform as required. If wrong feedback is revealed due to incorrect targets, S1-R2 declared that the team members could become de-motivated and may loose confidence and trust in the system (214, 213). Furthermore, people could *"invent the data"* claimed S1-R2 (217). Agreeing with this S1-R3 also asserted that people could manipulate the results to show the appropriateness of data (218).

5.4.1.4 Negative influences of performance measurement in construction research and development: industrial partners' perspective

This section discusses the negative influences of PM in construction R&D projects according to the industrial partners' perspective (Figure 5.6). S1-InP2 identified PM as a time and resource consuming task, especially if PM needs a separate person to do the reviews (422). Furthermore, in agreement with the views of the academic members, S1-InP2 also suggested that for a successful outcome the result of PM should be properly utilised or the efforts could result in a waste of time and resources (421). As opposed to demonstrating that good performance motivates a team, S1-

InP2 stated *that "they (PM) can identify poor delivery, which can lead to moral issues, frustration and the performance can be damaged thereafter" (411).* S1-InP1 saw lack of appropriate and measurable targets as a weakness of the system (432). He added, *"self fulfilling prophecy so you set targets you want to achieve. It's a bit like the staff appraisal system, you really want to set some targets you know are easy to achieve, or you would be able to report successfully" (434).* S1-InP2 suggested that such targets may not be the correct performance measure as they are not developed rigorously or independently but based on the personal interest (435).

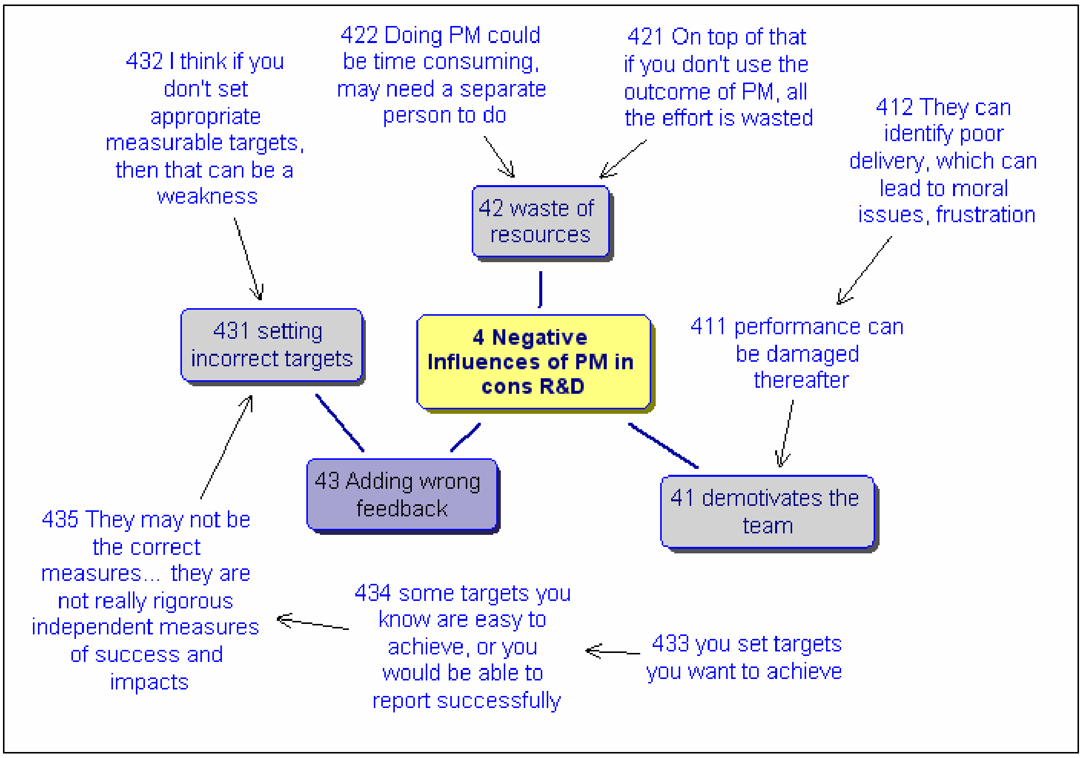


Figure 5.6: Cognitive map on the industrial partners' view on the negative influence of performance measurement in construction research and development

5.4.1.5 Synthesis on the influence of performance measurement in construction research and development

Section 5.4.1 looked into the positive and possibly negative influences of PM in construction R&D projects. Table 5.1 presents the key concepts elicited from the above analysis and this section synthesises these key concepts.

Table 5.1: Influences of performance measurement in construction research and development

Positive influences of PM in construction R&D	Negative influences of PM in construction R&D
Academic members' perspective	
Monitoring and controlling tool Motivates the team Directs the team members Facilitates inter project comparisons Improves communication Improves transparency of the work Identifies alternatives Identifies contribution of team members	Manipulation of the results Adds incorrect feedback due to setting incorrect targets/ Adds wrong feedback due to biasness of the reviewer Waste of resources
Industrial partners' perspective	
Monitoring and controlling tool Motivates the team Validates the achievements Improves the quality of the project	Waste of resources De-motivates the team members Adds wrong feedback due to setting incorrect targets

Continuous monitoring and controlling is important for the success of construction R&D projects. Accordingly, PM helps to monitor the R&D activities and keep the team focused on the targets that they need to achieve. When the performance measures are in place, achieving them shows that the project objectives are fulfilled and the project is moving forward as expected. As stated by S1-R1 *"it (PM) helps extensively to keep your research focused, without that your research can go all over. So by having performance measures … you know that at the end of the day you are achieving your aims and objectives"*. Furthermore, failure to achieve the set targets/ performance measure indicates the lagging areas within the R&D project. Identifying lagging areas could direct the project team to take corrective measures such as allocation of additional resources, or even to re-base/ re-plan the set targets based on current performance. Taking corrective measures promptly ensures that the

R&D project would not arrive at a situation where it is impossible to retrieve the situation. Thus, continuous monitoring and controlling by PM ensures the smooth flow of work and that the output is aligned within the set aim and objectives of the project. This increases stakeholder satisfaction by indicating their requirements and expectations are properly addressed, and getting the value for money and commitment, that they are investing in. It was identified in Section 2.4.5 that funding bodies and industrial partners are reluctant to invest and contribute to construction R&D activities as a result of non achievement of expected targets. Thus, utilisation of PM within construction R&D projects would minimise such issues as the project goes from initiation to launch phase. Achieving expected targets would reassure funding bodies and help to provide continued funding for future projects. Furthermore, the satisfaction of industrial partners' requirements would create long term research partnerships and provide effective contributions throughout the R&D project leading to production of results with more applicability. As part of the monitoring and controlling process, PM helps to report on the success of achieving the targets, analyse any lagging areas and reveal the utilisation of resources. In Section 2.4.5 it was identified that due to improper reporting mechanisms, the parties involved within R&D projects do not have a clear understanding of its status thus, the importance of creating clear and visible links between the R&D spending and their impact was highlighted. Section 2.6.2 indicated that the accountability of R&D investments has increased due to the interest of investors and shareholders on knowing the utilisation of R&D resources. Therefore, as discussed above, PM would improve the reporting structure of R&D projects and would show how R&D investment is used thus, enhancing the success of R&D activities.

Moreover, PM was claimed as a milestone for the reflection of activities. As part of monitoring and control, PM helps to reflect on the achievement of targets, their success or failure, whether there would have been alternative ways of achieving those targets and how those targets have contributed to the overall success of the project. Such reflections are important in further improving the current R&D project and can be used to make improvements for other R&D projects. Thus, PM leads to continuous improvement of R&D projects. In addition, the case study revealed that PM helps to identify the contributions of team members. In Section 2.4.5 the importance of accessing the contribution of the team members in R&D projects was noted. This fact was further highlighted by S1-PI1 who stated that identification of such contributions from team members is important from the funding body's point of view in order to ensure value for money. Identification of the contribution of different parties leads to another benefit of PM; that of improving the transparency of the work. In a R&D project, there can be partners from different locations even from different countries. Within that scenario, PM improves the transparency of the work by demonstrating the utilisation of resources and showing the contribution of parties towards the success of the project.

When performance measures are put in place with their time lines, team members can concentrate on those and plan the work accordingly thus directing team members towards achieving the targets within their given time frame. It was revealed that having short term targets was a successful way of achieving the overall objectives of the project. As stated by S1-R1 *"Generally it is good practice to have a set of small activities combine together to formulate the big project. We are terming it in our research projects as work packages. In work package what you do is, you get a set of activities to be completed within a certain time period, and that work package is designed as a mini project. So while achieving all the aims and objectives and their timelines and milestones everything, ultimately we are making sure that the big project aims and objectives are met within the given time periods"*.

PM is a motivator for the project team as the achievement of the performance measures indicates the project is progressing smoothly. Hence, PM was identified as a means of bringing people together to celebrate the success of the project. In addition to this, PM acts as a *"quality controller"* by ensuring the R&D project accomplishes the expected standards. When the quality parameters are set out within the performance measures, achieving those measures shows that the project is well within the required standards set. Also, PM helps to validate the findings of the project through peer reviews, publications, citations and demonstrates that the results of R&D work are acknowledged and appreciated by the wider community. Moreover, the case study revealed that PM aids the improvement of communication within the R&D project. Through the performance measures, the project team is aware of the overall objectives of the project. Further, due to the PM, the project team are familiar with the progress of the R&D project: whether the project is heading towards its objectives or not.

It was identified from the literature review (see Section 2.5.2 and 2.6.2), that PM has a number of advantages. Similar to general and R&D specific literature on the benefits of PM, the above discussion from the empirical investigation suggested that there are number of influences from PM towards construction R&D activities.

Besides the benefits of PM, a number of negative influences were also revealed. If the results of PM do not become part of the R&D project, the process of PM will not add value to the R&D project. This demonstrates the need for providing feedback from the PM results to the R&D project thus, making PM an integral part of the R&D project. It was discussed that time and other resources consumed for PM could be used elsewhere to achieve the objectives of the project. S1-PI1 stated *"You can waste lots of resource of the project measuring what's happening and rather than trying appropriate methods, practices within the project. This can distract you from what you should be doing*". This highlights the need for developing efficient and effective performance measures which would not consume extensive time and manpower. As identified within the literature review (see Section 2.5.3.1 and 2.6.3), the existence of a large number of performance measures could create problems in time and resource consumption and create difficulties in integrating them within the organisational performance making the implementation of PM complicated. Thus, developing performance measures based on a few key factors which drive the R&D performance is important. Such selection would not only minimise the time of PM process but also yield maximum benefits by indicating the success or failure of those key factors. In addition to this, setting incorrect targets as performance measures could result in the wrong information being feed into the system. Hence, when selecting the performance measures, it is important to consider the requirements and expectations of the project and parties involved in the project. The development of performance measures based on a few key factors of performance and selecting the correct targets are referred in the literature review (see Section 2.7.1) and in the expert opinion (see Section 4.4.2) which corroborates the importance of identifying the CSFs of construction R&D for the design of performance measures. If the performance measures can be derived from the success factors of the construction

R&D function, it would ensure the achievement of the success factors and thereby ultimately achieve the research objectives (see Section 5.4.2 for the identification of CSFs of construction R&D).

Case study further identified that incorrect timing of PM could result in adding incorrect feedback to the system. Therefore, in addition to the selection of efficient and effective performance measures, the correct timing of measurement must be emphasised for PM to be successful. Where good performance motivates team members, poor performance could de-motivate the project team. Furthermore, presenting results that are subjective due to the bias of the reviewer and lack rigour and good background knowledge to formulate the norms of performance measures affect the effectiveness of PM applications. Therefore, the formulation of performance measures based on previous knowledge and experience can be emphasised.

This section synthesised the influence of PM on construction R&D projects. In discussing the negative influences of PM the importance of making PM an integral part of the R&D project so that it acts as a feedback loop was suggested. Selection of efficient and effective performance measure, correct timing of performance reviews and selection of performance measures based on previous knowledge and experience was also considered essential. Most significantly, the importance of choosing the correct target/ performance measures was highlighted. The section below evaluates the case study findings on the CSFs of construction R&D projects.

5.4.2 Critical success factors for construction research and development function

From the general and R&D related literature, it was discovered that the use of multiple performance indicators has sometimes created confusion and makes the PM applications complicated due to the presence of large numbers of performance indicators (see Sections 2.5.3.1 and 2.6.3). Therefore, choosing the performance indicators to reflect the critical factors behind performance improvement is emphasised. Since, what is measured is presumed to be important, the *"measurement process"* affects the behaviour of the team and how they observe or overlook critical factors related to the performance and this could also influence the team in deciding what future actions are required. . This is reflected in the well-rehearsed adage *"what gets measured gets done"* thus what is not measured tends to be ignored. This highlights the importance of setting and measuring the *"correct targets"* of performance, and the areas where the management wants to concentrate or improve on. Failure to set correct targets/ performance measures could result in generating either unnecessary or incorrect information about the performance. Accordingly, the identification of setting correct targets for the PM was well established from the literature review (see Section 2.7.1) and from expert opinions (see Section 4.4.2). This fact was also highlighted at the exploratory stage of the case study (Section 5.4.1.5). The interviewees asserted that formulation of incorrect targets could result in providing incorrect information about the performance (see Sections 5.4.1.3 and 5.4.1.4). With this in mind this section explored the CSFs of construction R&D project as it goes through the Initiation (Section 5.4.2.2), Conceptualisation (Section 5.4.2.4), Development (Section 5.4.2.6), and Launch (Section 5.4.2.8) phases and at the project management (Section 5.4.2.10) to ascertain factors which could lead the R&D work towards achieving its objectives by providing correct targets for performance measurement.

As the first step for identifying the CSFs, 13 semi structured interviews were carried out (see Table 3.4 for the details of the interviewees). By using the NVivo software, the interview transcripts were coded to identify the success factors (see Section 3.4.1.3.2 and 3.4.1.6.2). In addition to the semi structured interviews, an extensive literature review was carried out on the CSFs in other disciplines (see Section 2.7). Following the identification of the success factors pertaining to each phase of the R&D project, the second step was to prepare a questionnaire (see Section 3.3.4.3.2). The questionnaire (see Table 3.6 for the response rate), asked respondents to identify the importance of the success factors and the extent of implementation of the success factors during the different phases of the R&D function (see Appendix G for the questionnaire).

The responses received from the questionnaire regarding the importance of the success factors were initially analysed by using their mean value (see Section 3.4.2.3.1). The overall mean value and academic members' and industrial partners' mean values regarding the importance of the success factors were calculated and based on the overall mean value the success factors were ranked (e.g. : Table 5.3). After ranking the success factors, two filtering stages were used to derive the CSFs: firstly by considering the overall mean value (see Section 3.4.2.3.1) and secondly based on the Wilcoxon signed rank test results (see Section 3.4.2.3.2). During the first filtering stage, the success factors with a mean value of less than 4 were excluded from further analysis as they were considered not to be critical to the success of the construction R&D function. This elimination was done as the factors with a mean value less than 4 belong to unimportant (value 1), of the little important (value 2) or moderately important (value 3) based on the assigned values of the questionnaire survey analysis (see Table 3.5). In the same way as this study, Sun and Wing (2005) also used mean value to identify the CSFs. Following this, during the second filtering stage Wilcoxon signed rank test was used for the remaining success factors i.e. the factors which have an overall mean value above 4. By taking a consecutive pair of data, the Asymptotic significance (Asymp. sig.) was calculated. The paired data which showed an Asymp. sig. < 0.05 was considered as not critical (see Section 3.4.2.3.2 and example in Table 5.3). It should be noted that when presenting the Asymp. sig. related to a consecutive pair of success factors, the relevant figure was indicated as shown in Table 5.2.

Table 5.2: Presentation of the asymptotic significance in tables

Success Factors	Academia	Industry Partners	Total		Asymp. Sig.
	Mean	Mean	Mean	Rank	
Factor 1				1	
Factor 2				2	0.07
Factor 3				3	0.51

Asymp. Sig. of Factor 1 and 2

After identifying the CSFs from the above process, they were grouped based on their similarities for ease of analysis. Although the researcher initially used factor analysis to group the CSFs, identification of terminology for the principle components extracted from the factor analysis became a difficulty. Thus, the researcher had to group them according to their similarities.

Furthermore, to identify whether there is a significant difference between the perspectives of academic members' and industrial partners' regarding the CSFs of construction R&D function, Mann Whitney U test was used (see Section 3.4.2.3.3). The CSFs which obtained an Asymp. sig. < 0.05 was considered as having a significant difference of perception between academic members and industrial partners.

In this context, the following sections on the CSFs are structured as follows. Firstly, the section identifies and ranks the CSFs based on the questionnaire survey findings. Secondly, the identified CSFs are analysed by referring to the details gathered from the semi structured interviews from the case study. Further, literature findings are used to consolidate the findings of the empirical investigation. When presenting the findings, the details of the semi structured interviews are supported with the NVivo coding structure and cognitive maps.

5.4.2.1 Critical success factors during the initiation phase

Table 5.3 shows the academic members' and industrial partners' responses regarding the importance of the success factors at the initiation phase. The results were ranked according to the overall mean value of the respondents.

Table 5.3: Ranking of the success factors at the initiation phase

Success Factors	Academia	Industry Partners	Total		Asymp. Sig.
	Mean	Mean	Mean	Rank	
Establish the research problem clearly	4.74	4.85	4.79	1	
Commitment of the principal investigator	4.59	4.52	4.56	2	0.06
Selecting a competent team	4.50	4.44	4.48	3	0.51
Leadership of the principal investigator	4.35	4.19	4.28	4	0.08
Consider industrial partners' requirements	4.03	4.56	4.27	5	0.99
Consider funding bodies' requirements	4.29	4.22	4.26	6	0.87
Understand the market and its dynamics	4.21	4.04	4.13	7	0.45
Consider researchers' requirements	3.85	3.70	3.79	8	

It can be seen that the importance of focusing on the researcher's requirements have received an overall mean value less than 4. Therefore, it was excluded from further analysis and rest of the factors were subjected to the Wilcoxon signed rank test. As can be seen from the Table 5.3, when subjected to the Wilcoxon signed rank test to identify the demarcation point of the CSFs, all the factors showed an Asymp sig > 0.05. This indicates the respondents' views regarding the importance of the remaining seven success factors are not significantly different at 5% significant level. Thus, the factors ranking 1-7 were considered as critical for the success of construction R&D project during the initiation phase.

Table 5.4: Difference in opinion of the academic members and industrial partners at the initiation phase

Success factors at Initiation	Asymp. Sig.
Understand the market and its dynamics	0.420
Establish the research problem clearly	0.507
Selecting a competent team	0.736
Leadership of the principal investigator	0.233
Commitment of the principal investigator	0.592
Consider funding bodies' requirements	0.685
Consider industrial partners' requirements	0.002
Consider researchers' requirements	0.770

According to Table 5.4, except for the CSF *"Consider industrial partners' requirements"*, the other factors have obtained an Asymp. Sig. > 0.05 from the Mann-Whytney U test results. This indicates the opinion regarding the importance of *"considering the industrial partners' requirement"* varies significantly between academic members and industrial partners. From the mean values given for the success factor *"consider industrial partners' requirements",* it can be noted that the mean value obtained from the industrial partners is higher than the mean value obtained from the academic members (4.56 and 4.30 respectively).

5.4.2.2 Synthesis of the critical success factors at initiation phase

After identifying the CSFs pertaining to the initiation phase, this section refers to the semi structured interviews and discusses why those factors were identified as important by the respondents.

Under the CSFs at the initiation phase, seven factors were identified and they were categorised into three groups namely; *"solid upfront work", "consider stakeholder requirements" and "authority and commitment of the principal investigator"* (see Figure 5.7). The section below analyses each group by considering their constituent parts.

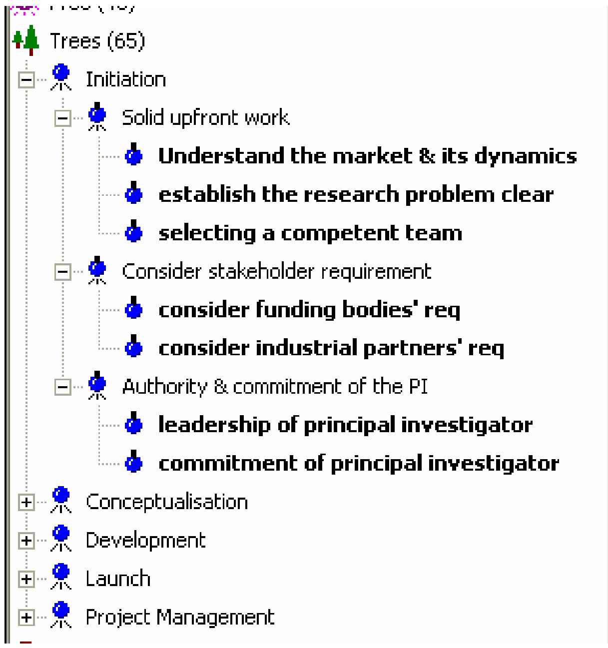


Figure 5.7: Coding structure for the critical success factors at initiation phase of research and development function

5.4.2.2.1 Solid upfront work

At the initiation phase the CSFs *"solid upfront work"* consists of three sub factors which are; *"understand the market and its dynamics", "establish the research problem clearly", and "selecting a competent team"* (see Figure 5.8).

According to S1-PI2, problems within construction R&D activities arise when the research proposal is not properly prepared. (1333). He stated *"… that's why it is so important to get the up front investment, make sure that the proposal is comfortable, well resourced" (1334).* Thus, S1-PI2 identified doing the research proposal thoroughly, as a *"mini project"* (1331). Further, he added "…*that (research proposal) is the core, as any thing it's important to have a solid core in place" (1332).* Similarly S1-InP1 identified the importance of establishing the research gap clearly through literature review and existing knowledge about the subject area (1337, 1335, 1336). Adding to the above views, S1-R3 also acknowledged the importance of establishing the research proposal clearly (1338). She stated *"When you have the research problem clearly, the rest is only building upon that" (1340).* The above empirical data shows the need for establishing the research problem clearly from a good theoretical background via a thorough and rigorous process of literature review. The study carried out by Cooper and Kleinschmidt (2007) also revealed the importance of carrying out upfront homework in the form of market analysis, business analysis, customer research etc. They identified that failure to carry out such work has been the major cause of failures in product development activities.

In addition to this, the case study findings revealed the importance of addressing market needs from the research problem (1351, 1356). S1-R3 stated *"at the end of the day, to get people to buy into it you need to sell that idea to them" (1357).* Similarly, S1-PI1 stated that having an interesting idea can become the driving force for the research (1355) and will be the reason for the funding body to support it (1354). Due to the changes in market dynamics, the interest of society (especially industry's interest) can be changed, commented S1-R3 (1353, 1352). She stated *"So we need to respond to that change quickly. Those are the kind of factors that influences especially with the industry engagement" (1352).* As with the findings of this case study, Sun and Wing (2005) also revealed that for a successful NPD process it is important to have a clearly defined target market at the idea generation and conceptualising phases. In addition to the above, selecting a competent team for R&D work was identified as a CSF by the interviewees (1311). S1-PI3 claimed that selecting a team with the wrong skills may result in the need to recruit people from elsewhere to see the project through (1312).

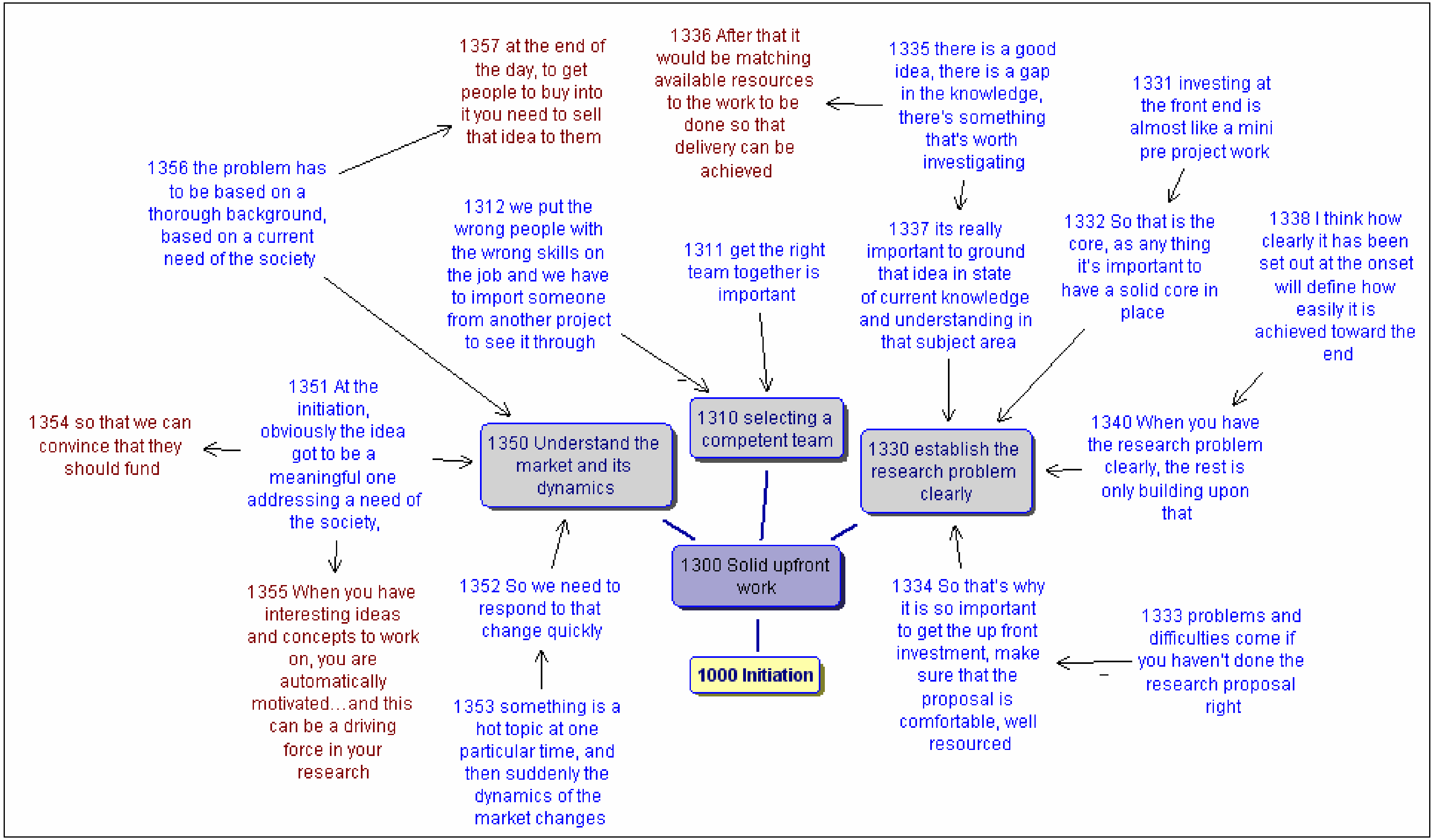


Figure 5.8: Cognitive map of the critical success factor "solid upfront work" at initiation phase

5.4.2.2.2 Consider stakeholder requirements

Addressing funding bodies' and industrial partners' requirements were identified as CSFs by number of interviewees (see Figure 5.9). S1-R1 and S1-PI4 stated that it is important to strike a balance between the requirements of the funding bodies' and industrial partners' when compiling the research proposal (1215, 1216, 1217). This avoids compromising the industrial partners' requirements against the requirements of the funding body. Section 2.4.5 of the literature review explained that lower level of investments for construction R&D activities are evident due to the dissatisfaction of the funding body that research projects failed to achieve their expected benefits. This can be avoided by addressing the requirements of the funding body through the research project. The case study findings also supported this view. For instance, S1-R1 commented that if there are specific reasons for the funding body to provide funding; such reasons should be specifically investigated (1213, 1214). S1-R4 also agreed with S1-R1 and highlighted the importance of addressing the industrial partners' requirement to secure their commitment towards the project (1231 and 1232). Even the literature review identified the failure of the R&D output to address the requirements of the industrial partners as a barrier to get their commitment and involvement to research projects (see Section 2.4.5). Therefore, it was recommended to include industrial partners' requirements as constituent parts of the overall aim and objectives of the R&D project.

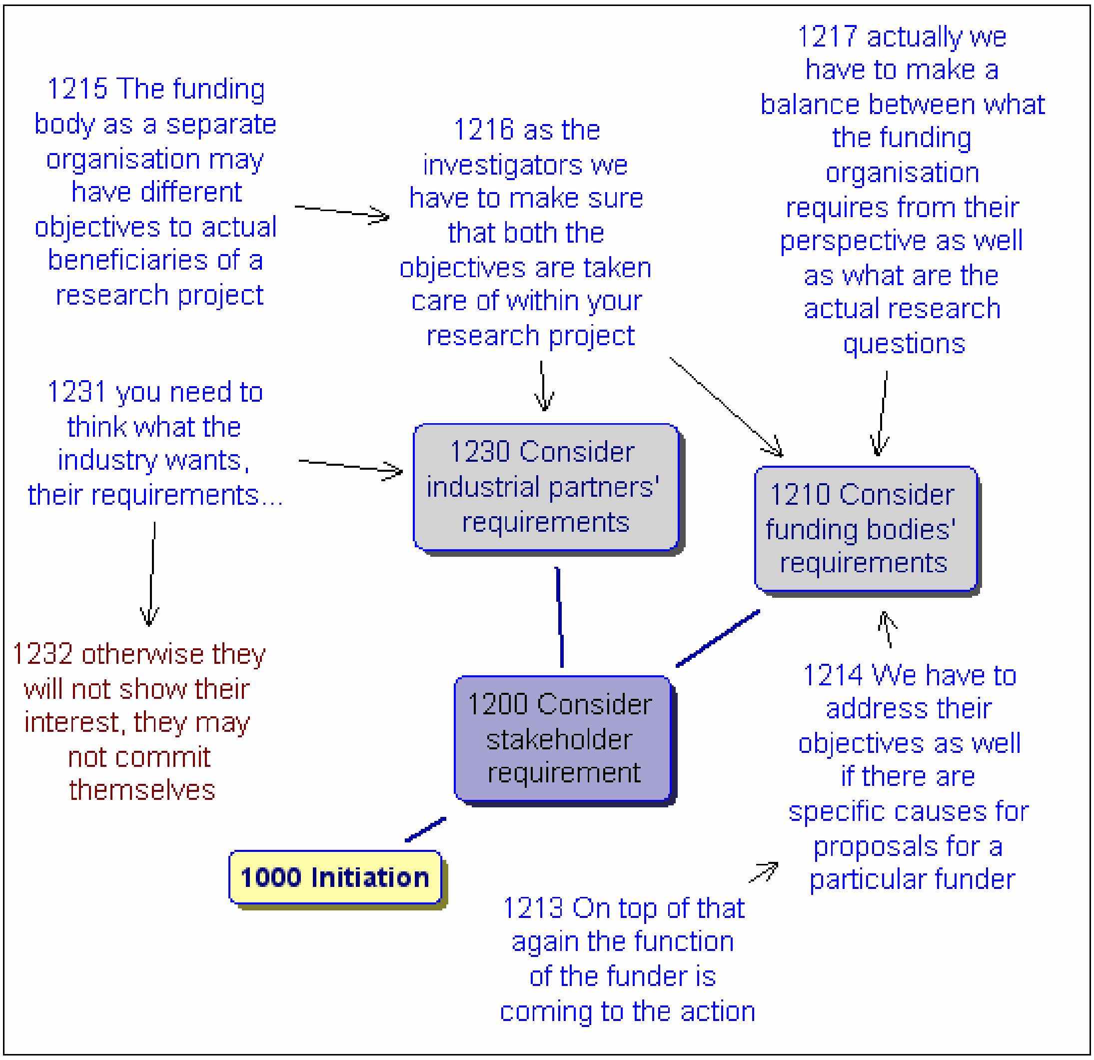


Figure 5.9: Cognitive map of the critical success factor "consider stakeholder requirement" at initiation phase

5.4.2.2.3 Authority and commitment of the principal investigator

As shown in Figure 5.10, S1-InP3 noted the importance of principal investigators leading the project from the beginning by identifying the resource requirements and also listening to the views of the other team members (1136, 1137). Furthermore, S1-P12 stated that it was the principal investigator's responsibility to arrange the informal organisational requirements of space and other resources for the project (1131, 1132). He added *"So that's also hard negotiations, internal relationship building within your research organisation" (1135).* Apart from the leadership, the commitment of the principal investigator towards the project was identified as important. S1-R1 stated that though the principal investigators have other duties and commitments within research institutions, paying proper attention to each part of the research project is important (1112, 1111, 1113, 1114). *"One of the key elements is*

…not winning the projects, not winning the bids, but managing it" claimed S1-R1. Research carried out in other disciplines also witnesses the commitment and leadership of senior managers in organising the resources, playing a central role in decision taking and reviewing processes (Cooper and Kleinschmidt, 2007; Lester, 1998). Lester (1998) believed that senior management could support the proper progress of research work by providing correct vision, strategy and sponsorship. Though Sun and Wing's (2005) study identified the importance of leadership of the project leader, commitment of the senior management was among the least important factors for effective NPD work. They commented that commitment of the senior management was identified as not critical due to the small scale of teams formed for toy industry, which their study was based on.

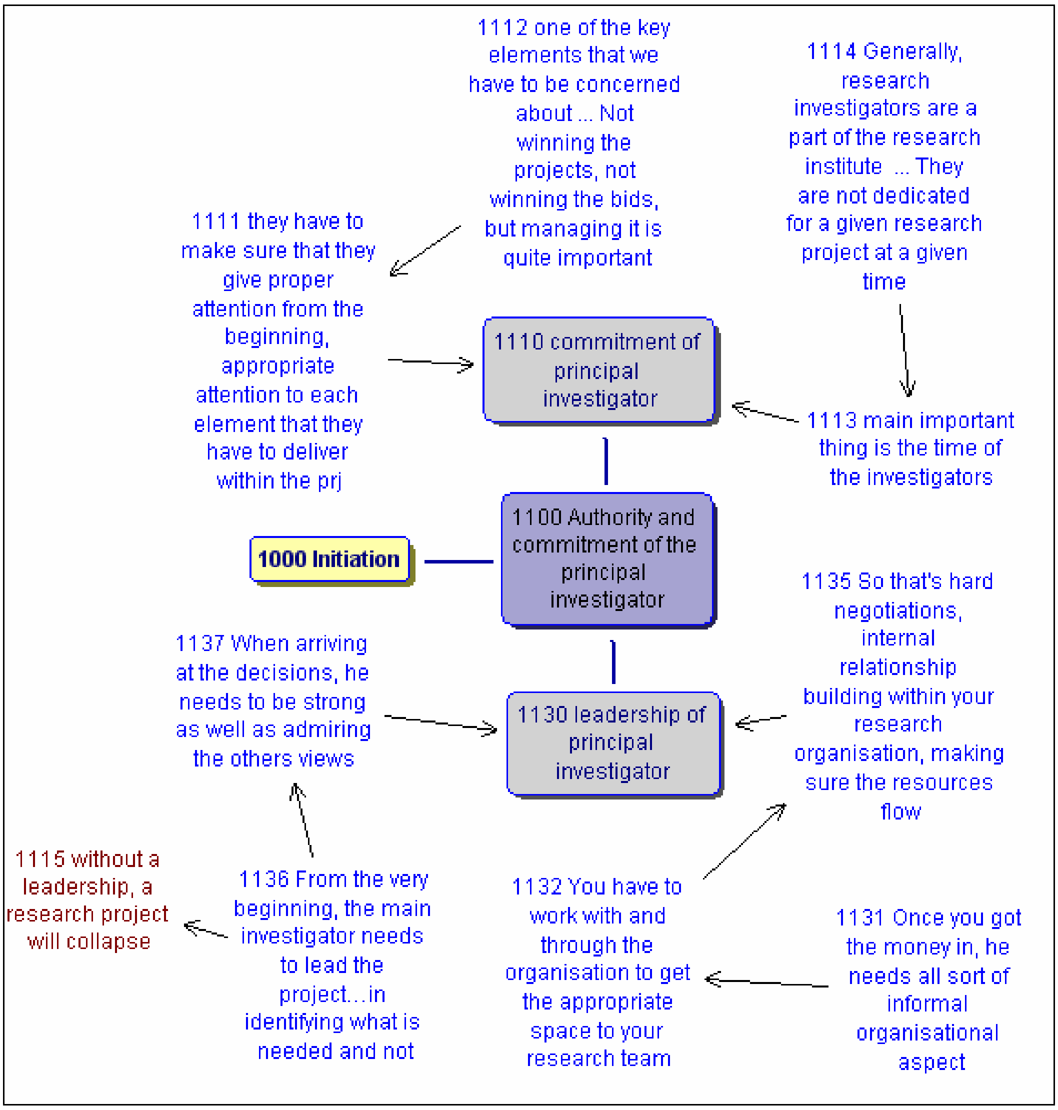


Figure 5.10: Cognitive map of the critical success factor "authority and commitment of the principal investigator" at the initiation phase

Based on the above analysis, Table 5.5 shows the CSFs during the initiation phase.

Table 5.5: Critical success factors during the Initiation phase

Initiation Phase	
Solid upfront work	Understand the market and its dynamics Establish the research problem clearly Selecting a competent team
Consider stakeholder requirement	Consider funding bodies' requirements Consider industrial partners' requirements
Authority and commitment of the principal investigator	Commitment of the principal investigator Leadership of the principal investigator

5.4.2.3 Critical success factors during the conceptualising phase

The success factors identified during the conceptualising phase are ranked according to the overall mean as illustrated in Table 5.6. It can be seen that a comprehensive briefing process, recognition for team members, consider researchers' requirements and a fast decision making process have an overall mean value of less than 4. Thus, those four factors were omitted from further analysis to obtain the CSFs. The remaining 14 factors were subjected to Wilcoxon signed rank test to identify the demarcation point of differing opinions regarding the success factors. As shown in Table, the factors from 1-12 had an Asymp sig > 0.05. However, the Asymp sig was less than 0.05 between *"consider funding bodies' requirements"* and *"absence of lengthy bureaucracy"* indicating that there is a significant difference of opinion between those two factors. Thus, the *"absence of lengthy bureaucracy"* and *"early involvement of the industrial partners"* were considered as not critical during the conceptualising phase for the success of construction R&D function.

Table 5.6: Ranking of the success factors at the conceptualising phase

Success Factors	Academia	Industry Partners	Total		Asymp. Sig.
	Mean	Mean	Mean	Rank	
Check the feasibility of the project	4.68	4.85	4.75	1	
Commitment of the principal investigator	4.62	4.52	4.57	2	0.07
Committed and cooperative team members	4.48	4.59	4.53	3	0.55
Establish clear and realistic goals/ deliverables/ milestones	4.41	4.63	4.51	4	0.99
Adequate resources/financial support	4.44	4.44	4.44	5	0.52
Allocation of responsibilities to team members inline with competencies	4.41	4.37	4.39	6	0.61
Establish a plan to disseminate research results	4.35	4.44	4.39	7	1.00
Leadership of the principal investigator	4.26	4.37	4.31	8	0.58
Having a skilled team	4.38	4.19	4.30	9	0.76
Establish clear method to measure success	4.18	4.44	4.30	10	1.00
Consider industrial partners' requirements	4.35	4.22	4.30	11	0.95
Consider funding bodies' requirement	4.35	4.19	4.28	12	0.97
Absence of lengthy bureaucracy	3.91	4.11	4.00	13	0.03
Early involvement of industrial partners	3.76	4.30	4.00	14	0.94
Comprehensive briefing process	3.88	4.11	3.98	15	
Recognition for team members	3.88	3.96	3.92	16	
Consider researchers' requirements	3.91	3.74	3.84	17	
Fast decision making process	3.59	3.88	3.72	18	

The results of the Mann-Whytney U test show a significant difference of opinion between the academic members and industrial partners for the *"early involvement of industrial partners"* (see Table 5.7). The academic members have given a lesser overall mean value (3.76) than the industrial partners (mean 4.30) for the aforementioned success factor.

Table 5.7: Difference in opinion of the academic members' and industrial partners at the conceptualising phase

Success factors at conceptualising phase	Asymp. Sig.
Check the feasibility of the project	0.170
Consider funding bodies' requirement	0.557
Consider industrial partners' requirements	0.646
Consider researchers' requirements	0.546
Establish clear and realistic goals/ deliverables/ milestones	0.425
Establish clear method to measure success	0.168
Allocation of responsibilities to team members inline with competencies	0.772
Establish a plan to disseminate research results	0.694
Comprehensive briefing process	0.284
Adequate resources/financial support	0.799
Having a skilled team	0.266
Early involvement of industrial partners	0.025
Leadership of the principal investigator	0.903
Commitment of the principal investigator	0.591
Committed and cooperative team members	0.582
Recognition for team members	0.624
Fast decision making process	0.134
Absence of lengthy bureaucracy	0.433

5.4.2.4 Synthesis of the critical success factors at conceptualising phase

The CSFs identified from the above process were grouped into four main categories as shown in Figure 5.11 by using NVivo coding structure. Accordingly, this section analysed the CSFs pertaining to the conceptualising phase under the groups of *"clarity and focus of work"* (Figure 5.12), *"adequate resources and capabilities"* (Figure 5.13), *"consideration of stakeholder requirements"* (Figure 5.14) and *"team dynamics"* (Figure 5.15).

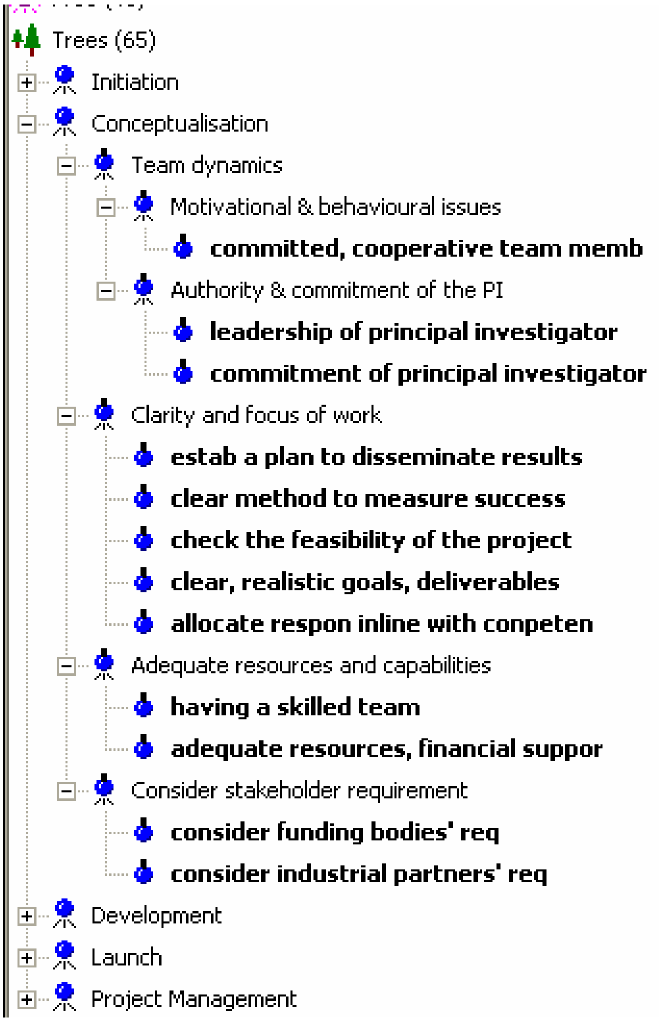


Figure 5.11: Coding structure for the critical success factors at conceptualisation phase

5.4.2.4.1 Clarity and focus of work

PI3 identified carrying out feasibility studies about the research project as an important factor (Figure 5.12). He stated that such studies would help to foresee the success of ideas in the long term and prevent people from carrying out research just for the sake of it (2263, 2264). S1-PI1 also acknowledged the need for having a feasibility stage for R&D work (2262, 2261). Scrutinising the research work would screen and evaluate the best option for the research project on the criterion of value offered to the beneficiaries and the ultimate impact of research results. Therefore, feasibility studies will prevent waste of money, time and the commitment of people carrying out unfeasible research projects. The need for proper scrutiny of research proposals is admired by Cooper and Kleinschmidt (2007) who identified that projects that follow the "*ready, fire, aim*" approach usually fail due to a lack of understanding of the prevailing factors which could harm their future developments.

Establishment of clear and realistic goals, deliverables and milestones have been identified as important for the success of construction R&D project by a number of interviewees. S1-PI1 and S1-PI3 observed being overambitious when formulating the aim and objectives of some projects (2212). In those instances, the R&D project had to be broken into two projects, stated S1-PI3 (2213). S1-PI4 and S1-PI1 highlighted the importance of considering the resource constraints when formulating the aim and objectives of the project (2212, 2214). Furthermore, being overambitious could result in putting the research team under pressure to achieve unrealistic targets. Agreeing with the above views, S1-InP2 stated *"clear understanding of the work involved would be the main improvement I would say… so a more task identification rather than generic ideas is needed"* (2215, 2216). Having clear deliverables and milestones would determine the tasks which need to be carried out within a given period of time. In addition, team members involved in the R&D project can identify the common purpose towards which they are working. Similarly, S1-R2 also believed that lack of clarity in the research proposal could lead to problems (2217). These findings coincide with the literature review, which stipulated the need for clear operational objectives for construction R&D work (see Section 2.7.1). The findings of CRISP (2004) showed that clear objectives would reduce the risk of setting inappropriate targets for the team members involved in the research project. Similarly, the studies in other disciplines also suggested having clear, defined and written goals as the *"basic ingredients"* for the success of R&D work (Cooper and Kleinschmidt, 2007; Sun and Wing, 2005).

According to S1-R1, specific mechanism to check whether the project is achieving its aim and objectives are needed (2251, 2252). He stated *"if you have set up an objective to accomplish something at the end of third week, there should be a set of measures to determine whether the objectives have been achieved during that particular period, rather than going by ad-hoc means"(2251).* The opinions of S1-R1 resonate well with Lorch (2000) and Seaden and Manseau (2001) who stated that the lack of methods to measure the project progress and lack of links between the utilisation of resources and the contribution of the team members has negatively affected the success of R&D work. Furthermore, such issues have created a negative impact in attracting funds and industrial partners' contribution for research activities. S1-PI3 observed that different people can bring different specialities to support the success of the project (2273, 2274). Thus he stated "*What we need to have is appropriate skills levied to the research tasks. We use a variety of mechanisms, obviously the first is the tacit knowledge, we know who is going to do what. But sometimes we also tend to use something called the Belbin questionnaire which tends to tease out strengths and weaknesses of people when we are putting teams together" (2271, 2272)* acknowledging the allocation of responsibilities to suit the skills of the team members. S1-R5 highlighted the need for establishing a dissemination plan so that the people involved in the project have a clear idea of their contribution when disseminating the work (2231, 2232, 2233, 2234).

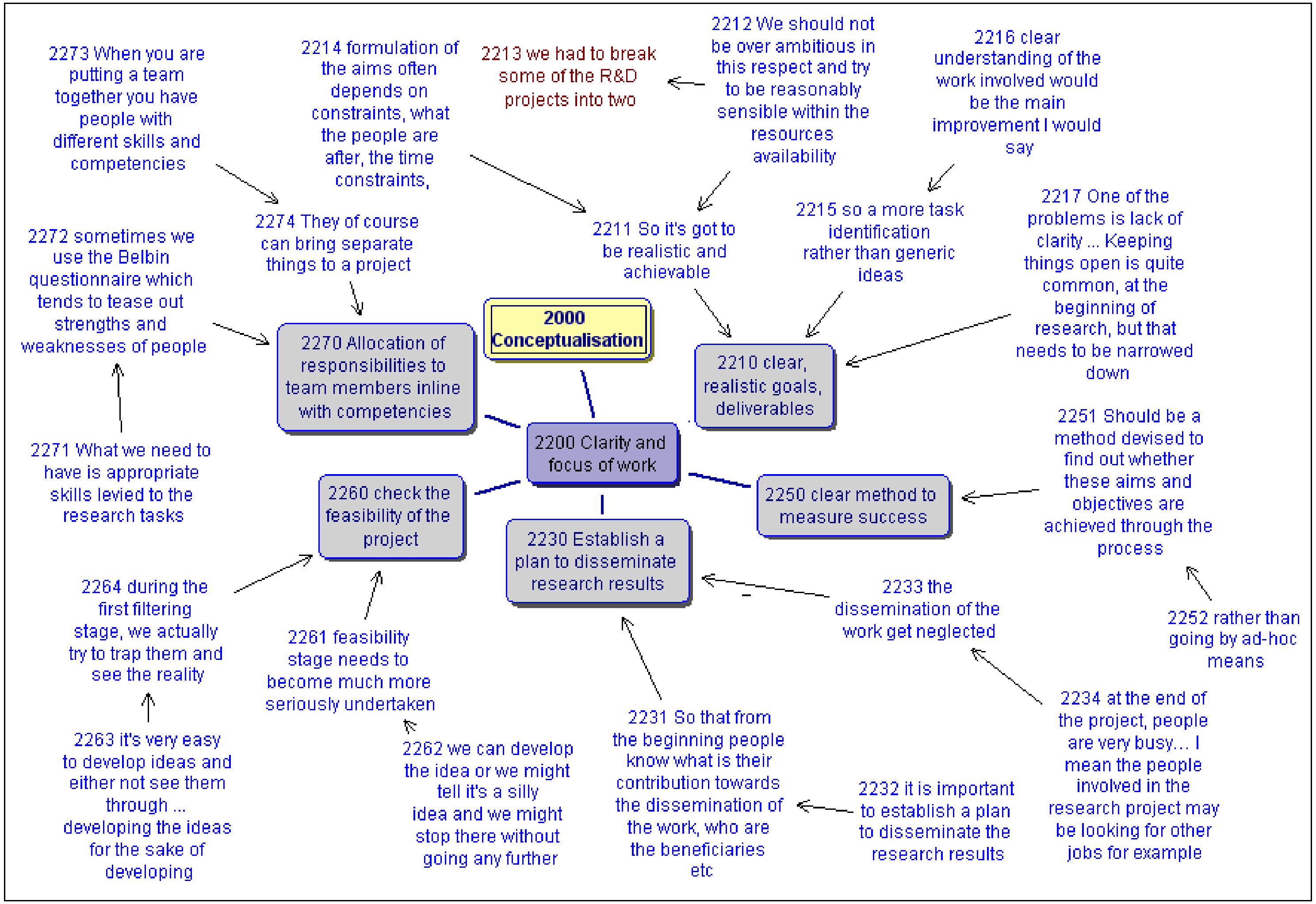


Figure 5.12: Cognitive map of the critical success factor "clarity and focus of work" at the conceptualising phase

5.4.2.4.2 Adequate resources and capabilities

According to S1-PI2, having a skilled team is the primary success factor for a construction research project (see Figure 5.13). *"Always the most important one is the human resource, that's the key. Good, capable, motivated research team including research assistants or research fellows. Laptops may be very nice but, we are in a knowledge intensive business, we are in a people's business"* (2311, 2312) attested S1-PI2. Agreeing with this, S1-InP2 also stated that the poor performance of individuals can affect the success of the R&D project (2313). In addition to people, other resources such as working space, additional facilities to work in collaborative environments and financial support throughout the project lifecycle was acknowledged as important by the interviewees (2231, 2232, 2234). Lack of these resources could lead to problems within the R&D project stated S1-PI1 (2235).

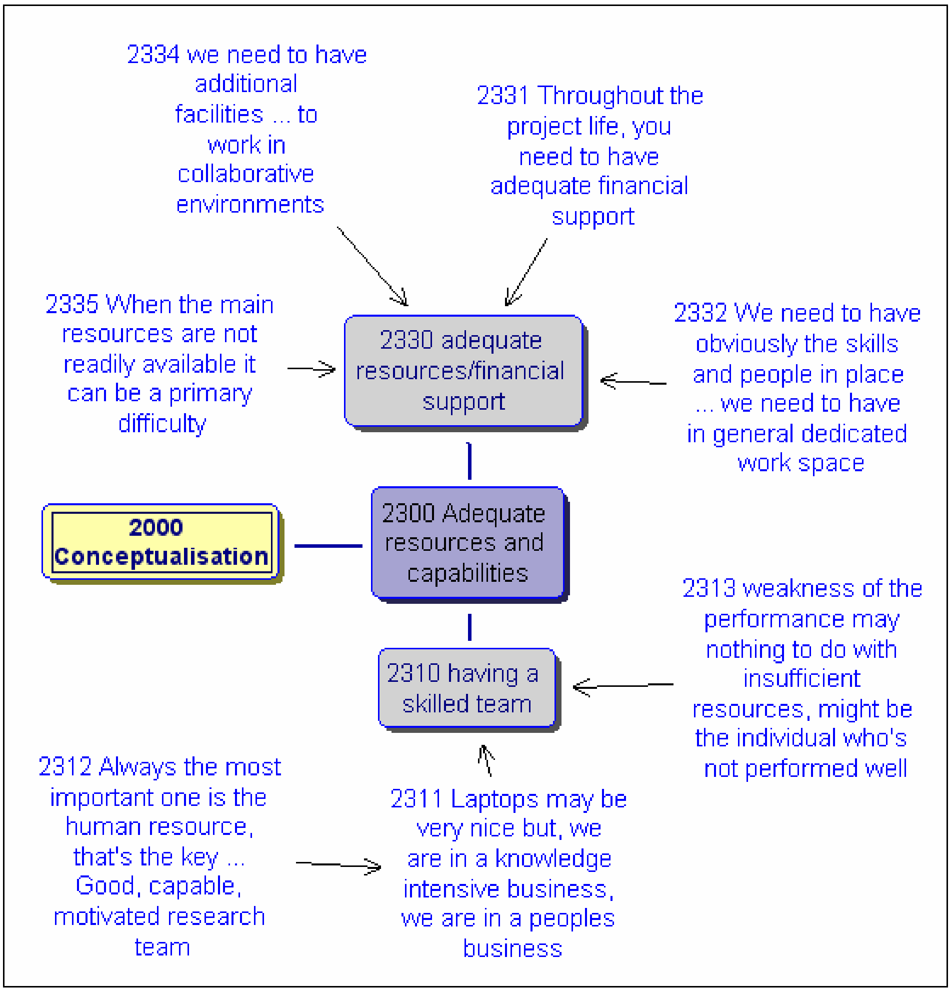


Figure 5.13: Cognitive map of the critical success factor "adequate resources and capabilities" at the conceptualising phase

The findings of the case study are corroborated by Cooper and Kleinschmidt (2007) who highlighted the importance of resources, both people and money are for the success of R&D activities. Sun and Wing (2005) also considered that the idea generation and conceptualising phase of the NPD process should be supported with skilled people. Lester (1998) believed that a team with diverse skills could provide a greater range of view points, adding value to the effective development of ideas for the research project. Therefore, based on concepts generated through the case study and literature review (see Fairclough, 2002) it can be stated that the lack of human and other resources could result in neglecting those activities which are needed for the success of R&D work, as well as disrupting and delaying the achievement of the milestones and creation of poor quality deliverables. Hence, it is important to align the resources with the objectives and the processes of the R&D project.

5.4.2.4.3 Consider stakeholder requirements

As shown in Figure 5.14, S1-InP2 suggested that too much academic push within the project decrease the interest of the industrial partners involved in the project (2137). Thus, assuring the industrial partners that they will benefit from the project is important (2133, 2134). Further, PI4 asserted *"The aims and objectives of the research are quite remote or foreign to the contractors. There interest is about the benefit to them …so you have to show benefits and root benefits for them are simply objectives of the project" (2138, 2131, 2132).* As identified in Section 5.4.2.2.2 the importance of considering the funding bodies' requirements was highlighted during the conceptualising phase (2111, 2112, 2113). S1-PI2 perceived the importance of formulating a coherent set of aims and objectives where all the parties can share the benefits (2136, 2135). He added *"everyone can see an area they can commit to, contribute to and every one can get an appropriate sharing of the benefits of that research" (2114).* Similar to S1-PI2, S1-R1 also commented that the aim and objectives of the project should have a major bearing for the beneficiaries needs (2115, 2116).

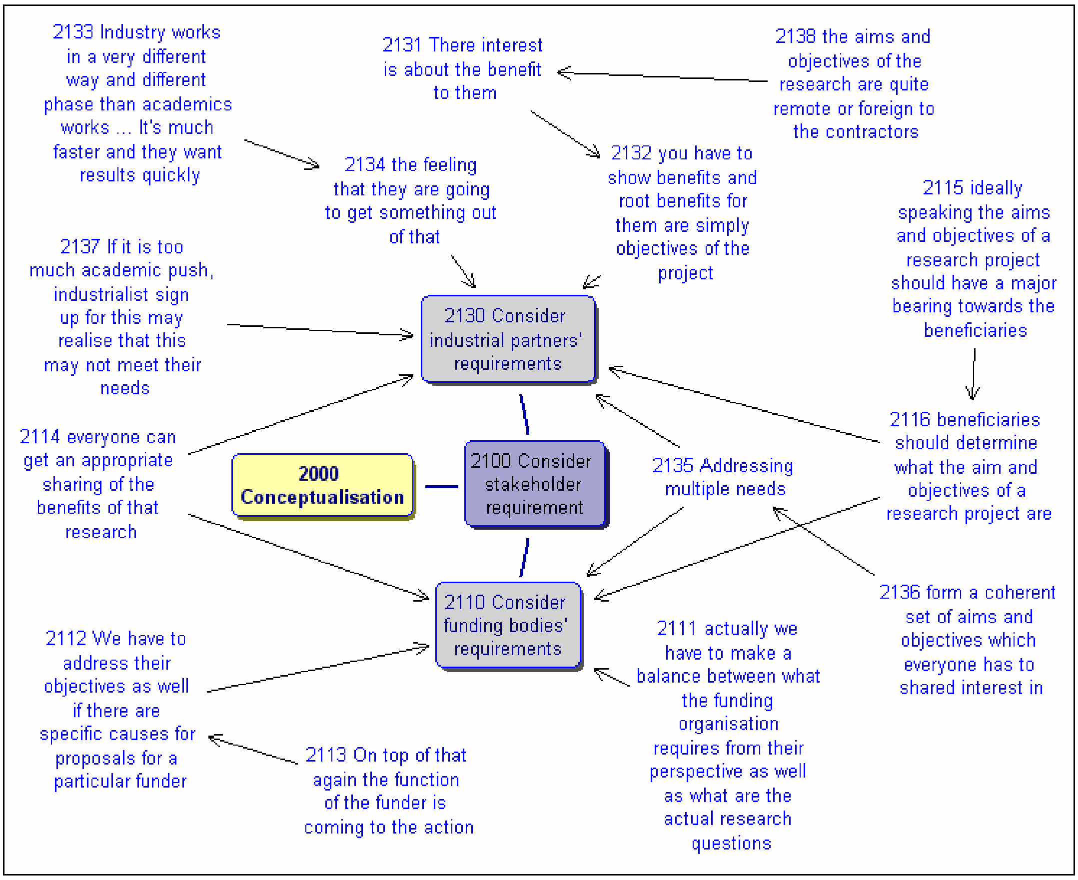


Figure 5.14: Cognitive map of the critical success factor "consider stakeholder requirements" at the conceptualising phase

5.4.2.4.4 Team dynamics

As with the commitment required of the principal investigators, committed and cooperative team members are another factor for the success of construction R&D function (see Figure 5.15). Supporting this, S1-PI1 stated that lack of cooperation from team members could negatively affect the success of the project (2414, 2415, 2412). He stated *"…they feel alienated from the project, when they don't see them as full part of it (the project)"* hence, acknowledging the need for identifying the success of the project as an achievement of the whole team (2421). Thus, he stressed the importance of obtaining the contribution of all the team members (2420). S1-InP3's view was that involvement in research activities is not a priority for the industrial partners (2419). Thus, S1-InP3 stated *"… you need to have enthusiastic industrial partners, industrial partners there not to make the numbers. They should be part of the project, and the feeling that they are going to get something out of that" (2418, 2413).* S1-PI4 also shared the view of S1-InP3 that securing the commitment of the industrial partners in research activities is difficult (2416).

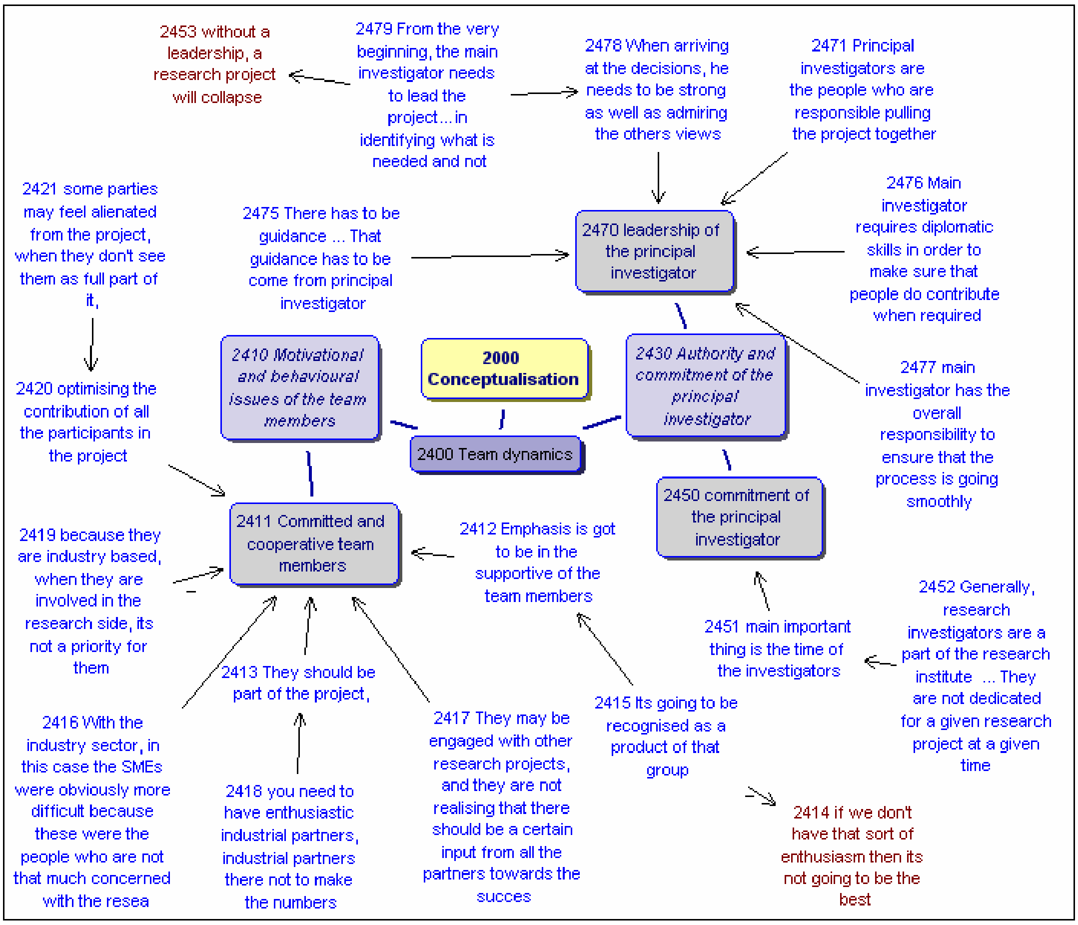


Figure 5.15: Cognitive map of the critical success factor "team dynamics" at conceptualising phase

Similarly, the studies carried out in other disciplines also shows that people assigned to particular projects would neglect their duties either due to involvement in other projects or simply because of doing *"their real job"* (Cooper and Kleinschmidt, 2007). Within the construction related literature, it was identified that lack of participation by industrial partners in research activities was a factor which could inhibit the success of R&D projects (see Section 2.4.5). Thus, clearly specifying the team members contributions towards the project, providing awareness the duties and obligations, and being realistic about the allocation of duties and responsibilities would result in obtaining the commitment and cooperation from the team members. Furthermore, other ways of gaining the commitment and contribution from the industrial partners is by ensuring that their expectations are well covered within the objectives of the research project. In addition, by addressing the current needs of the industry and by demonstrating that the benefits of engaging in research activities could benefit their personnel/ organisational developments, the contribution and commitment of industrial partners would be obtained.

Commitment and leadership of the principal investigator was highly regarded during the conceptualising stage similarly in the initiation phase of the R&D function (see Section 5.4.2.2.3). S1-PI4 and S1-R2 believed that it is the principal investigator's responsibility to ensure the proper flow of the R&D process (2477, 2471). Agreeing with this view S1-PI1 claimed that the principal investigator needs to use diplomatic skills during the R&D process to encourage the team members to complete tasks (2476). Furthermore, S1-R1 stressed the importance of being guided by the principal investigator (2475).

Table 5.8 shows the summary of CSFs at the conceptualising phase as discussed above.

Table 5.8: Critical success factors during the conceptualising phase

Conceptualising Phase	
Team dynamics: ***Authority and commitment of the principal investigator***	Commitment of the principal investigator Leadership of the principal investigator
Motivational and behavioural issues of the team members	Committed and cooperative team members
Consider stakeholder requirement	Consider funding bodies' requirement Focus on the industrial partners' requirements
Clarity and focus of work	Check the feasibility of the project Establish clear and realistic goals/ deliverables/ milestones Establish clear method to measure success Allocation of responsibilities to team members inline with competencies Establish a plan to disseminate research results
Adequate resources and capabilities	Having a skilled team Adequate resources/financial support

5.4.2.5 Critical success factors during the development phase

Table 5.9 shows the success factors during the development phase are ranked according to the overall mean. It can be recognised that from the 17 success factors, 3 of them has an overall mean value of less than 4 *("fast decision making", "having a risk mitigation strategy" and "testing the market")*. When the Wilcoxon signed rank test was applied to the remaining 14 factors, the Asymp sig value attained less than 0.05 between *"leadership of the principal investigator" and "absence of lengthy bureaucracy",* thus indicating a significant difference of opinions between these two factors. Therefore, *"absence of lengthy bureaucracy", "meeting researchers' requirements"* and "*recognition for team members*" were excluded from the CSFs.

Table 5.9: Ranking of the success factors at the development phase

Success Factor	**Academia**	**Industry Partners**	**Total**		**Asymp. Sig.**
	Mean	Mean	Mean	Rank	
Committed and cooperative team members	4.62	4.56	4.59	1	
Commitment of the principal investigator	4.56	4.59	4.57	2	0.83
Adequate resources/financial support	4.53	4.59	4.56	3	0.91
Having a skilled team	4.53	4.48	4.51	4	0.55
Meet funding bodies' requirements	4.53	4.48	4.51	5	0.99
Share a common understanding about the work	4.38	4.44	4.41	6	0.29
Having a well establish operational procedure	4.50	4.26	4.39	7	0.91
Meet industrial partners' requirements	4.24	4.59	4.39	8	0.98
Secure momentum/ motivation of the team	4.41	4.33	4.38	9	0.91
Flexibility and responsiveness to change	4.38	4.37	4.38	10	1.00
Leadership of the principal investigator	4.38	4.37	4.38	11	0.94
Absence of lengthy bureaucracy	4.03	4.22	4.11	12	0.02
Meet researchers' requirements	4.09	4.07	4.08	13	0.75
Recognition for team members	4.00	4.04	4.02	14	0.58
Fast decision making process	3.82	4.11	3.95	15	
Having a risk mitigation strategy	3.85	4.08	3.95	16	
Testing the market	3.79	4.07	3.92	17	

The results of the Mann-Whitney U test indicates that academic members' and industrial partners' opinions on the importance of *"meet the industrial partners' requirement"* shows statistically significant at 5% significant level, implying a different perception regarding the aforementioned success factor. When compared the mean values assigned by the academic members and industrial partners for this success factor, it can be noted that the industrial partners have given a higher value (4.24).

Table 5.10: Difference in opinion of the academic members and industrial partners at the development phase

Development	Asymp. Sig.
Adequate resources/financial support	0.723
Having a skilled team	0.862
Having a well establish operational procedure	0.092
Having a risk mitigation strategy	0.315
Flexibility and responsiveness to change	0.841
Leadership of the principal investigator	0.555
Commitment of the principal investigator	0.878
Committed and cooperative team members	0.796
Share a common understanding about the work	0.628
Recognition for team members	0.788
Secure momentum/ motivation of the team	0.904
Fast decision making process	0.112
Absence of lengthy bureaucracy	0.444
Testing the market	0.221
Meet funding bodies' requirements	0.695
Meet industrial partners' requirements	0.028
Meet researchers' requirements	0.781

5.4.2.6 Synthesis of the critical success factors at development phase

The CSFs obtained by considering the mean values and Wilcoxon signed rank test were grouped into three categories namely *"stakeholder satisfaction", "adequate resources" and "capabilities and team dynamics"*. Figure 5.16 shows the NVivo coding structure while Figure 5.17, Figure 5.18, Figure 5.19 and Figure 5.20 depict the cognitive maps for this phase.

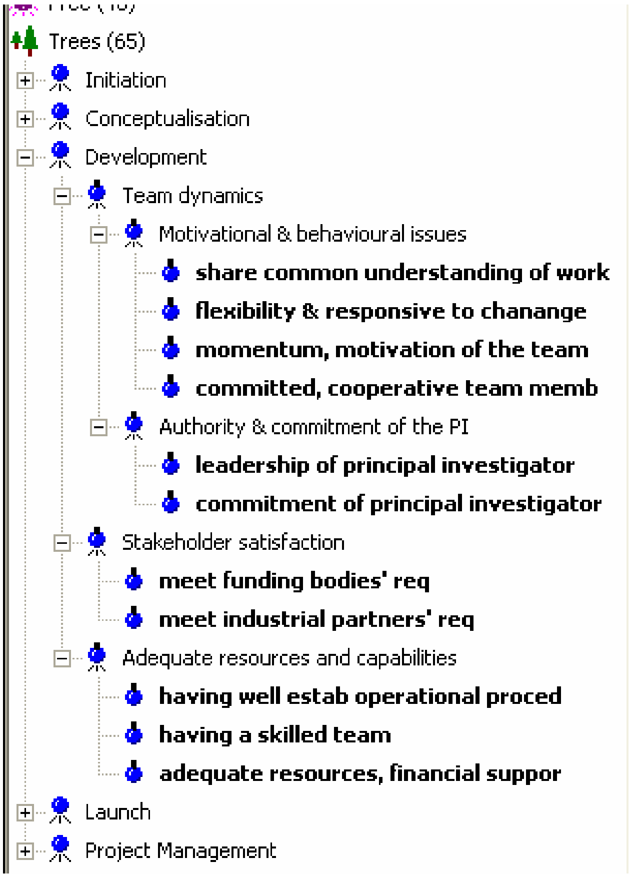


Figure 5.16: Coding structure for the critical success factors at development phase

5.4.2.6.1 Stakeholder satisfaction

During the development stage, satisfying the stakeholders' needs was identified as important (see Figure 5.17). Generating value for money for the funding body (3211), sharing appropriately the benefits of the project (3231), and achieving the deliverables of the project to satisfy the funding bodies' requirements (3214, 3215) were observed by the interviewees in addressing the stakeholders' needs.

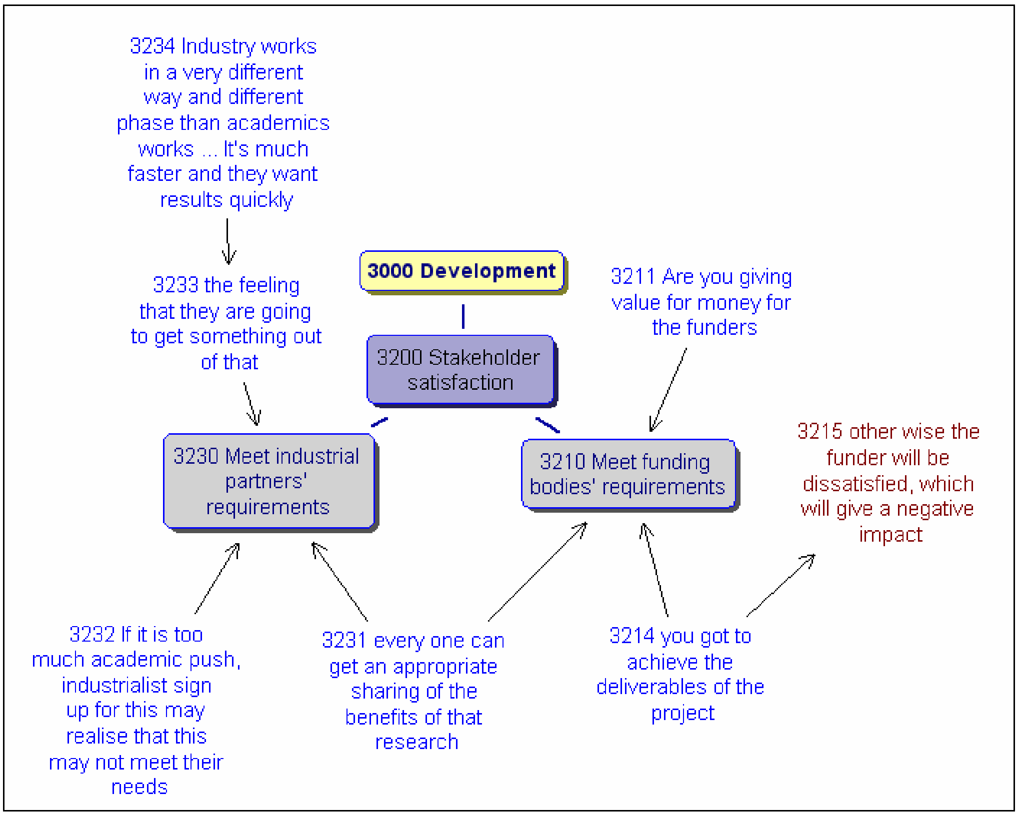


Figure 5.17: Cognitive map of the critical success factor "stakeholder satisfaction" at development phase

5.4.2.6.2 Adequate resources and capabilities

As noted at the conceptualising phase, having a skilled team and the availability of resources and financial support during the development phase were highlighted as success factors for R&D function (see Section 5.4.2.4.2). Having a well established operational procedure was identified as important during the development phase (see Figure 5.18). S1-PI3 asserted "…*all stages through the project life cycle are detailed with deliverables and dates, of people responsible for that and a risk mitigation strategy is put in place with all these activities" (3135, 3134).* He further added *"So we know what to do if one particular activity doesn't go to plan" (3134).* Therefore, a well established operational procedure will identify the proper communication channels, monitoring mechanisms, risk management strategies, detailing the activities involved during the each phase of the R&D function and the decision and milestone points which are crucial for progress of the R&D work.

S1-R1 suggested having proper mechanisms for communication depending on the stakeholders involved in the project (3136, 3137, 3133). Further, he suggested having short term deliverables and milestones in place for effective R&D work. *"If you have all these things in place, you know what to deliver in given short term time. So at short meetings, you can determine whether the project is achieving its desired objectives"* stated S1-R1 *(3138, 3139).* Similarly, Cooper and Kleinschmidt (2007) also revealed the importance of having a high quality new product development process. However, they claim that the mere existence of a new product process would not develop performance, but that the quality and nature of the process with inbuilt best practices would yield the success. Furthermore, Sun and Wing (2005) also identified a well established operational procedure as a critical factor for NPD process during the definition and specification phase.

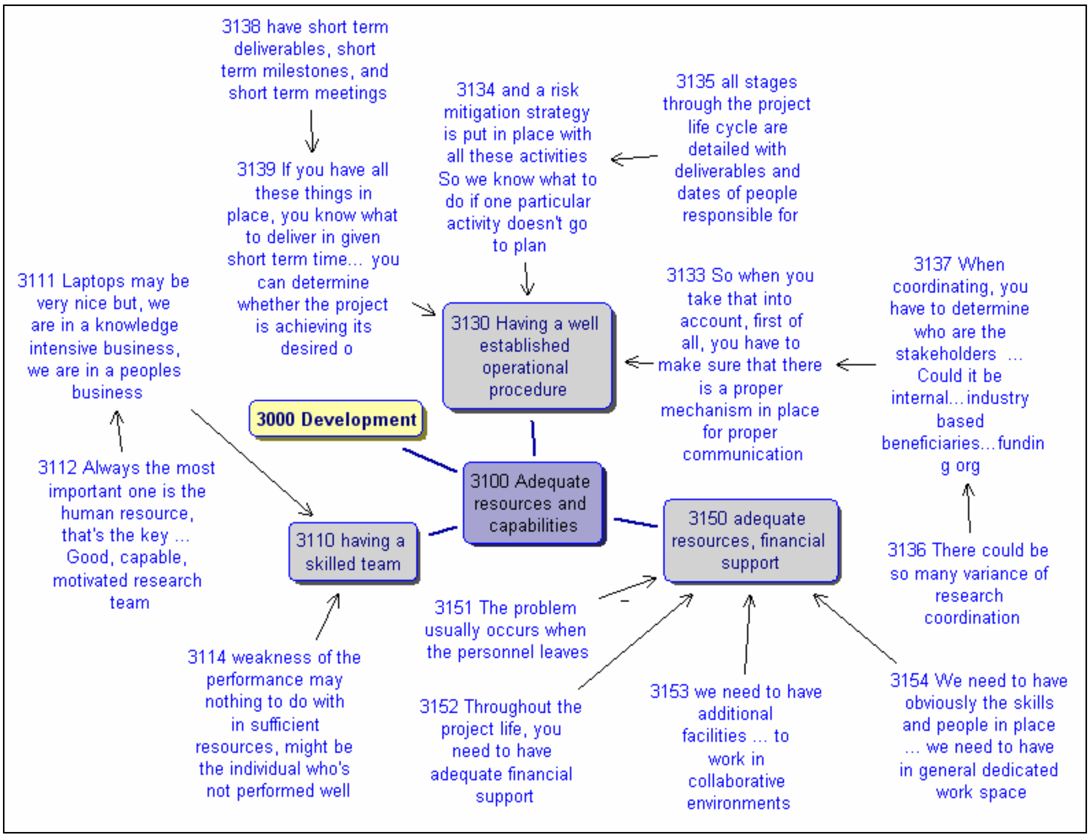


Figure 5.18: Cognitive map of the critical success factor "adequate resources and capabilities" at development phase

5.4.2.6.3 Team dynamics: authority and commitment of the principal investigator

In a similar way to the initiation and conceptualising phases, the commitment and leadership of the principal investigator was considered vital during the development phase (see Sections 5.4.2.2.3 and 5.4.2.4.4 and Figure 5.19). S1-R3 stated that as the project progresses the principal investigators could lose their commitment towards the project (3371). Agreeing with this view, S1-R1 pointed out that, researchers alone cannot work on the success of the research projects, and that proper guidance has to come from the principal investigators (3372). In terms of leading the project and getting the required contribution from the team members towards the project, S1-PI4 stated that the principal investigator may have to use financial power (3393, 3394).

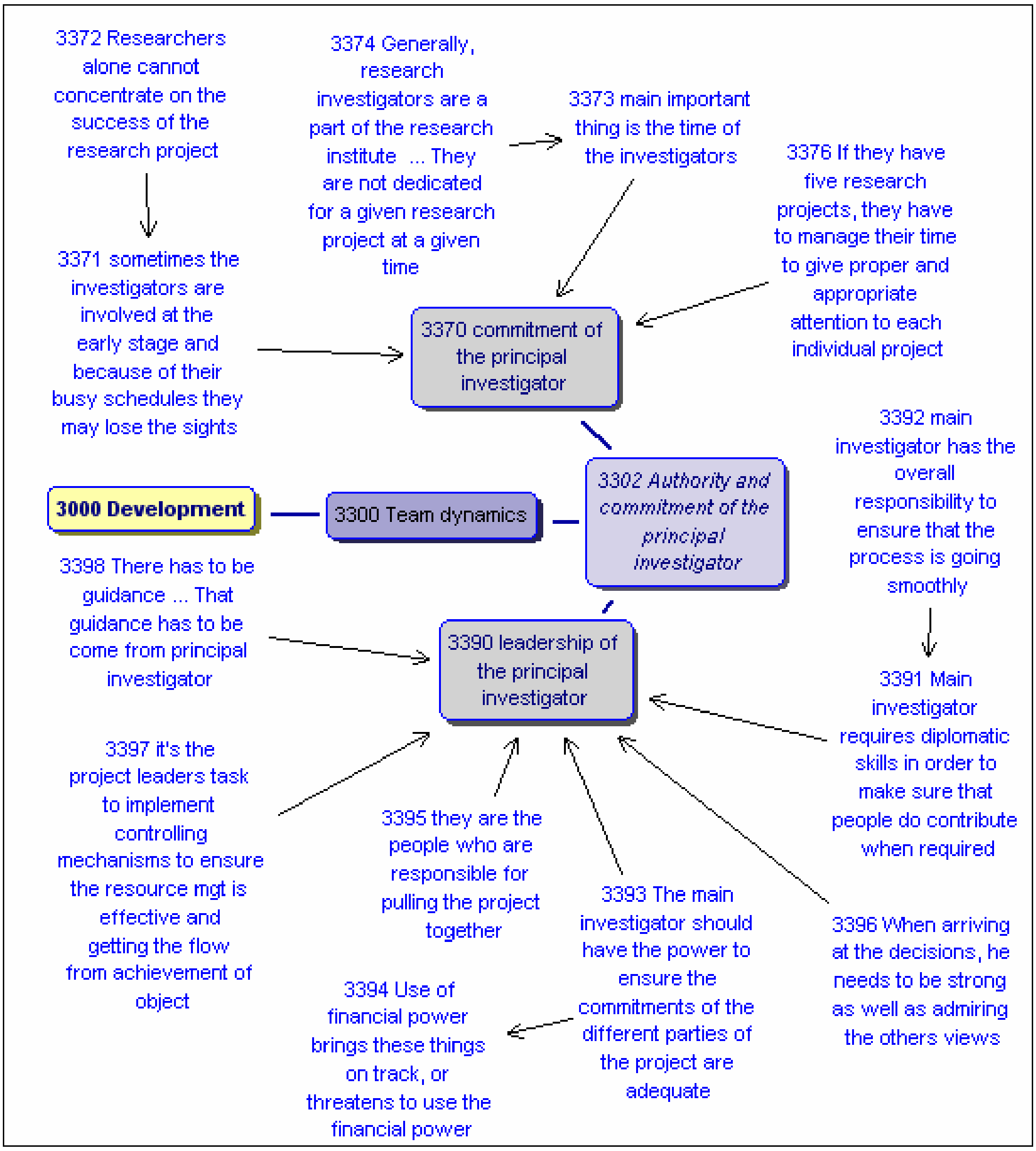


Figure 5.19: Cognitive map of the critical success factor "authority and commitment of the principal investigator" at development phase

5.4.2.6.4 Team dynamics: motivational and behavioural issues of the team members

As in the conceptualising phase, having committed and cooperative team members was identified as important during the development phase (see Section 5.4.2.4.4). In addition, the momentum and motivation of the team members has being identified as important (see Figure 5.20). Thus, S1-R2 put forward the view that *"above all the important thing is you enjoying it. Enjoying in the sense, creating the right environment where people are rewarded in such a way that they enjoy it. It could be travelling, it could be meeting people, it could be reading and challenging your own ideas" (3339, 3340).*

S1-InP2 stated that team building is important for effective R&D work (3338) and felt that many projects are not successful due to the distance relationship between the academic and industry teams (3337, 3336). S1-R2 also valued team building activities suggesting investment in activities such as away days (3341, 3342, 3343). Agreeing with the importance of maintaining the momentum and motivation of the team, S1-PI3 claimed *"I personally take a strong interest in making sure people become part of the team that they empowered and they are sufficiently motivated" (3335, 3333).* Collaborative research projects involve team members from different disciplines, with varying priorities and expectations regarding the project. Within this background achieving common consensus within the team members, common understanding of what is needed from the project was identified as important (3311, 3314, 3312, 3369). In his study, Lester (1998) also viewed having a common understanding of work as a prerequisite for the success of research work, as such would align the individuals goal with the overall.

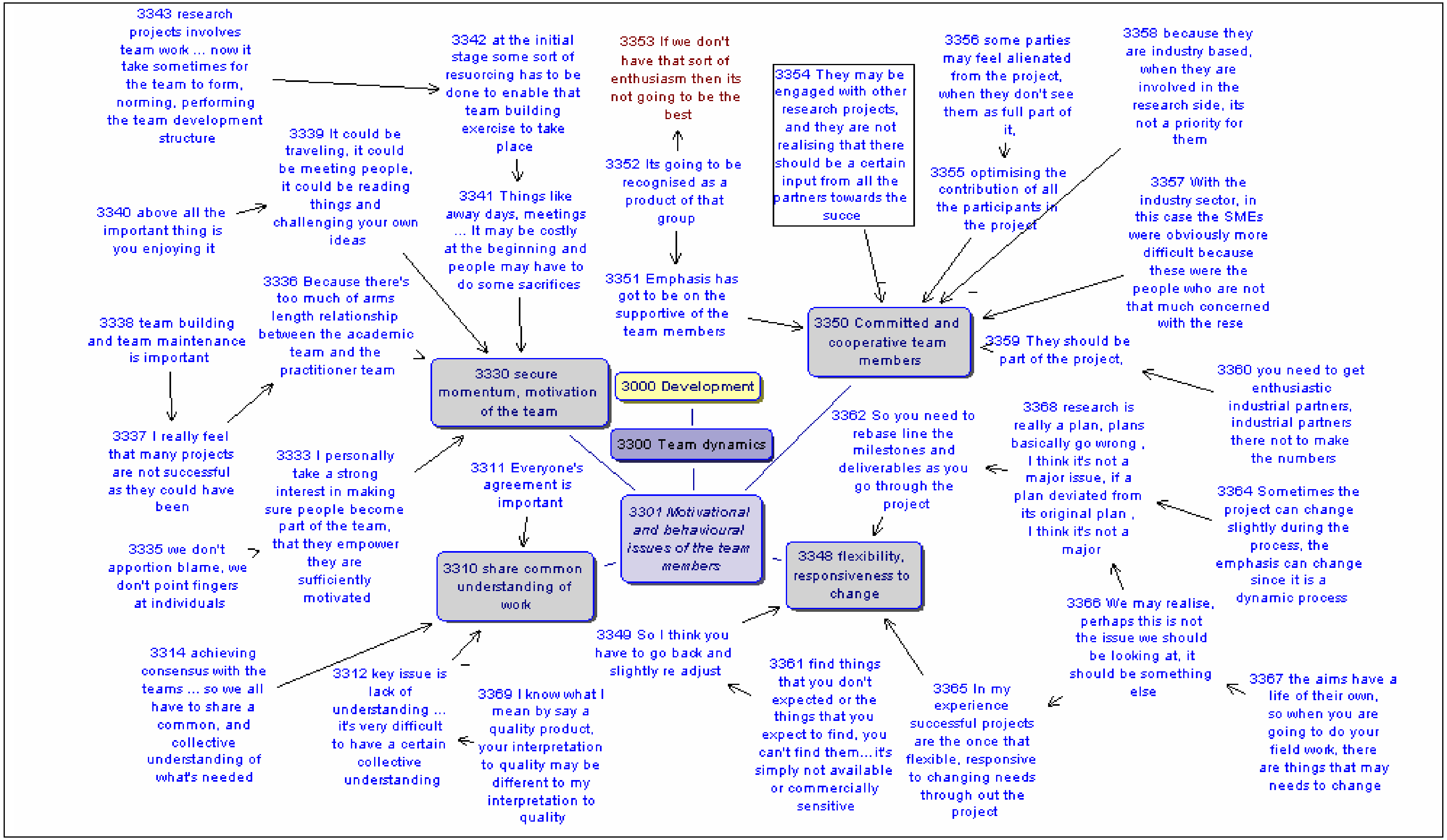


Figure 5.20: Cognitive map of the critical success factor "motivational and behavioural issues of the team members" at development phase

Flexibility and responsiveness to change was identified by a number of interviewees as another capability of the research team. S1-InP1 commented that the expected data from a project may not be available or may be commercially sensitive (3361) or the emphasis of the project could change due to the dynamic nature of research (3364). Further, S1-PI2 claimed *"the aims have a life of their own, so when you are going to do your field work, there are things that may need to change. We may realise, perhaps this is not the issue we should be looking at, it should be something else" (3366, 3367).* Thus, they admitted the need for being responsive to the changes encountered during a R&D project (3362, 3368, 3365). Being flexible during the R&D process (see Section 4.5.1) was highlighted by the expert interviewees as well as confirming the importance of flexibility and responsiveness to change as a desirable characteristic of the research team. Failure to build in flexibility in a new product development process and following a rigid formal process have been identified as drawbacks in studies carried out in other industries (Cooper and Kleinschmidt, 2007; Sun and Wing, 2005).

The above analysis arrived at the classification provided in Table 5.11.

Table 5.11: Critical success factors during the development phase

Development Phase	
Adequate resources and capabilities	Having a skilled team Adequate resources and financial support Having a well established operational procedure
Team dynamics: ***Motivational and behavioural issues of the team members***	Committed and cooperative team members Secure momentum/ motivation of the team Share a common understanding about the work Flexibility and responsiveness to change
Authority and commitment of the principal investigator	Leadership of the principal investigator Commitment of the principal investigator
Stakeholder satisfaction	Meet industrial partners' requirements Meet funding bodies' requirements

5.4.2.7 Critical success factors during the launch phase

The success factors during the Launch phase are illustrated in Table 5.12. From the 8 factors 2 of them *("meet researchers' requirements" and "refinement of the output after launch")* have an overall mean value below 4. Thus, they were excluded from further analysis as they are not critical during the launch phase. When subjected to Wilcoxon signed rank test, Asymp sig value was found to be less than 0.05 between *"launch the output within the planned time frame"* and *"comprehensive project review and feedback"*. This shows a significant difference between the opinions between these two factors. Therefore, *"comprehensive project review and feedback"* was considered as not critical.

Table 5.12: Ranking of the success factors at the launch phase

Success Factors	Academia	Industry Partners	Total		Asymp. Sig.
	Mean	Mean	Mean	Rank	
Effective dissemination of the results	4.56	4.48	4.52	1	
Meet funding bodies' requirements	4.65	4.30	4.49	2	0.73
Having a well established dissemination/ marketing plan	4.47	4.48	4.48	3	0.88
Meet industrial partners' requirements	4.21	4.63	4.40	4	0.46
Launch the output within the planned time frame	4.35	4.37	4.36	5	0.93
Comprehensive project review and feedback	3.91	4.22	4.05	6	0.03
Meet researchers' requirements	3.74	4.07	3.89	7	
Refinement of the output after launch	3.94	3.70	3.84	8	

The factor *"importance of meeting industrial partners' requirements"* shows statistically significant differences at 5% significance level when subjected to the Mann-Whytney U test (see Table 5.13). When referred back to the mean values of the academic members and industrial partners regarding the importance of this success factor, it can be identified that the industrial partners have assigned a higher value (4.63) than the academic members (4.21).

Table 5.13: Difference in opinion of the academic members and industrial partners at the launch phase

Launch phase	Asymp. Sig.
Having a well established dissemination/ marketing plan	1.000
Launch the output within the planned time frame	0.815
Effective dissemination of the results	0.807
Meet funding bodies' requirements	0.082
Meet industrial partners' requirements	0.022
Meet researchers' requirements	0.055
Comprehensive project review and feedback	0.131
Refinement of the output after launch	0.301

5.4.2.8 Synthesis of the critical success factors at launch phase

The NVivo coding structure and the cognitive map relating to the CSFs during the launch phase is shown in Figure 5.21 and Figure 5.22 followed by the analysis of the CSFs.

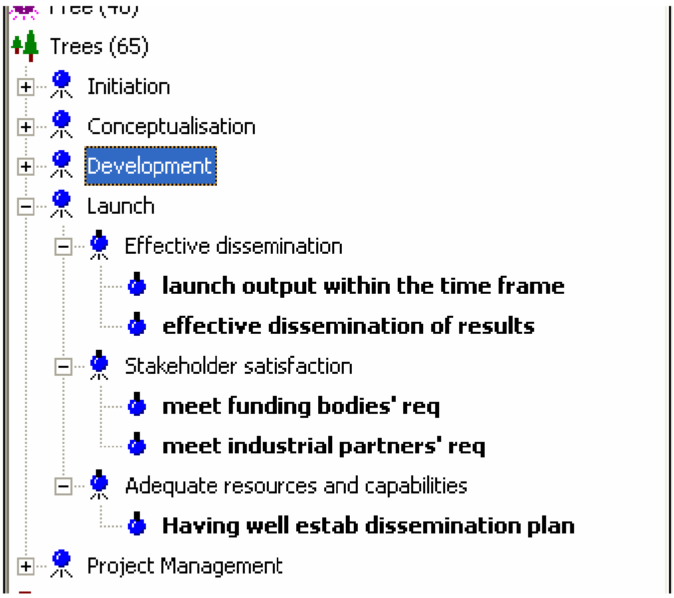


Figure 5.21: Coding structure for the critical success factors at launch phase

5.4.2.8.1 Stakeholder satisfaction

Similarly to the development phase, addressing the industrial partners' and funding bodies' requirements were identified as critical (see Section 5.4.2.6.1).

5.4.2.8.2 Effective dissemination of the work

Effective dissemination of the work was identified as important by a number of interviewees (see Figure 5.22). S1-InP3 claimed that the output of R&D activities is not properly disseminated to the construction industry (4335) whilst S1-InP1 stated that the R&D output is disseminated to a specific target group only (4334, 4333). Both S1-R2 and S1-InP3 acknowledged that effective dissemination of R&D output would help the industry to move forward (4331, 4332). Further, launching the output within the expected time frame was identified as important, otherwise, the results of the R&D work may lose value, stated S1-PI5 (4311). Effective dissemination will satisfy the stakeholders especially the funding body and improve the usability of the research results. Sun and Wing (2005) also recognised timely delivery of a new product to the customers as a CSF.

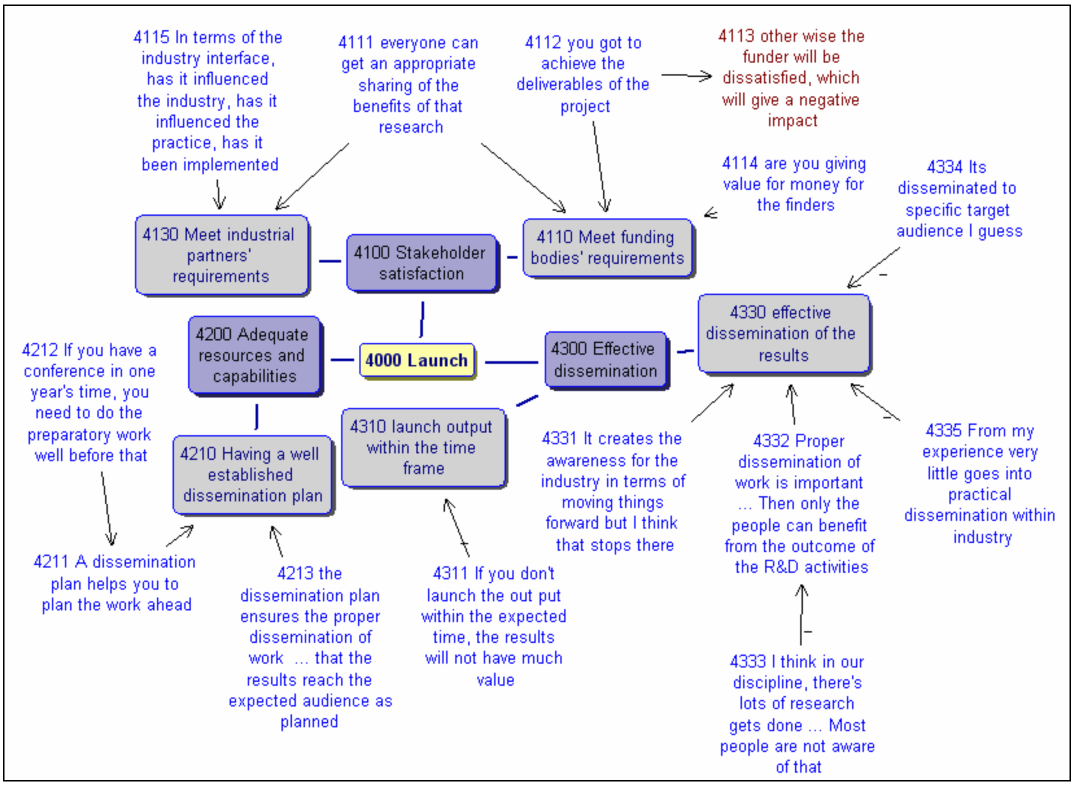


Figure 5.22: Cognitive map for critical success factors at the launch phase

5.4.2.8.3 Adequate resources and capabilities

As shown in Figure 5.22, the benefit of having a dissemination plan was highlighted by S1-R5 especially in terms of planning future work related to the dissemination of the research results (4211, 4212). Further, S1-R5 added *"dissemination plan ensures the proper dissemination of work. That the results reach the expected audience as* *planned"* (4213). Based on the above analysis, the CSFs during the launch phase are presented in Table 5.14.

Table 5.14: Critical success factors during the Launch phase

Launch Phase	
Adequate resources and capabilities	Having a well established dissemination/ marketing plan
Stakeholder satisfaction	Meet funding bodies' requirements Meet industrial partners' requirements
Effective dissemination of results	Launch the output within the planned time frame Effective dissemination of the results

5.4.2.9 Critical success factors during the project management

Table 5.15: Ranking of the success factors at the project management

Success Factors	**Academia**	**Industry Partners**	**Total**		**Asymp. Sig.**
	Mean	Mean	Mean	Rank	
Effective communication	4.68	4.74	4.70	1	
Effective collaboration	4.62	4.63	4.62	2	0.28
Effective planning, controlling, and organising of activities	4.41	4.67	4.52	3	0.29
Continuous reviews	4.35	4.63	4.48	4	0.53
Effective resource management	4.26	4.44	4.34	5	0.19
Effective management of the people	4.38	4.26	4.33	6	0.85
Having an external person to do reviews	3.97	4.00	3.98	7	
Evaluating post delivery success	3.82	4.11	3.95	8	
Having a separate project administrator	3.41	3.44	3.43	9	

Among the 9 success factors, 3 factors obtained an overall mean value of less than 4 indicating they are not critical (see Table 5.15). When subjected to Wilcoxon test for the remaining 6 success factors, the Asymp. Sig. value was above 0.05 indicating no significant difference at the 5% significant level between the remaining success factors. Hence, the factors ranking from 1 to 6 were considered as critical during the project management.

The Table 5.16 shows the Mann-Whitney U test of two independent samples which suggests that a statistically significant differences in opinion exist for "*the importance of continuous reviews*". The industrial partners (4.63) have given a higher value for the importance of continuous reviews than the academic members (4.35).

Table 5.16: Difference in opinion of the academic members and industrial partners at the project management

Project Management	Asymp. Sig.
Continuous reviews	0.04
Effective collaboration	0.986
Effective communication	0.716
Effective planning, controlling, and organising of activities	0.133
Effective resource management	0.307
Effective management of the people	0.544
Evaluating post delivery success	0.131
Having a separate project administrator	0.829
Having an external person to do reviews	0.783

5.4.2.10 Synthesis of the critical success factors at project management

The CSFs at project management were grouped into two categories namely project coordination (Figure 5.24) and resource management (Figure 5.25). Figure 5.23 shows the coding structure related to the CSFs during the project management.

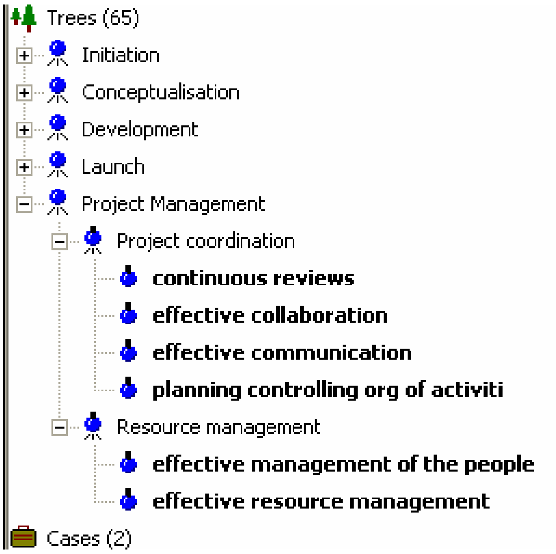


Figure 5.23: Coding structure for the Critical success factors at project management

5.4.2.10.1 Project coordination

It was evident in Section 2.4.5, that lack of reporting of the achievement of milestones, utilisation of resources has negatively affected construction R&D activities. Thus, improving reporting mechanisms and establishing proper communication channels in R&D activities was highlighted (see Section 2.6.5). Empirical investigation of this study also revealed the need for effective communication within the R&D project (see Figure 5.24). As commented by the interviewees, effective communication helps the team members to understand their roles and responsibilities in the project and the expectation of the team members from the project (5284, 5278). S1-PI1 stated "*disseminate all the information, good, bad news, outputs of the project so that everyone is informed and kept up to date" (5282)*. Agreeing with this view, S1-PI5 and S1-R2 also stated that when something is not happening as expected, it should be recognised and communicated to the team members (5276, 5271, 5272, 5273). S1-PI1 believed that due to such communications, the team members will feel part of the project (5283). However, S1-PI3 felt that certain information should not be communicated to some team members.

He stated "*however, there are certain circumstances where some of them (information) are commercially sensitive of which we then have to be little bit careful what we actually pass to some people" (5280)*. Nevertheless, S1-PI3 confirmed the importance of creating awareness of the objectives along with the research methodology to get the support of team members (5278). S1-InP2 noted that regular and meaningful communication between the team members was important to achieve a good relationship between the academic and practitioner teams (5274, 5275). In addition to creating a good relationship between the academic team and the practitioner team, S1-R2 believed that constant discussions between the principal investigators and researchers could minimise the distance between them and could affect the project positively (5286, 5287, 5288). Sun and Wing (2005) also noted having internal communication within the project team as a vital factor during the prototype and development phase of NPD work.

Planning, control and organisation of work is another CSF of a construction R&D project. Accordingly, S1-PI1 stated that understanding the deliverables, the people who are going to deliver them, the time scales and organising the activities to achieve them is important (5231). In support of his view, he added *"so its understanding of the project and the key elements and what time and resources required to achieve (the project objectives)"*.

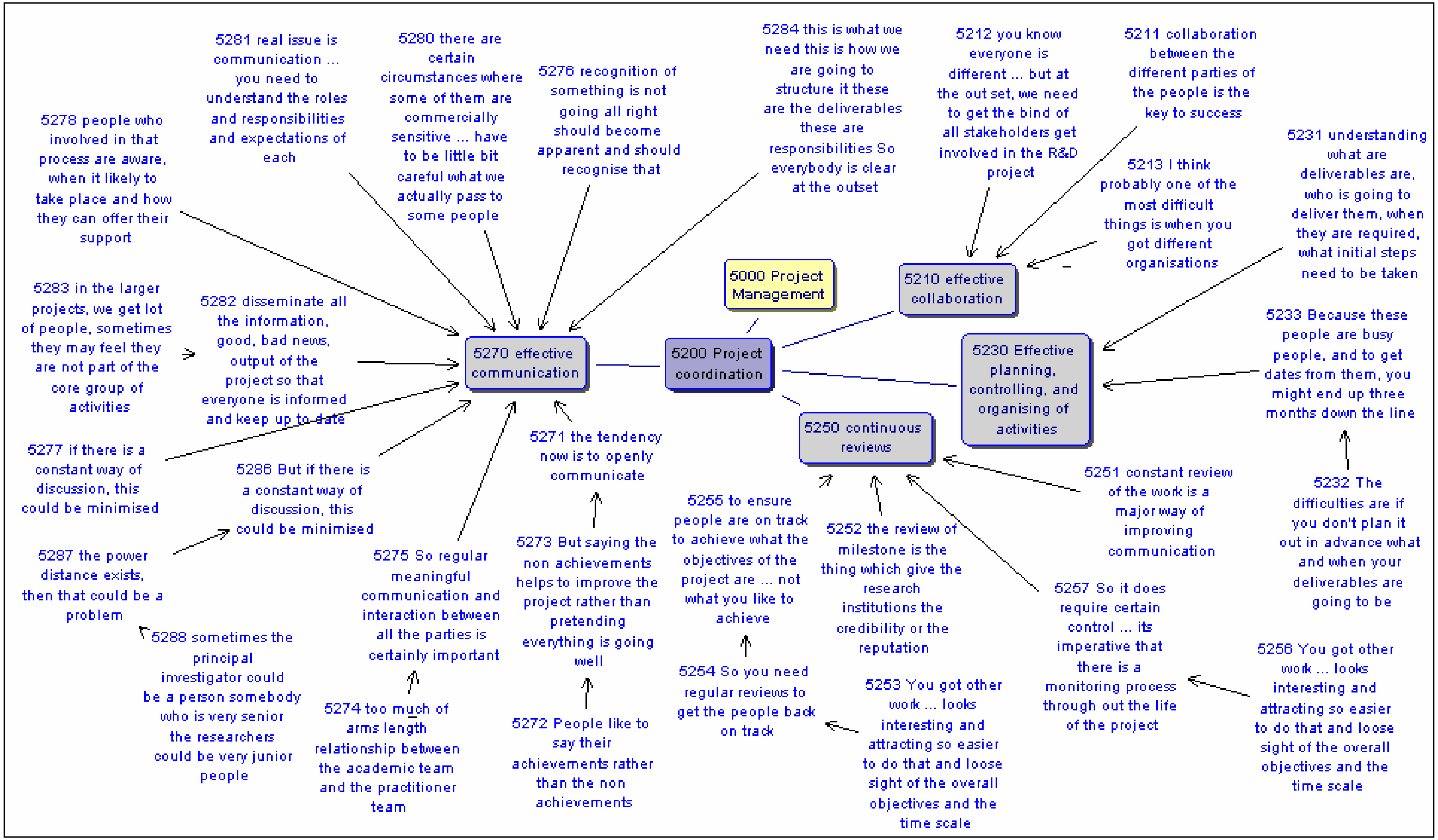


Figure 5.24: Cognitive map of the critical success factor "project coordination" at project management

Further, S1-R3 commented that because of the busy schedules of the parties involved in the R&D projects, it is important to plan the activities well ahead (5232, 5233). Thus, proper planning and organising of activities would enable the identification of any potential pitfalls or unnecessary delays well ahead, allowing enough time to take corrective measures without disrupting the flow of work.

Carrying out regular reviews is observed as important for the success of construction R&D function. S1-PI5 identified the review of milestones as a way of showing the credibility and reputation of the research institution (5252). For S1-R2, constant reviews are a way of improving communication (5251). S1-PI4 believed that regular reviews could put people back on track if they are deviating from the main objectives of the research project (5253, 5254, 5255). The concepts of the interview respondents correspond with Cooper and Kleinschmidt (2007), who viewed having frequent project update meetings, progress reviews, and problem resolution sessions as important. Sun and Wing (2005) also identified the same is important during the prototype and development phases.

Effective collaboration between the team members is another key factor for the success of R&D work (5211). S1-InP1 admitted that when there are different organisations, collaboration becomes a difficult task. Agreeing with this view, S1-PI3 stated *"we need to get the bind of all stakeholders get involved in the R&D project" (5212).* Due to the other work within a R&D project, S1-PI1 stated that it is easy to loose sight of the main objectives of the project (5256). Thus, he recognised the importance of having a monitoring process throughout the life of the project (5257).

5.4.2.10.2 Resource management

Resource management is identified as being a CSF of a construction R&D project (see Figure 5.25). S1-R1 asserted *"... right throughout the process, you got to be realistic about the resource requirement, effective in how you deploy them…"* (5140). Further, lack of resources within the project is identified as detrimental to the proper flow of work (5139). S1-PI1 stated that over spending of resources on a particular deliverable could result in inadequate use of resources which could impact on resources for other activities. (5134). Similarly, under utilisation of resources could result in reduction in the following years budget, commented S1-InP1 (5132).

Thus, he suggested directing surplus resources to some other activity within the project (5131). The effective resource management without over or under spending the resources is acknowledged by the interviewees (5137, 5136).

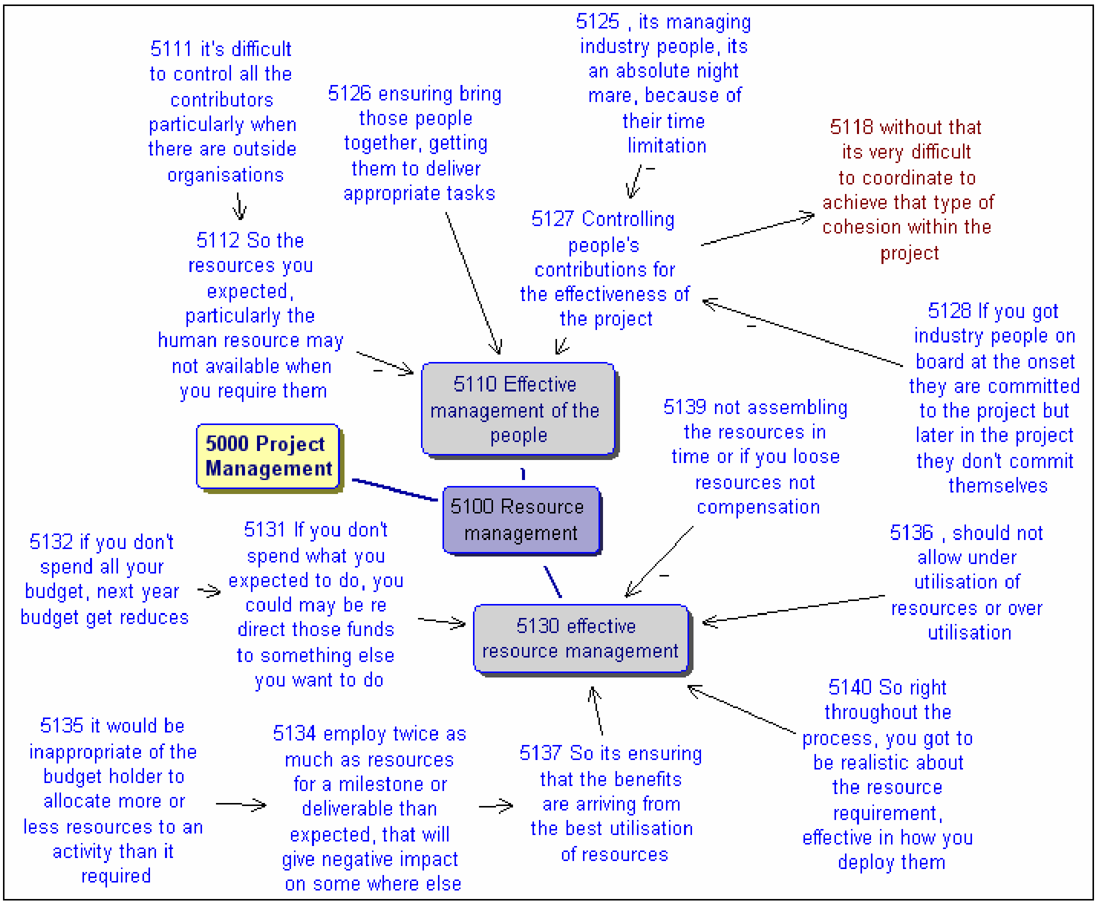


Figure 5.25: Cognitive map of the critical success factor "resource management" at project management

From the literature review it was elicited that human resource as one of the main requirements for effective R&D work (see Section 2.7.1). Thus, in order to get maximum support and commitment from the human resource, their management is critical. The empirical investigation also supported this view. Thus, getting the contribution of the team members for the effectiveness of the project is identified as important (5126, 5127). However, many interviewees felt that it is difficult to control the contributions especially from the external parties (5125, 5128, 5111). Thus, S1-PI1 stated that lack of human resource at a time when it is required may create difficulties for the coordination of the project (5112). Table 5.17 shows the CSFs during the management.

Table 5.17: Critical success factors during the project management

Project Management	
Project coordination	Continuous reviews Effective collaboration Effective communication Effective planning, controlling, and organising of activities
Resource management	Effective resource management Management of the people

The above sections presented the CSFs gathered through the empirical investigation for a construction R&D project as it goes from initiation (see Section 5.4.2.2, conceptualising (see Section 5.4.2.4), through development (see Section 5.4.2.6), to launch (see Section 5.4.2.8) phases and for the management of the project (see Section 5.4.2.10).

Section 5.4.1 of the empirical investigation, looked into the influences of PM within construction R&D projects and arrived at a number of benefits of PM such as: monitoring and controlling the R&D work; motivation of the team members; direction of the team members towards common goals; validation of the research results; improvement in the quality of research work; identification of alternative options to further improve the research work; improvement in communication and facilitation of inter project comparisons. Section 5.4.2 identified the CSFs of construction R&D project from initiation to launch phases and at the project management. By evaluating the CSFs identified in Section 5.4.2, the researcher deduced performance improvements which could be obtained through the implementation/consideration of CSFs during the R&D function (Figure 5.26). The performance improvements were categorised by considering their direct influence on the performance of the construction R&D function. Figure 5.26 further illustrates how the majority of benefits influence the proper progress of construction R&D work and ultimately all of their contribution towards the satisfaction of the stakeholders.

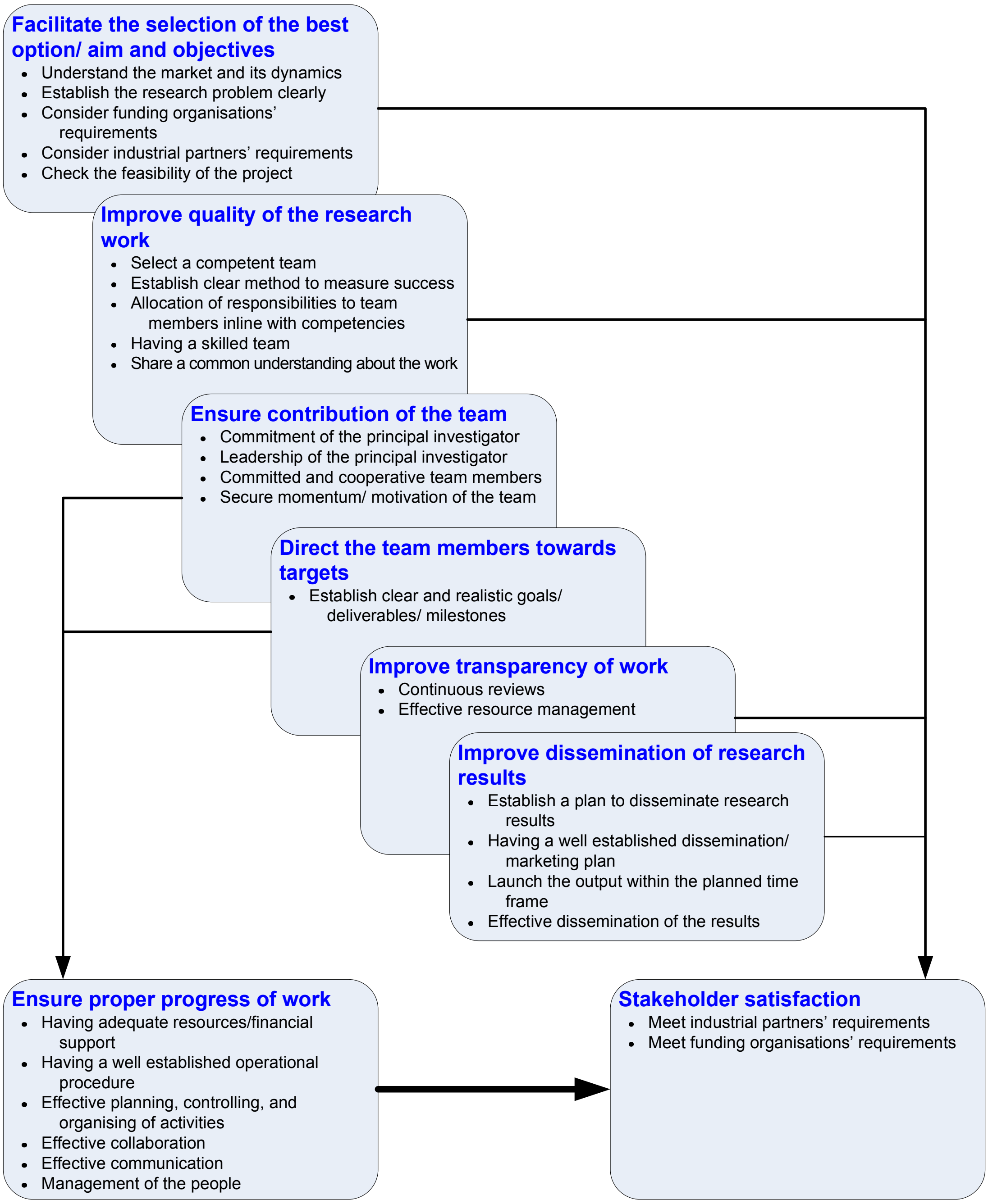


Figure 5.26: Influences of performance measurement towards construction research and development

5.4.3 Implementation of success factors

5.4.3.1 Analysis of the importance of success factors against their implementation/consideration

In addition to identifying the importance of the success factors, the questionnaire survey evaluated their implementation/consideration during the R&D project from initiation to launch phases and at the project management (see Appendix G for the questionnaire). Figure 5.27 shows the comparison of the importance and implementation of success factors at the initiation phase.

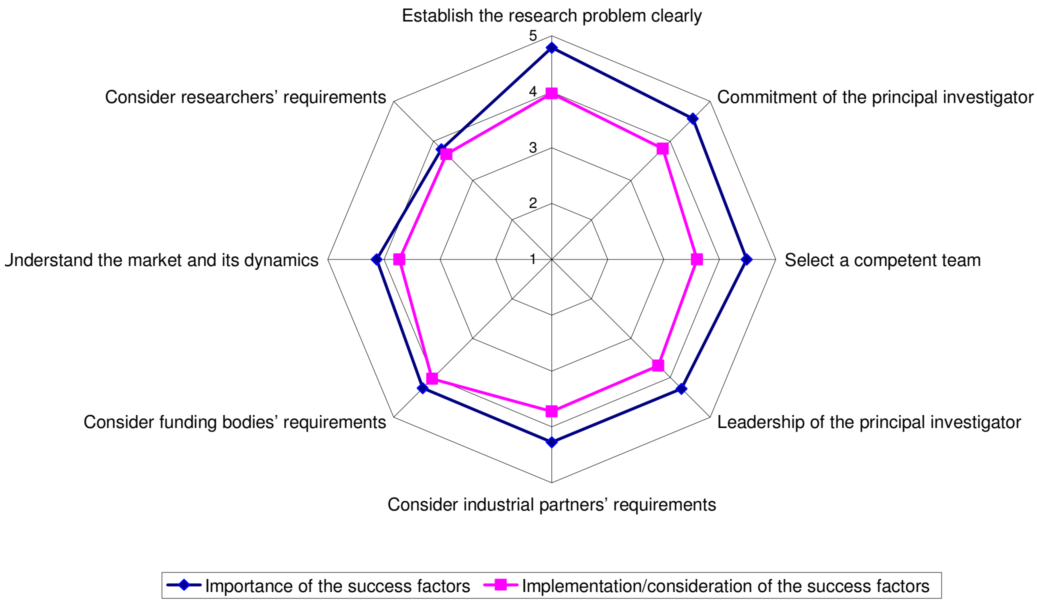


Figure 5.27: Comparison of the importance of success factors against their implementation/consideration at the initiation phase

At the initiation phase all the success factors except for *"considering funding bodies' requirements"* (mean 4.02) have obtained mean value of less than 4. Further, it can be noted that *"considering the funding bodies' requirements", "establishing the research problem clearly"* and *"commitment of the principal investigator"* are being identified as the most implemented/considered factors while *"selecting a competent team"* and *"considering researchers' requirements"* as the least implemented/considered factors.

Figure 5.28 illustrates the importance and implementation/consideration of success factors at the conceptualising phase. Within this phase, all the success factors have acquired a mean value less than 4. Nevertheless, similar to the initiation phase, *"considering funding bodies' requirement"* has been ranked as number one. *"Establishing a plan to disseminate research results"* and *"checking the feasibility of the project"* is ranked second and third respectively, while *"a fast decision making process"* and *"absence of a lengthy bureaucracy"* as the least implemented/considered factors.

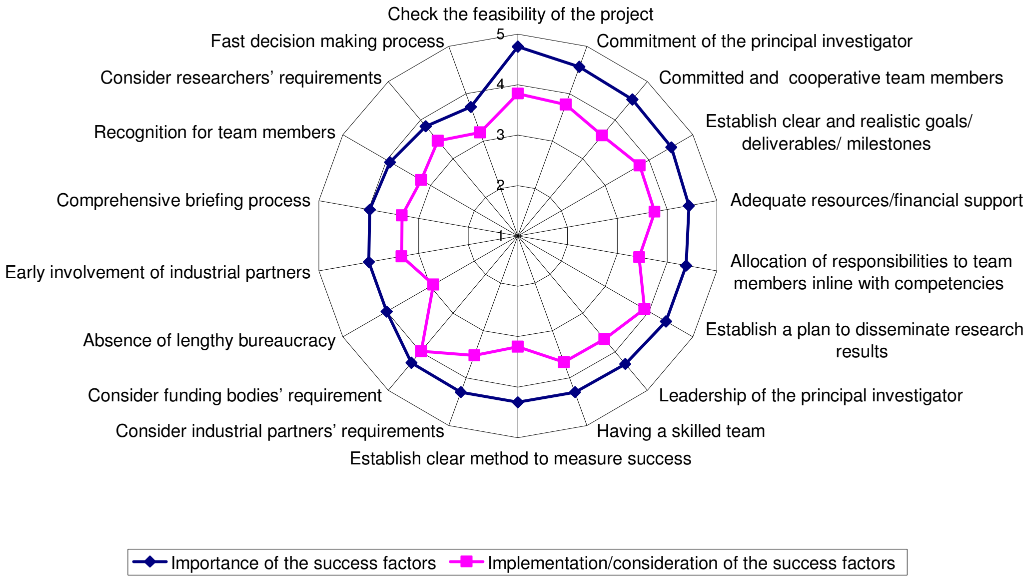


Figure 5.28: Comparison of the importance of success factors against their implementation/consideration at the conceptualising phase

Similar to the initiation and conceptualising phases, all the success factors have obtained mean values of less than 4 at the implementation/consideration during the development phase (see Figure 5.29). Further, *"addressing the requirements of the funding body"* has been ranked number one, while *"commitment of the principal investigator"* and *"having adequate resources"* have been ranked two and three according to their implementation/ consideration.

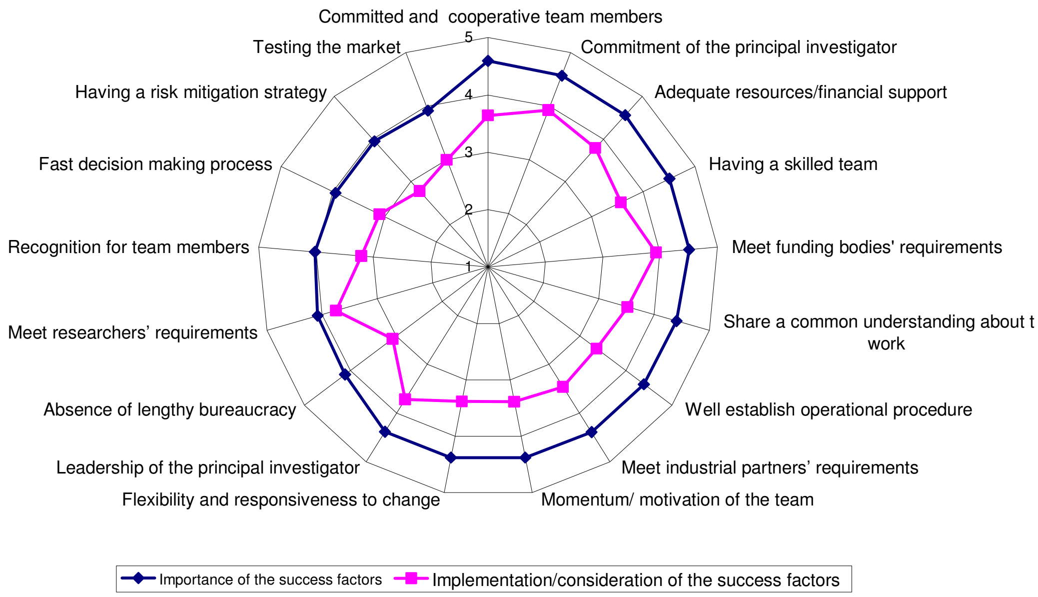


Figure 5.29: Comparison of the importance of success factors against their implementation/consideration at development phase

At launch, addressing the funding bodies' and industrial partners' requirements have been selected as the factors that were mostly implemented/ considered (see Figure 5.30). The success factors *"refinement of the output after launch" and "carrying out project reviews and feedback"* are identified as being the least implemented/considered factors. Corresponding to the other phases, at the launch phase also all the success factors have obtained their mean values less than 4.

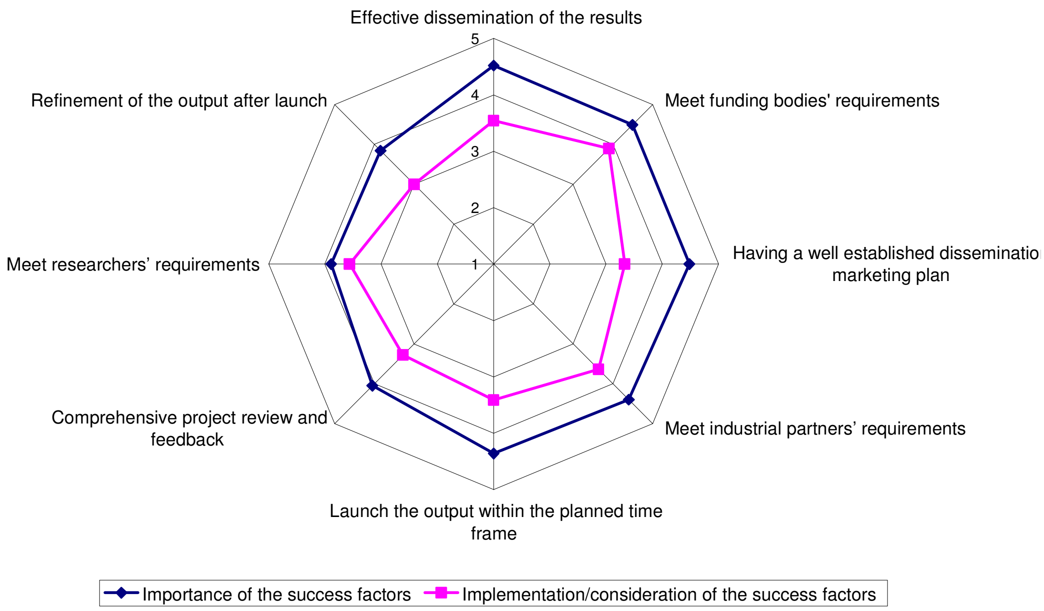


Figure 5.30: Comparison of the importance of success factors against their implementation/consideration at the launch phase

Carrying out continuous reviews and effective communication are identified as being the most implemented/considered success factors when managing the R&D project (see Figure 5.31). *"Engaging a separate person to undertake project administration work"* and *"evaluation of post delivery success"* have been selected as the least implemented/considered factors.

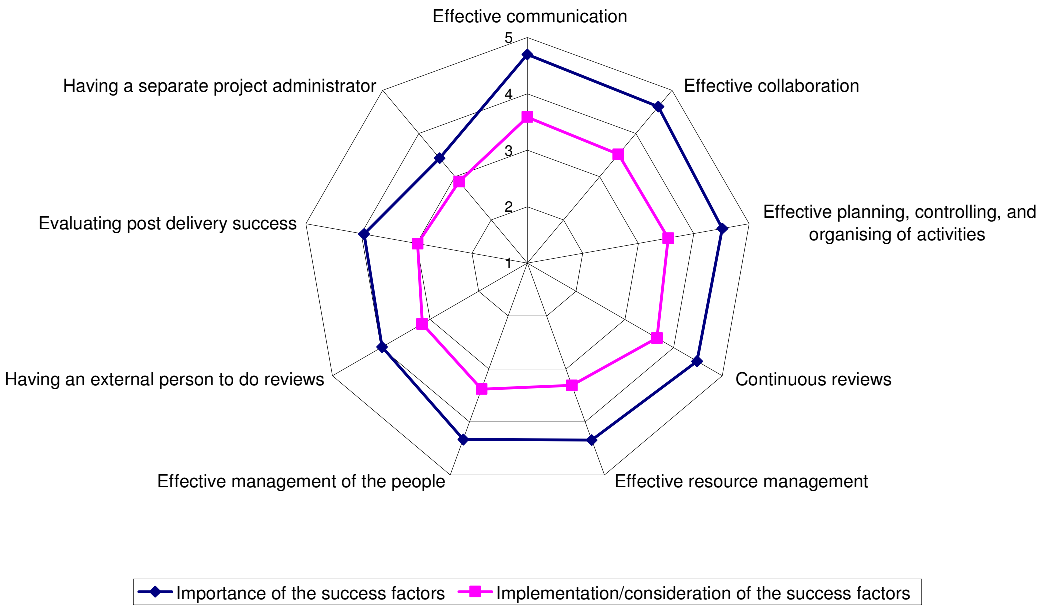


Figure 5.31: Comparison of the importance of success factors against their implementation/consideration at project management

5.4.3.2 Synthesis of the importance of success factors against their implementation/consideration

The above data indicates that the majority of success factors (except for *"considering the funding bodies' requirements")* are not very often (value 4) or always (value 5) implemented/ considered during the construction R&D function but are implemented sometimes (value 3) when evaluated against their assigned values for the questionnaire (Table 3.5). Further, satisfying the funding bodies' requirements is given a higher priority than the other success factors at all the phases. The success factors which were identified as non critical after considering their mean values and Wilcoxon signed rank test (see Table 5.5, Table 5.8, Table 5.11, Table 5.14 and Table 5.17) have generally been ranked lower at the implementation/consideration (except for *"meeting the researchers requirements"* during the development and launch phases). This gives a positive correlation between the importance and implementation of non critical success factors.

Though *“selecting a competent team”* has been ranked third according to its importance at the initiation phase, it has been ranked eighth at the implementation. Similarly, factors *“committed and cooperative team members”* at the conceptualising and development phases (rank 3 and 9, 1 and 6 respectively), *“allocation of responsibilities to team members inline with competencies”* at the conceptualising phase (rank 6 and 12) and *“establish a clear method to measure success”* during the conceptualising phase (rank 10 and 16) have taken higher rankings for their importance when compared with their implementation. This indicated that the above factors are not given due consideration during the implementation when compared to their importance. On the other hand, *“establish a plan to disseminate research results”* at the conceptualising phase (rank 7 and 2), and *“leadership of the principal investigator”* at the development phase (rank 11 and 5) have been given a higher ranking for implementation when compared with the ranks obtained for their importance.

Accordingly, some factors showed an inconsistency between the importance and implementation based on their assigned ranks. Such inconsistency of CSFs based on the importance and implementation was identified in the study carried out by Sun and Wing (2005). Further, the results revealed that, when compared with the importance, it is seldom that almost all the CSFs are given enough attention during the actual implementation. This suggests that the R&D project requires certain goals and performance indicators for the effective implementation/ consideration of the CSFs.

The above section evaluated the CSFs related to the construction R&D function and their implementation during the R&D function. The data analysis and findings provided in the section below leads this chapter into identifying the existing PM practices within the case study.

5.4.4 Status of the application of performance measurement, performance indicators and measures

The general and R&D specific performance measures and their characteristics were explored in Section 2.5.3 and 2.6.3. The literature review highlighted the drawbacks of using solely financial oriented performance measures and emphasised the need for multiple performance measures which capture both financial and non financial aspects of the performance (see Section 2.5.3). Further, from the expert interviews it was revealed that within construction R&D, more emphasis is placed on the identification of the knowledge gained, development of researchers and the intangible benefits to the project rather than the financial returns (see Section 4.4).

Having empirically evaluated the influence of PM in construction R&D in Section 5.4.1, this section discusses the issues related to the PM applications and explores the existing PM practices within the case study. Accordingly, the section below first discusses the opinion of the interview participants regarding the usage and shortcoming of the current PM applications.

5.4.4.1 Status of performance measurement applications in construction research and development

S1-PI2 noticed that both the funding bodies and industrial partners are not demanding enough on the project performance evaluations of the R&D projects. *"I can't see how they (funding body) can allocate hundreds of thousand pounds based on an entire feedback mechanism on quality of piece of work in 6 pages"* commented S1-PI2. Further, he believed that if the project failed to deliver the stipulated outcome, funding body need to consider that in the future bidding process.

According to S1-R1 the performance measures used during the project lack the flexibility to make changes. He stated "*one problem with that (PM) could be the logical framework is very hard to compile initially. When you go through the process, there could be so many instances where you can simply miss important measurement aspects. Since it is one simple document, not all the aspects will be documented within that document. It is during the process that you realise, ok these are the important factors that you have take into account in the measurement. But the logical framework simply doesn't accommodate that, at least within a certain given* *period*". S1-PI1 stated that lack of performance measures to identify the impact upon the beneficiaries as a shortcoming of the current PM applications. He stated *"in many research projects, you can do the research fully, make all your deliverables, but the actual impact can be very small, almost not at all, when the project finishes, its almost like nothing happened, as far as the beneficial recipients are concerned"*. He suggested that the funding body should make post project evaluation a part and parcel of the project and the funding body should be willing to fund that.

S1-InP3 identified lack of measures on assessing the quality of R&D work as shortcoming of the current PM applications. Similarly to the views of S1-InP3, S1-InP2 also stressed the importance of incorporating quality parameters as performance measures. *"Performance measures have to be something that other people can take a view of as well as yourself. It's very easy to get self deluded… So peer reviews comes to my mind"* stated S1-InP2 suggesting using peer reviews on the R&D work to improve quality.

S1-R2 viewed lack of feedback within the current PM system as a drawback. *"…people don't know how they are assessed, people don't know what the assessors are doing with what ever the data and quite frankly, the whole purpose of PM gets lost"* stated S1-R2. Thus, he stated rather than keeping the PM results to the higher level management, it needs to be effectively communicated to the researchers and those who are involved within the R&D process. He added *"… that's where works gets done. And that's where work can be improved actually"*. Agreeing with the above comments, S1-R1 also highlighted the importance of getting the beneficiary input to the PM applications. He commented *"I think, when and where we deliver the outputs to the intended beneficiaries, if there's a mechanism to get the feedback from them about the effectiveness of it, then that could be a big measure towards the performance"*.

In addition to the above drawbacks of the current PM applications, S1-PI1 stated that the current performance measures are informal and vague thus, not giving a proper indication of the performance level. Similarly, S1-R5 also had the same view and commented *"it's quite informal. We haven't used any formal structures. So the difficulties of that could be that it is not so easy to know how much more to do as* *well as the success so far"*. S1-PI2 stated that PM should become part of the project culture and should not be something that the people work against.

The above sections discussed the opinions gathered from the semi structured interviews on the current PM applications within the case study. The section below analyses the data gathered from the questionnaire survey on the usage of performance measures.

5.4.4.2 Applicability of performance measures during the construction research and development project

The use of performance indicators and measures were initially evaluated via the semi structured interviews carried out within the case study and through the questionnaire survey. When asked about the use of performance measures during the R&D project, all the interviewees stated that they use performance measures. S1-PI1 commented *"…it (PM) needs to be done, the important part is continuous monitoring and controlling of the research project. Employing all the measures that are necessary is important"*. S1-PI1 admitted that he preferred to measure the straightforward targets such as time and budget whilst S1-PI3 laid emphasis on the quantitative measures. *"We try to stick to the quantitative ones primarily. Because they are more objective and they are easily measurable"* stated S1-PI3. In contrast to that, S1-PI2 favoured the use of measures such as customer (industrialist) satisfaction, academic peer group satisfaction, acceptance of journal papers, the impact that has been made by the research findings, satisfaction of the researchers and career development of the researchers. S1-PI2 preferred to place more emphasis on performance measures related to *"human resources"*. Thus he asserted *"Some researchers come in and they want to stay in academia, so have you helped them on their journey to progress in what ever field they want to. If researchers want to go back into industry, have you helped them to develop the contacts, and the transferable experiences and skills to go into industry"*. However, he stated that such targets are measured in an informal manner and do not need a formal appraisal format hence he stated *"every time when you meet a researcher in the corridor, at a meeting, in the pub etc, the constant interaction is important"*.

All the interviewees acknowledged the positive influences of PM towards construction R&D activities (see Sections 5.4.1.1 and 5.4.1.2). However, S1-PI2 claimed *"performance measurement is a construct I am not comfortable with, with respect to research projects…"* though he identified the benefits of PM within construction R&D.

Having identified the general opinion about the usage of PM within construction R&D through the semi structured interviews, the section below is the data gathered from the questionnaire survey. Section 3 of the questionnaire survey examined the performance measures used within construction R&D project and their usage (see Appendix G). There were three questions on identifying the performance measures used by the researchers. When constructing the questionnaire, these questions were excluded from the industrial partners' questionnaire due to their irrelevance to them. However, three academic members and two industrial partners restrained from answering to Section 3 of the questionnaire. Furthermore, among the respondents who answered Section 3 of the questionnaire, another six respondents did not identify the type of performance measures used during the R&D project (see Table 5.18).

Table 5.18 shows the percentage usage of performance measures during the construction R&D project and ranked them accordingly. For the three questions which were not included in the industrial partners' questionnaire, the percentage obtained from the academic members were taken as the overall value when ranking.

Table 5.18: Types and percentage usage of performance measures

	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	Performance measures
Measures on the project finance (requirement, allocation and utilisation)	84.00	1	96.77	1	91.07	1	Analysis of project budget; delays due to lack of finance
Measures on the project time	84.00	1	90.32	2	87.50	2	Achievement of milestones, deliverables; time deviations from the expected
Measures on the accomplishment of the project objectives	80.00	3	83.87	3	82.14	3	Achievement of milestones, deliverables
Measures to identify the stakeholder requirements/ expectations from the project	80.00	3	74.19	6	76.79	4	Stakeholder requirement analysis
Measures on the accomplishment of the milestones	72.00	5	80.65	4	76.79	4	Achievement of milestones, deliverables
Measures on the project quality	68.00	7	77.42	5	73.21	6	Achievement of deliverables to the required standards
Measures on the stakeholder involvement and commitment	64.00	9	70.97	7	67.86	7	Time commitment of stakeholders; project meeting attendance; absence ratio
Measures on the feasibility of the project	52.00	12	70.97	7	62.50	8	Measures on cost and benefits analysis; achievement of project goals against the potential risks
Measures on the project team performance	68.00	7	58.06	9	62.50	8	Number of publications made by the team

	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	**Performance measures**
							members; number of awards won; presentation at workshops/ conferences
Measures on identifying the satisfaction of the stakeholders	72.00	5	54.84	11	62.50	8	Achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys
Measures to identify the market needs	64.00	9	58.06	9	60.71	11	Market analysis
Measures on the other resources (human, equipment etc)	64.00	9	48.39	12	55.36	12	Resource requirement and utilisation analysis; delays of work due to lack of resources
Measures on the post delivery success	44.00	13	48.39	12	46.43	13	Response from the industry on the utilisation of the research results
Measures to identify the researchers' requirements/ expectations from the project	-		45.16	15	45.16	14	Researchers' requirement analysis
Measures on the education and training of researchers	-		41.94	17	41.94	15	Qualifications and experience of the researchers; training activities provided
Measures on the comprehensiveness of the research proposal	32.00	14	45.16	15	39.29	16	A research justification plan
Measures on the development of new research directions	28.00	16	48.39	12	39.29	16	Acquisition of new research projects
Measures on the learning and growth of the stakeholders and researchers (knowledge	32.00	14	38.71	18	35.71	18	Completion of postgraduate degrees (PhDs); Number of publications by the team

	Industry % N=26	Rank	Academia % N= 34	Rank	Overall % N= 60	Rank	Performance measures
gains/ knowledge creation, transfer and exploitation)							members; presentations at conferences
Measures on identifying the satisfaction of the researchers	-		35.48	19	35.48	19	Time commitment of researchers; project meeting attendance; absence ratio
Measures on the retention of the stakeholders	28.00	16	16.13	20	21.43	20	Follow on funding; continuous engagement/ partnership of stakeholders
Measures on the acquisition of new business relationships	28.00	16	16.13	20	21.43	20	Number of subsequent projects acquired and new opportunities derived from the project; follow on funding

It can bee seen from Table 5.18 that the performance measures on the R&D project finance is ranked first by both industrialists and academic members and obtained an overall percentage above 90, indicating their intense usage. Furthermore, performance measures on time and accomplishment of objectives of the project are identified by the respondents (both industry and academic members) as the mostly used measures within projects obtaining above 80% usage. Moreover, measures on the identification of stakeholder requirements, accomplishments of milestones and project quality take the overall rankings of 4 and 6 respectively with an overall average above 70%. The measures on identifying whether the stakeholders are actually satisfied with the project outcome have taken an overall percentage of 62.5. Though the overall value obtained for the *"measures on the satisfaction of the stakeholders"* is less when compared with the measures which are implemented to satisfy the stakeholders (finance, time, objectives, quality, milestones), the industrial partners have ranked it in 5th place with a percentage value of 72.

Though the utilisation of measures on finance is identified as being the most implemented performance measure (ranking 1st), the use of measures on the other resources (human, equipment etc) has taken the overall rank of 12. The measures regarding the evaluation of impact made by the research output such as post delivery success, development of new research directions, retention of the stakeholders and acquisition of new business relationships have obtained a percentage value of less than 50. Similarly, the measures which evaluates the researchers' requirements and development (identify the researchers' requirements/ expectations from the project, education and training of researchers, satisfaction of the researchers) have also achieved a percentage values less than 50.

5.4.4.3 Synthesis on the current performance measurement applications

The interviewees showed interest in and acknowledged the use of performance measures during the construction R&D project. A variety of performance measures were being used in the construction R&D project ranging from financial to non financial, qualitative to quantitative. Nevertheless, the interviewees had their own preferences in choosing the performance measures whilst the majority of them primarily focusing on the quantitative measures due to their straightforwardness and ease of measurement. Further, some favoured the use of performance measures related to the human resources as human resource is a vital factor behind the success of construction R&D activities.

Lack of demand from the funding bodies and industrial partners to come up with better performance measures which show the efficiency and effectiveness of the R&D work can be identified as a lack of PM applications in the current system. Further, rigidity of the current system in making amendments during the R&D process to the existing performance measures is another drawback. This forbids the possibility of accommodating correct and necessary performance measures during the R&D process thus the project has to go ahead with the performance measures even if they are incorrect or assess the wrong targets. Therefore, the PM applications need to be flexible enough to add or omit correct performance measures during the process. Moreover, the PM applications should be designed in such a way as to identify future improvements and alternative methods of improving the success rather than stopping when the required performance is achieved.

Lack of measures to evaluate the actual impact of R&D project for its beneficiaries is another shortcoming. Thus, incorporating and allocating funds for the evaluation of post delivery success within R&D PM applications is recommended. Another drawback of the current PM applications is lack of feedback from PM to the on going R&D process and lack of communication of the results to the people who are involved. This fact was identified as a negative aspect in Section 5.4.1.3 and failure to give feedback on the PM applications was identified as a waste of resources utilised to measure the performance. Further, in Section 2.4.5 it was identified that the lack of communication on the performance of the R&D project (whether the project is moving as expected, the success or failure and information on the resource utilisation) has weakened the interest of the funding bodies and industrial partners resulting in low investment and lack of involvement by industrial partners.

Moreover, feedback on the ongoing R&D process would enable further improvements to the future process. Thus, creating appropriate feedback loops, effective communication on the progress to the involved parties and obtaining the views of the beneficiaries towards the on going R&D process is important for its development. Lack of clarity, structure and the use of informal methods to measure the performance of R&D project is another issue. Lack of formality, may lead to confusion over the scope of the work required. Further, lack of quality parameters within PM applications is another drawback which may lead to substandard outcomes. Thus, incorporation of peer reviews and building up testing and validation for research results is needed. It was identified in Section 2.5.2, that PM has become an integral part of the planning and control of the organisation. This fact was further supported by the case study findings where S1-PI2 highlighted the importance of making PM a part of the culture. He commented *"… performance measurement should be part of the culture. It is partly the way we do things…So it should be about peer pressure, peer review that constantly monitoring your own performance and other people's performance in a positive organic way, not abstracting out so then becomes sort of external things which we work against"*.

From the results on the usage of performance measures (see Table 5.18), it can be seen that the performance measures which are required to satisfy the stakeholder requirements (funding bodies' and industrial partners') are being well implemented within R&D project. More than 70% of the respondents have identified the use of measures on project finance, time, accomplishment of objectives, milestones and quality within the R&D project. Moreover, a higher usage of performance measures on the identification of stakeholder requirements from the project was also viewed as important by both industrialist and academic members. This proves that during the R&D project as it moves from initiation to launch phases, more attention is paid to the identifying and satisfying the stakeholders' requirements through achieving the cost, time, quality targets and accomplishing the project objectives. Further, it can be argued that more emphasis is paid to the project finance and time targets than quality of the project. This fact further coincides with the identification of CSFs in Section 5.4.2 as consideration and satisfaction of the funding bodies and industrial partners are being treated as CSFs during the R&D function. Further, it was noticed that in terms of the implementation of CSFs, the satisfaction of the funding body was ranked first in most of the phases, indicating it is well implemented during the R&D project than the other factors (see Section 5.4.3).

In opposition to the satisfaction of the stakeholders, (funding bodies' and industrial partner's), researchers' satisfaction was not identified as critical for the R&D project. In most of the situations, it obtained an overall mean value less than 4 (see Section

5.4.2). This fact was further proven in Table 5.18 as the measures on the learning and growth of the researchers, education and training of the researchers and identification of the satisfaction of the researchers obtained a lower rank when compared with similar measures to the other stakeholders. Further, it can be said that within the R&D project more attention is paid to the effective management of finance than other resources such as human resources and equipment. The results of Table 5.18 imply that after the launch, less attention is paid to the evaluation of the success of the new venture. This fact was observed even in the interviews carried out as S1-PI4 recommended the evaluation of the post delivery success of the project as an area requiring improvement. Further, allocating separate funding to assess the success of R&D work after the launch is also suggested by S1-PI4.

The above sections discussed the findings of the exploratory stage of the case study. Based on the findings of the exploratory stage and the characteristics of the Performance Measurement System (PMS) (see Section 2.5.4.1), a PMS was populated (see Figure 5.32) by mainly identifying the performance measures (see Table 5.19) for the construction R&D function. Further, a cause and effect map was prepared to show how the intangible assets could create value for the R&D project (see Figure 5.33). The development of the PMS is discussed in the section below.

5.5 Theory development

This stage focuses on the development of a Performance Measurement System (PMS) to measure the performance of construction R&D activities based on the finding of the exploratory stage of the case study.

5.5.1 Need of a performance measurement system to measure success of construction research and development

As discussed in Section 5.4.1.1 and 5.4.1.2 through semi structured interviews, a number of positive influences of PM were identified. Positive influences of PM suggested that effective and efficient PM within construction R&D activities will help to minimise the issues (see Section 2.6.5) within the construction R&D (see Section 5.4.1.5). In addition to the positive influences of PM, the respondents revealed negative influences of PM. The negative influences of PM emphasised the need for using correct targets for PM and the need for making PM a part of the R&D project (see Section 5.4.1.5). The importance of identifying correct targets for PM justified the identification of CSFs of construction R&D function. Finally, ensuring the implementation of CSFs through performance measures would deliver success to construction R&D work. Accordingly, through semi structured interviews and the questionnaire survey administered within the case study, the CSFs of construction R&D projects from initiation to launch phases and at the project management was extracted (see Section 5.4.2). When evaluating the importance of the success factors against their implementation, it was revealed that almost all the CSFs were not implemented to the extent that their importance implied (see Section 5.4.3). Further, some of the CSFs showed an inconsistent correlation among the rankings obtained for importance and implementation. These findings pointed to the need for performance measures to ensure the proper achievement of the CSFs. Moreover, within the current PM applications of the case study, non-existence of a robust PM approach was evident. Instead, the PM approaches were characterised by informality, lack of structure, and lack of rigour in identifying and measuring the performance (see Section 5.4.4). From the above mentioned findings of the exploratory stage of the case study, it is apparent that construction R&D activities need PM applications which have the characteristics as follows:

- correct targets in measuring performance (see Sections 5.4.1.5);
- ensuring the proper implementation of CSFs in construction R&D activities (see Section 5.4.3);
- a structured approach to measure the performance (see Section 5.4.4).

Having identified the need for a PMS within construction R&D, the section below discusses how PM could be used to bridge the gap between organisations' strategy and R&D and the implementation of R&D strategy.

5.5.2 Strategy and performance

The contribution from R&D to the success of business (see Section 2.2.1) was well highlighted, with particular reference to the importance of R&D within the construction industry (see Section 2.3.3). Further, it was ascertained in Section 2.2.2 that R&D activities are needed to cover a broad spectrum of areas in fulfilling the requirements of the organisation while satisfying its customers and shareholders.

Therefore, it was asserted that R&D activities need to be integrated into the organisational strategy (see Section 2.2.2). Thus, a number of authors have specified R&D as a factor which determines the strategic success of organisational development (see van Rooij, 2008; Herath and Bremser, 2005; Bremser and Barsky, 2004). Therefore, it is important to recognise the influence of R&D activities on other functions of the organisations as well as on the success of organisational strategy as a whole. In this context, PM on R&D helps to creates links between the organisation's strategy and R&D by translating the organisation's strategy into performance measures which could, in turn, be linked to R&D activities. The need for aligning strategy with performance measures for the successful attainment of the mission/ vision was discussed in Section 2.5.4.1. When the vision is linked to the performance indicators, the implementation of performance indicators would ensure the proper implementation of the vision. Therefore, it can be argued that the vision of R&D can be implemented through the use of PM applications. Accordingly, from the empirical investigation of this study "*what is important for effective construction R&D function"* was identified in the form of CSFs (see Section 5.4.2) during the exploratory stage and performance indicators and measures are designed to represent and implement the CSFs (see Figure 5.32 and Table 5.19). Therefore, from the above process, the R&D strategy is translated into measurable goals through the identification of CSFs. Thereafter, through the performance measures, the strategy can be communicated to the parties involved in, thus making the strategy known to the wider community while ensuring its achievement.

5.5.3 Development of performance measurement system for construction research and development

A draft PMS was developed based on the findings of the exploratory stage of the case study (see Section 5.4) and was refined through a series of semi structured expert interviews during the explanatory stage of the case study (see Section 5.6). In addition to the refinement of the PMS, the impact PMS could make towards the success of construction R&D function was assessed through the experience of the interviewees (see Section 5.6). The draft PMS shows the CSFs at the four phases of the R&D project and at project management. Further, performance indicators which lead to achieving the CSFs are also illustrated in the PMS (see Figure 5.32).

Furthermore, performance measures which represent the performance indicators are also identified and presented in Table 5.19. The project management section of the PMS shows the iterative nature of R&D activities and the feedback and feed forward processes. After developing the PMS, it was transferred to a map which consists of three perspectives namely; stakeholder satisfaction, internal business process and learning and growth (see Figure 5.33). By doing so, the links between the perspectives and how intangible assets could create value for the R&D effort was identified and visualised.

The PMS, the success map and the table representing the performance measures are presented in Figure 5.32, Figure 5.33 and Table 5.19 respectively after carrying out modifications based on the comments received from the expert interviews at the explanatory stage of the case study (see Section 5.6).

5.5.4 Success map

It is important to communicate the overall objectives of the R&D activities to the parties involved. Thus, the PMS developed for the construction R&D function was transferred to a success map. The success map of the construction R&D function illustrates how the resources, infrastructure and the capabilities are linked with the overall objectives of R&D activities (see Figure 5.33) .

5.5.4.1 Stakeholder satisfaction

The first perspective, that of stakeholder satisfaction focuses on satisfying the funding bodies' and industrial partners' requirements. The importance of ascertaining stakeholders' needs and expectations and delivering value to them are well established in the exploratory stage of the case study (see Sections 5.4.2.2.2, 5.4.2.4.3, 5.4.2.6.1 and 5.4.2.8.1).

5.5.4.2 Internal business process

The second perspective looks at the processes needed to satisfy the stakeholder requirements. Accordingly, at the initiation phase building up a solid foundation for R&D work is essential in the form of establishing a clear research problem by proper market analysis and selection of a competent research team to provide multidisciplinary skills required for the R&D project. Further, clearly identifying the requirements of the funding body and industrial partners is needed, so that their requirements and expectations can be properly catered from the project. Moreover, carrying out a feasibility study to identify any pitfalls that could hinder the success of the research project, being realistic about the expectations of the project, proper allocation of responsibilities to suite the capabilities of team members and establishing a dissemination plan to ensure the effective dissemination of the work is important. In addition to this, establishment of clear methods to evaluate the achievement of goals, milestones, and deliverables is important so that the research project is continuously monitored and corrective actions are taken when the project deviates from its original goals. Apart from the aforementioned factors, proper communication and collaboration of the parties involved within the project, appropriate planning, coordination, organisation of activities and resource management is important. Further, effective dissemination of the research results and launching the output within the proper timeframe are important for the success of the R&D function. Overall, the activities involved within the internal business process perspective ensure a proper base is provided for the R&D work whilst ensuring efficiency and effectiveness of supportive activities needed for the success of R&D work. By doing so, the stakeholders requirements can be properly met, thus satisfying them.

5.5.4.3 Learning and growth

The third perspective is learning and growth which refers to the correct resources, infrastructure and capabilities needed to facilitate and improve the R&D processes. Provision of a capable, motivated and committed team to carry out the work, finance and other resources needed for the success of R&D activities, supportive infrastructure such as well established operational procedures and dissemination plans are addressed from this perspective. In addition to this, the learning and growth perspective of this success map looks into characteristics required by the principal investigators in terms of his/her commitment and leadership. Further, having a common understanding of the work and being flexible and responsiveness to change within R&D work is acknowledged.

The empirical investigation in this study (see Section 5.4.2.2.2, 5.4.2.4.3, 5.4.2.6.1 and 5.4.2.8.1) and the literature review (see Section 2.4.5) elaborated on the importance of satisfying the stakeholders of construction R&D activities to safeguard continuous funds and to secure their contribution and involvement. Accordingly, the success map also acknowledges and illustrates the importance of delivering value to the stakeholders to win their loyalty and thereby enhancing construction R&D activities.

In this context, the map illustrates the availability of resources, infrastructure, capabilities, intellectual skills and team characteristics needed to adequately support the business process of the R&D work. Through these processes, the stakeholders' requirements and expectations can be satisfied. The satisfaction of the stakeholders would increase their loyalty and willingness to be involved in future research activities. The satisfaction for the funding body would safeguard future funding whilst satisfaction for industrial partners could increase their commitment and contribution towards the research activities thus making the research results more applicable to the industrial needs. Hence, through the satisfaction of the stakeholders the research institution's strategy can be successfully implemented.

Having developed the PMS for construction R&D function, and a success map, the section below detail out the strengths, applicability and the advantages of the PMS.

5.5.4.4 Strengths of the performance measurement system

The PMS has incorporated multiple performance indicators to identify the factors that influence the performance (see Figure 5.32). Further, it presents a combination of leading (e.g.: resource allocation and utilisation, time commitment of the team members and absence ratio) and lagging indicators (e.g.: achievement of deliverables and milestones). The lagging indicators of the PMS demonstrate the impact or status that the performance has been achieved (see Section 2.5.4.1). Therefore, presence of lagging indicators inform the success of the activities carried out, initiatives taken and modifications made for the R&D function. Conversely, leading indicators demonstrate the performance of the team, processes and direction of resources thus, they help in taking corrective actions before the overall performance is affected (see Section 2.5.4.1). Therefore, having leading indicators within the R&D PMS would help taking initiatives and making modifications to keep the overall R&D function within the expected goals. Accordingly, the use of leading and lagging indicators within the PMS ensures the proper flow of R&D activities.

Furthermore, the PMS consists of quantitative measures (hard measures) i.e. measures which are straightforward and easy to quantify such as project meeting attendance, number of publications and number of training activities provided and qualitative measures (soft measures) i.e. the intangible attributes such as satisfaction of the stakeholders and deviations from the required quality standards. However, the PMS does not incorporate specific performance indicators for the CSFs *"leadership of the principal investigator"* and *"flexibility and responsiveness to change"*. Yet, it is argued that there should be a proper awareness of those factors within the R&D function or in other words, recognising them as CSFs within the R&D function could influence the performance in R&D activities. Moreover, the PMS consists of input measures (e.g.: resource requirement analysis), process measures (e.g.: comparison of allocation of duties and responsibilities with their achievement), output measures (e.g.: achievement of deliverables, milestones) and outcome measures (e.g.: number of subsequent projects acquired) as similar to Brown's (1996) framework (see Section 2.5.4.2.5).

5.5.4.5 Applicability of the performance measurement system

This PMS applies to collaborative R&D work initiated by universities. Though the performance indicators and measures used within this PMS can be applicable to other scenarios of construction R&D activities, further investigation is needed to identify precise performance indicators and measures.

5.5.4.6 Advantageous of the performance measurement system

Through the integration of CSFs, performance indicators and measures in the PMS a typical construction R&D project will achieve the following benefits:

- precise understanding of the targets and the work involved within each phase of the R&D function guides the team members in identifying their contributions in terms of achieving the overall goals of the research project. Further, allocation of roles and responsibilities to the correct personnel will ensure the right people are doing the right job thus enhancing the quality of work;
- identifies the stakeholder requirements, and incorporates them within the project aim and objectives to make sure sufficient attention is paid to them. Satisfaction of these requirements will provide benefits such as continuous funding, continuous engagement of work etc;

- carrying out market analysis to establish the research problem clearly, while ensuring the project explores and addresses any important issues which exists in the current market place will increase the value of the research outcome. Furthermore, feasibility studies will identify any pitfalls the research could encounter, thus helping to determine the best research option from the beginning of the R&D project;
- keeps team members aware of current progress;
- awareness of the motivation and behavioural issues of the team members and being, receptive to their contribution throughout the project ensures the smooth flow of work;
- being realistic about the entire research process and helping to identify alternative approaches if the activities deviate from the original plans;
- increases the accountability of resources due to the presence of performance indicators on resource management;
- improves the reporting of success, failures, deviations and resource utilisations to the team members providing proper awareness of the progress of the research work;
- the presence of leading performance indicators to identify lagging areas which need attention before they impair the outcome of the R&D activities.

Form the exploratory stage of the case study, empirical data was gathered on: the influence of PM towards construction R&D function (see Section 5.4.1); CSFs of the construction R&D function (see Section 5.4.2); the extent of implementation of the CSFs during the construction R&D function (see Section 5.4.3); and the existing PM applications, performance indicators and measures of the case study (see Section 5.4.4). During the development stage of the case study (see Section 5.5), by considering the empirical data from the exploratory stage, the study developed a PMS (see Figure 5.32) and performance measures (see Table 5.19) which could be used to evaluate the performance of construction R&D function. Further, the value creation from the PMS was illustrated in a success map as shown in Figure 5.33. The following section leads this thesis on to the explanatory stage of the case study which discusses the refinements of the PMS and performance measures and the assessment of the impact of PMS on the construction R&D function.

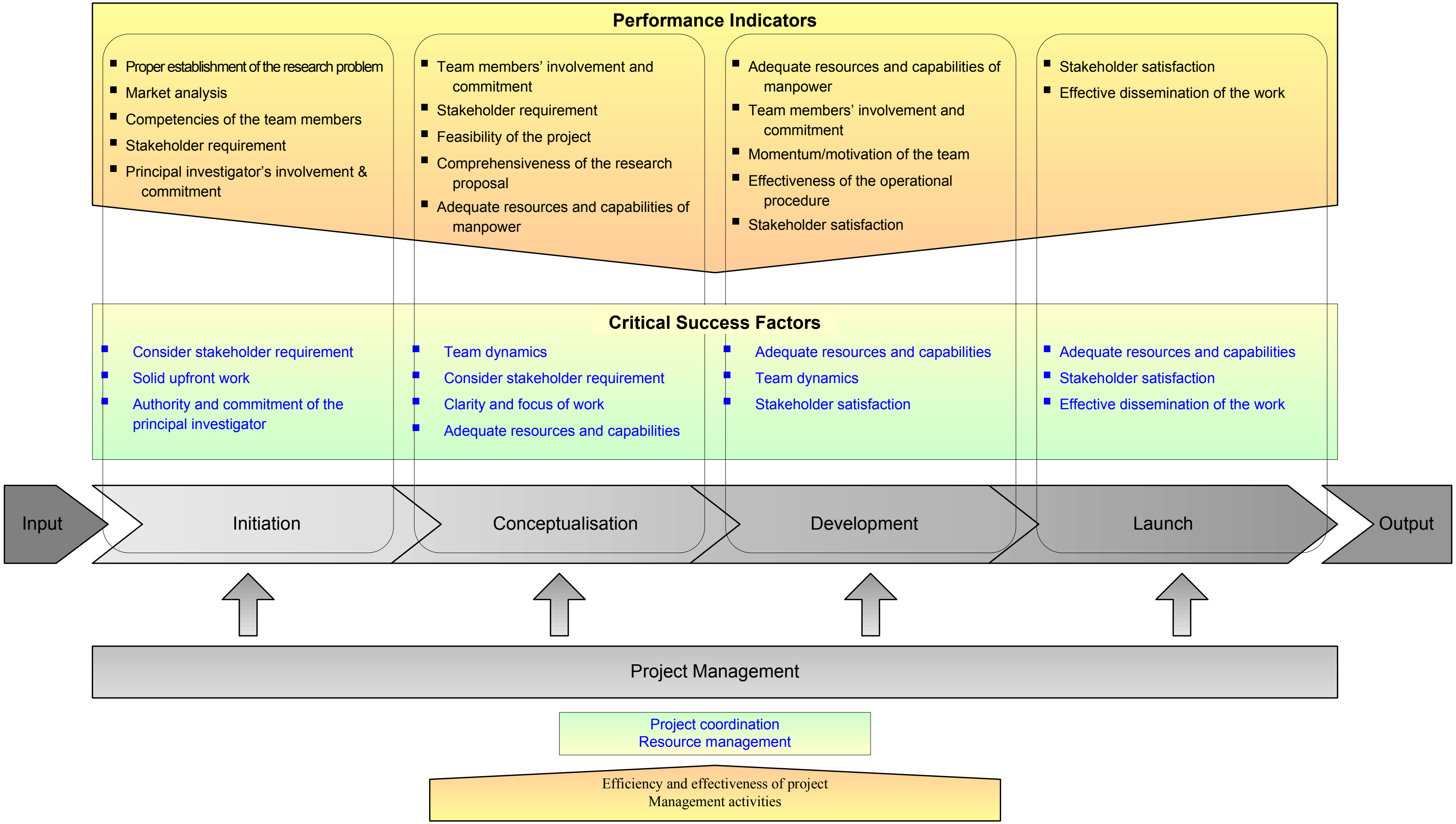


Figure 5.32: Performance measurement system for construction research and development function

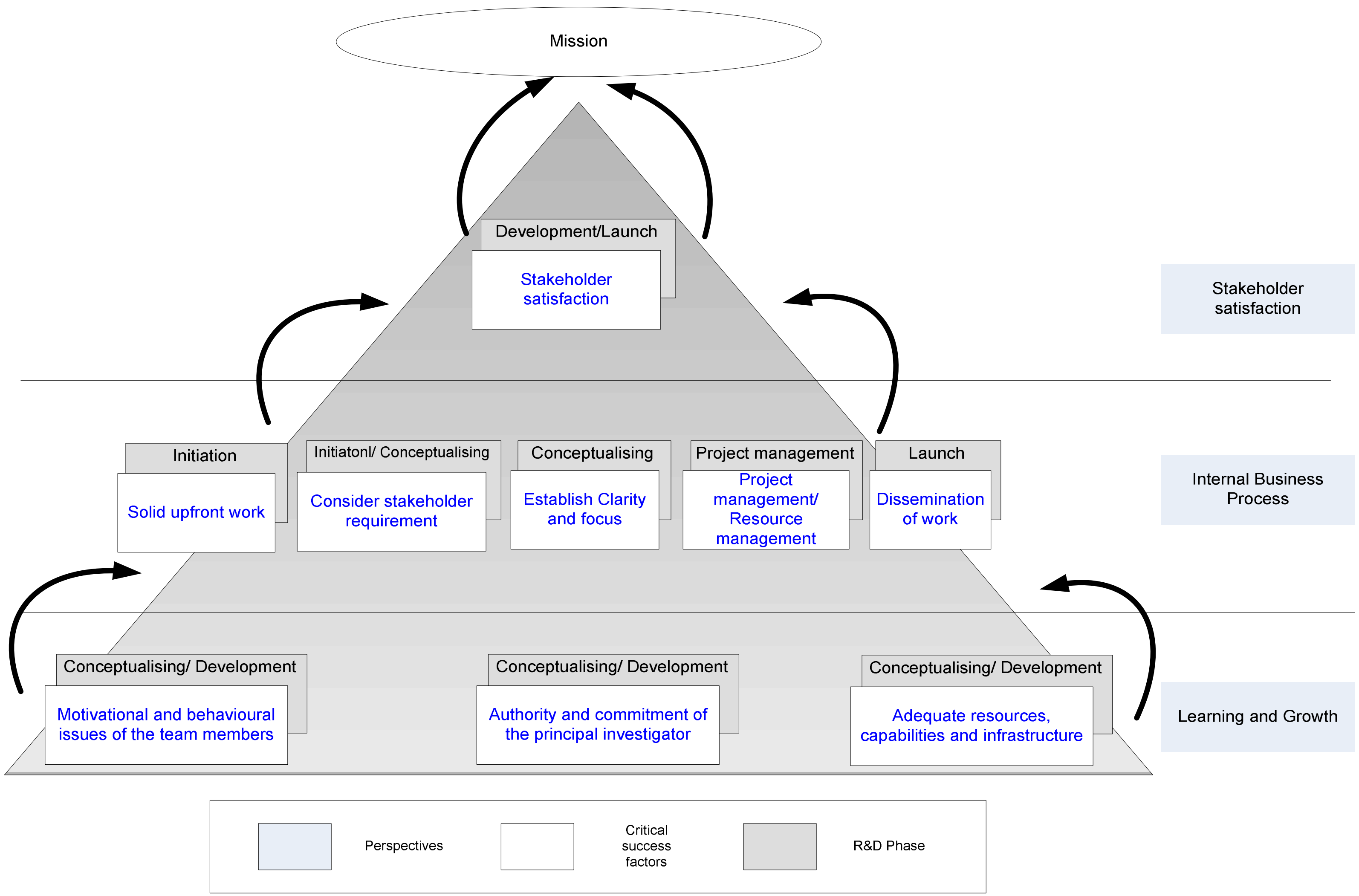


Figure 5.33: The success map

Table 5.19: Performance measures of construction research and development

Critical success factors	Performance measures (component parts of performance indicator)
Initiation Phase	
Solid upfront work	
Understand the market and its dynamics	Existence of market analysis
Establish the research problem clearly	Existence of a research justification plan; completeness of the research proposal in terms of knowledge gap and importance of the research problem
Select a competent team	Existence of a skills evaluations; existence of recruitment plan; comparison of skills needed with the qualifications of the potential researchers, industrial partners
Consider stakeholder requirement	
Consider funding bodies' requirements Consider industrial partners' requirements	Existence of a requirement analysis of the stakeholders
Authority and commitment of the principal investigator	
Commitment of the principal investigator	Time commitment of the principal investigator
Leadership of the principal investigator	
Conceptualising Phase	
Team dynamics:	
Authority and commitment of the principal investigator	
Commitment of the principal investigator	Time commitment of the principal investigator
Leadership of the principal investigator	
Motivational and behavioural issues of the team members	
Committed and cooperative team members	Existence of performance evaluation methods of team members; comparison of allocation of duties and responsibilities against their achievement; project meeting attendance; time commitment of the team members; absence ratio

Consider stakeholder requirement Consider funding bodies' requirement Consider industrial partners' requirements	 Existence of a requirement analysis of the stakeholders
Clarity and focus of work Check the feasibility of the project Establish clear and realistic goals/ deliverables/ milestones Establish clear method to measure success Allocation of responsibilities to team members inline with competencies Establish a plan to disseminate research results	 Existence of a feasibility analysis; measures on cost, benefits analysis, achievement of project goals against the potential risks Comparing project expectation with available resources Existence of a procedure to establish project evaluation methods (e.g.: identification of time targets to evaluate performance/reporting, reporting mechanisms and reporting structure of project performance, identifications of people responsible to do the evaluations/reporting; timing of reporting) Comparing the responsibilities with the competencies of the team members Existence of a procedure to develop a project dissemination plan (e.g.: identification of the mode of dissemination of work, the target group/ beneficiaries, allocation of sufficient funds and personnel for launch events/ dissemination, identifying the timeframe for launch events/ dissemination)
Adequate resources and capabilities Having a skilled team Adequate resources/financial support	 Number of publications and citations of the team members, generation of new ideas and findings, number of awards won, presentation at workshops/ conferences; number of training activities provided; evaluation of the skill level of the team members (e.g.: educational qualifications, experience) Existence of resource requirement analysis

Development Phase	
Adequate resources and capabilities	
Having a skilled team	Number of publications and citations of the team members, generation of new ideas and findings, number of awards won, presentation at workshops/ conferences; number of training activities provided; evaluation of the skill level of the team members (e.g.: educational qualifications, experience)
Adequate resources and financial support	Existence of resource requirement analysis
Having a well established operational procedure	Existence of a method to evaluate the operational procedure of the project (e.g.: identification of alternative approaches at cost, time, budget deviations)
Motivation and behaviour of the team members	
Committed and cooperative team members	Existence of performance evaluations of team members; comparison of allocation of duties and responsibilities against their achievement; project meeting attendance; time commitment of the team members; absence ratio
Secure momentum/ motivation of the team	Employee turnover
Share a common understanding about the work	Frequency of project meetings and comprehensiveness of the project briefing
Flexibility and responsiveness to change	
Authority and commitment of the principal investigator	
Commitment of the principal investigator Leadership of the principal investigator	Time commitment of the principal investigator
Stakeholder satisfaction	
Meet industrial partners' requirements Meet funding bodies' requirements	Existence of stakeholder satisfaction analysis; achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys; number of subsequent projects acquired and new opportunities derived from the project; follow on funding or spin off effects; number of new stakeholders/contacts acquired; % of time, cost, quality deviation from planned

Launch Phase	
Adequate resources and capabilities	
Having a well established dissemination/ marketing plan	Existence of a dissemination of plan (e.g.: identification of project results and output reaching the target audience, beneficiaries; dissemination of the outcome within the planned time frame, obtaining feedback from the stakeholders)
Stakeholder satisfaction	
Meet funding bodies' requirements Meet industrial partners' requirements	Existence of stakeholder satisfaction analysis; achievement of milestones, deliverables; scores on the stakeholder satisfaction surveys; number of subsequent projects acquired and new opportunities derived from the project; follow on funding or spin off effects; number of new stakeholders/contacts acquired; % of time, cost, quality deviation from planned
Dissemination of work	
Launch the output within the planned time frame	% deviation from proposed timeframe
Effective dissemination of the results	Response rate from the industry on the utilisation of research results
Project Management	
Project coordination	
Continuous reviews Effective collaboration Effective communication Effective planning, controlling, and organising of activities	Frequency of project reviews/ meetings; number of cancellation of meetings; existence of communication and coordination plans (e.g. : identification of communication mode,); efficiency of communication, coordination; effectiveness of the communication of project deviations, achievement of milestones, deliverables to team members; effectiveness of the feedback (e.g. : getting the feedback from the required personnel, integrating the feedback within the system, taking correct actions based on the feedback received); evaluation of the project management procedure (e.g. : identification of communication channels, structure_ who should communicate with whom)

Resource management Effective resource management Effective management of the people	Existence of human and other resource utilisation analysis (comparing the resource requirement with the utilisation; procedure to revise and reallocate resources if needed; procedure act on resource constraints) budget deviations from planned, % of delays due to insufficient finance, human resource and other resources

5.6 Explanatory stage: refinement and assessing the impact of the performance measurement system on construction research and development

The main intention of this stage was to identify the impact of the developed PMS on the success of construction R&D activities. However, implementing the PMS within a construction R&D project within this PhD study was limited due to the time span of R&D projects. To overcome this limitation, the researcher sought to gather the views of experts involved in research projects regarding the impact that the PMS could have on the success of R&D work. In addition to identifying the impact, it was also intended to refine the PMS developed during the explanatory stage.

A series of semi structured interviews with four principal investigators and two researchers who had been involved in research projects from the initiation to the launch phase was carried out (see Table 3.4 for the descriptions and the codes assigned for the interviewees). Accordingly the interview guidelines (see Appendix C), the draft version of the PMS diagram and the table illustrating the performance measures were sent to the interviewees prior to the interview. Similar to the interviews carried out during the exploratory stage, these interviews were also tape recorded and transcribed.

Before starting the interviews, the interviewees were briefed on the current status of the case study in relation to PM applications by presenting the findings of the exploratory stage. Also, the positive and negative influences, CSFs, performance indicators and measure extracted from the case study were presented. The interviewees were made aware of the current issues of PM applications in R&D work within the case study (see Section 5.4.4.3) and made aware of the lack of a structured approach to measure the performance within the case study. Furthermore, the existence of discrepancies between the importance of success factors and their implementation were also reported to the interviewees. From the aforementioned findings of the exploratory stage of the case study, the interviewees acknowledged the need for having a PMS to measure the success of the construction R&D activities.

5.6.1 Refinement of the performance measurement system

To refine the PMS, the interviewees were questioned about the completeness of the CSFs, performance indicators and performance measures. All the interviewees were satisfied with the extent of coverage of the CSFs, performance indicators and measures and agreed that the PMS has captured the important factors that need to be considered when measuring the performance of construction R&D work. S2-PI3 commented *"from what I can see here CSFs and indicators actually spans from initiation to the launch which pretty much covers all the CSFs and indicators that I can think of at this moment. I believe that they cover almost all the things that we should consider"*. S2-PI2 particularly appreciated the PMS in terms of using a balanced set of leading and lagging performance indicators and measures. *"…it is important that you have both (leading and lagging) as often as possible. Because it is very difficult to correct output measures…its too late. If you are doing badly in output measures, you failed really. Because it is a small time period, not like an organisation that can progressively improve"*.

When questioned about the ease of understanding in the PMS, a combination of positive and negative responses was obtained. S2-PI3 considered the PMS as a tool which will be understood even by a researcher who has just got involved in research projects. Thus, he commented *"ease of understanding, actually I am 100% confident and satisfied the way that you have presented the framework …it is very easy to understand the whole concept by going through these diagrams along with the table"*. However, the other interviewees had their concerns particularly on the use of terminology within the framework. *"When I had a glance at the performance indicators, I had my doubts whether they should be included with the performance indicators or they should be shifted to CSFs. Sometimes a researcher may not* *understand the terminology used for the performance indicators. But when I go through the other details given in the table, I've realised what you have meant. Perhaps some confusion in the terms you have used may be there…"* mentioned S2-R1. S2-PI1 and S2-PI3 suggested improving the clarity of the PMS by linking the CSFs and their respective performance indicators. Further, S2-PI2 suggested incorporating two performance measures (frequency of project meetings and comprehensiveness of the project briefing) under the performance indicator *"secure momentum and motivation of the team members"*. All the interviewees recognised the applicability of the PMS to construction R&D work and S2-PI2 commented *"in terms of applicability I can see as a researcher and as a principal investigator, the factors are definitely relevant. I don't have problems with any of the measures that you have proposed"*.

Having discussed the opinion of the experts on the refinement of the PMS, the section below explores the interviewees' views on the impact of this PMS towards the success of construction R&D activities.

5.6.2 Assessing the impact of the performance measurement system in construction research and development

Through the literature review (see Section 2.4.5) and during the exploratory stage of the case study (see Section 5.4.2) a number of issues were revealed within construction R&D activities throughout its life cycle. One of such issues is the ignorance by funding bodies of resource utilisation which has led to concerns for funding bodies investing in construction R&D activities (see Section 2.4.5). Furthermore, the construction R&D activities are accused of not addressing the needs of the industry's requirements (see Section 2.4.5). When the requirements of the industrial partners' are not addressed, the involvement by them in the research process and their contribution to the research process has been reduced. Therefore, the importance of incorporating the requirements of all the parties involved in R&D work is stressed, especially the requirements of industrial partners within the research objectives (see Sections 2.4.5 5.4.2.2.2 and 5.4.2.4.3). Furthermore, lack of commitment and contribution from the industrial partners to R&D activities was pointed out as a factor which affects the success of construction R&D activities (see Section 5.4.2.6.4). In addition to the above mentioned drawbacks, lack of proper communication mechanisms within the construction R&D activities has lead to insufficient provision of information on the progress of work, utilisation of funds etc (Sections 2.4.5). Further, in Section 2.6.5, the importance of showing that the results of R&D activities are properly aligned with the objectives is highlighted thus emphasising the need for control and monitoring of R&D activities. Moreover, during the exploratory stage of the study, the respondents claimed that the research results are not properly distributed and applied in the industry (see Section 5.4.2.8.2). Based on the aforementioned findings, the factors below were extracted from the literature review and the empirical investigation to assess the impact of PMS:

- resource identification and utilisation;
- addressing the requirements of the parties involved;
- get the commitment of team members;
- control and monitoring of the activities;
- effective dissemination of the work;
- improving feedback, communication and coordination of activities;
- improving the performance of construction R&D activities.

To assess the impact of the PMS towards the success of construction R&D activities, the interviewees were asked whether they could expect improvements in terms of the aforementioned factors when they apply the PMS to an on going or a completed research project.

As a whole all the interviewees agreed that they could expect performance improvements for the above factors due to the identification of CSFs, performance indicators and performance measures related to the construction R&D activities. S2-PI4 appraised the PMS in terms of resource identification and utilisation. He commented *"If you think about the bid preparation stage, by going through this (the developed PMS) and the guidelines provided by the funding organisation, we will be able to address resource identification and utilisation more effectively. For example, when you add this framework to the funding organisation's guideline, the success will definitely improve, because there are so many CSFs that you have identified within this framework. Actually those are the things that we miss as we are following the guidelines blindly sometimes. So having a framework like this will definitely give the focus when ever we need".*

According to S2-PI1 the PMS could be a useful tool for the principal investigators to manage the project management activities of the research project. *"I also think they are (project management activities) the skills many researchers are lacking, it may be many PIs don't know what type of things they should be doing to manage the project. So I think this type of framework actually provides guidelines for principal investigators"* commented S2-PI1.

S2-PI2 and S2-R1 specifically acknowledged the value of this PMS in terms of identifying the post delivery success. S2-PI2 stated that most of the funding bodies do not force evaluation of the success of the research work. Also, he highlighted that there are not enough mechanisms to identify whether the research project has optimised the funding they have received. He added *"There is no real following up of work to evaluate what happened to the satisfaction of the stakeholders, no of publications etc… have we taken maximum advantageous of it. I think that's where the real value of this framework would come"*. Similar to the S2-PI2's views, S2-R1 also identified the deficiency of follow up work within the research projects. *"I've never been convinced that research actually has much impact. There are many things produced and published that sits on shelves, never being looked at, but they need much longer term impact study rather then submitting a final report"* added S2-R1.

Despite the above recognition for the PMS, some of the interviewees pointed out the practical problems which could arise in its implementation. Accordingly, S2-PI4 asserted *"when preparing a bid, dealing with the guidelines provided by the funding organisation is a massive job so practically whether it would be possible for us to deal with another document is questionable"*. S2-PI2 highlighted the time constraints that they have when preparing the bids. "*I think the danger is whether it (the PMS) is demanding too much at the beginning. The projects that we had recently will have month or two to put the things together. Can we do a kind of skills analysis for example or can we choose our research team with such precision. I am not convinced that you get that much time"* commented S2-PI2.

5.7 Summary and link

This chapter discussed the data analysis and findings of the case study under three stages: exploratory, theory development and explanatory. During the exploratory stage, semi structured interviews and a questionnaire survey was used to gather the views of academic members and industrial partners. Accordingly, the influence of PM within the construction R&D, the CSFs, performance indicators, and the current practices of PM applications were gathered. It was identified that there are a number of benefits of PM within the construction R&D (see Section 5.4.1.5). In addition to the positive influences identified from the semi structure interviews (see Section 5.4.1.5), PM carried out by focusing on the CSFs derived from the study could improve the performance of construction R&D function in number of ways (see Figure 5.27). Thus, overall the influence of PM towards the construction R&D function can be attributed to facilitates the selection of the best option/ aim and objectives; improves quality of the research work; identifies and ensure contribution of the team; directs the team members towards targets; improves transparency of work; improves dissemination of research results; facilitates inter project comparisons; validates the achievements; improves communication; motivates the team; ensures proper progress of work; and improves the stakeholder satisfaction.

Despite the aforementioned positive influences, a number of negative influences were elicited from the PM application within case study. However, the negative influences revealed from the case study highlighted the importance of establishing correct targets for the PM and effective utilisation of the results of PM.

CSFs were gathered during the construction R&D project from initiation to launch phases and at the project management (see Sections 5.4.2.1, 5.4.2.3, 5.4.2.5, 5.4.2.7 and 5.4.2.9). The identification of CSFs leads to two main benefits. Firstly, providing correct targets for PM, based on the factors which influence success of the construction R&D activities. This ensures the critical areas which are needed for effective and efficient construction R&D are adequately looked after. Secondly, the identification of CSFs leads to recognition of the *"few factors"* which could influence the performance improvement of construction R&D activities. Thus, the complications which could arise due to the presence of a larger number of performance indicators will be minimised. Therefore, the identification of CSFs provides (see Section 5.4.2) a good foundation for PM. Further, when the PM is carried out based on the identified CSFs of this study, a number of benefits will be achieved in the construction R&D project (see Figure 5.26). However, the prominence attached to the importance of the success factors were not given when it comes to their implementation during the construction R&D project. Therefore, by deploying performance indicators and performance measure related to the CSFs, the effective implementation/ consideration of the CSFs can be assured.

Moreover, the findings of the exploratory stage noted that the satisfaction of the stakeholders (industrial partners and funding bodies) as a vital factor for construction R&D projects. Firstly, by identifying stakeholder satisfaction as a CSF during the whole process (see Sections 5.4.2.2.2, 5.4.2.4.3, 5.4.2.6.1, and 5.4.2.8.1) secondly, at the implementation, satisfaction of the stakeholders was ranked higher indicating its implementation was more important than the other factors (see Section 5.4.3), and thirdly, the use of performance measure to satisfy the stakeholders (see Section 5.4.4.2).

Based on the findings of the exploratory stage of the case study, a PMS was developed to measure the success of construction R&D activities. The PMS was transferred to a success map and was elaborated to show how the resources, capabilities and infrastructure within the case study supports the business process needed to satisfy the stakeholders which ultimately achieves the strategy of the research institution.

During the third stage of the case study, the PMS was refined and its impact on the construction R&D activities was assessed by using a series of semi structured interviews. In general, the interviewees acknowledged the PMS in terms of the completeness of the CSFs, performance indicators and performance measures and recognised it as a tool which can be applied within construction R&D projects. However, some interviewees had concerns about the terminology used within the PMS which were later refined based on their comments. Furthermore, the PMS was identified as a tool which could make a positive impact in improving the performance of the construction R&D activities. However, some interviewees thought that there could be practical problems in implementing the PMS due to the presence of other guidelines provided by the funding body.

This chapter presented the findings of the case study. The succeeding chapter draws up conclusions by linking the objectives of the study with the overall research findings through literature, expert interviews and the case study. Further, the theoretical and practical implications made by the study are also presented.

CHAPTER 6 CONCLUSION

6.1 Introduction

Chapter 2 of this thesis discussed and synthesised the main issues of the study through a comprehensive literature review. This was followed by the research methodology presented in Chapter 3 which disclosed the philosophical stances, research approach, and data collection and analysing techniques pertaining to the study. Chapter 4 combined the key issues derived from literature with expert opinion to develop the conceptual framework of the study. The data gathered from empirical investigation based on construction R&D project which follows the R&D function (see Section 3.3.3.2) was analysed and synthesised in Chapter 5. In this context, this chapter arrived at the conclusions by summarising the results of the overall study. Accordingly, the chapter is structured as follows:

- First, the findings for each objective of the study are given
- Second, the implications of theory and practice are discussed
- Third, the limitations of the study are presented
- Fourth, further research areas are suggested.

6.2 Synthesis on the objectives of the study

As stipulated in Chapter 1, this study explored the influence of Performance Measurement (PM) in construction Research and Development (R&D) activities due to the importance of the study area and the gap identified from the literature review on paucity of studies carried out (see Section 1.2). The aim of the study was examined by means of six research objectives (see Section 1.3) and five research questions (see Section 2.8). The first objective was the identification of the importance of R&D in the construction industry and was achieved by way of a comprehensive literature review (see Section 2.3). The second objective was to identify the current position of the construction R&D function and was addressed mainly through the literature review (see Section 2.4) supported by expert interviews and semi structured interviews carried out at the exploratory stage of the case study. The third objective of identifying the importance of PM within construction R&D was addressed via the case study findings and supported by the literature review and expert opinion (see Sections 5.4.1, 2.6.5, 4.4.1). The fourth and fifth objectives on exploring the current PM applications (see Sections 5.4.4.2, 2.6.4) and the critical success factors (CSFs) of construction R&D function (see Sections 5.4.2, 2.7.1) was empirically investigated in the case study supported by the literature review. The following sections summarise and present the key findings related to each research question of the study.

6.3 Objective 1: Identify the importance of research and development in the construction industry

As a subset of the built environment, the UK construction industry plays an important role in making the built environment a place which is accessible to everyone, comfortable and enjoyable. In bringing the built environment to the standards required by society, the construction industry faces a number of challenges in addressing social, economical and environmental constraints. For example, the construction industry is challenged to adhere to sustainable development policy by ensuring that its activities provide economic, social and environmental benefits; by reducing initial and lifecycle costs; by optimising use of natural resources; and by increasing the satisfaction of its stakeholders. Accordingly, many authors recognise R&D as a way forward in addressing these challenges in the construction industry (see Section 2.3.3). R&D activities produce efficient and effective construction processes, materials and components and develop management methodologies in addressing these challenges. Furthermore, R&D activities deliver intangible benefits such as knowledge creations and knowledge transfers within the research team members and their organisations, establish good rapport with stakeholders and create long term research partnerships and net woks (see Section 2.3.3). These intangible benefits add value to organisations by increasing their capacity for absorbing and using internal and external knowledge thus ultimately providing them with a competitive edge to survive in the market.

The down side of R&D activities is that they require additional resources, time and incur overhead costs. Furthermore, sometimes R&D activities are associated with risks which the organisations are not willing to take. Many question the value of R&D activities especially, when the links between resource consumption and the benefits of R&D are not explicit. Thus, the emphasis on proper management of R&D activities are highlighted to minimise the risk and to enhance success.

6.4 Objective 2: Identify the current position of construction research and development

Commitment towards construction research activities varies considerably depending on the priority tasks of the people/ organisations that carry out R&D work. While university based research institutions are capable of carrying out research work with much rigour and structure, the applicability of such research within the industry is being questioned. On the other hand, though the research work carried out by construction organisations has greater applicability towards the practical issues, they lack the theoretical aspect. Even though university based and industry based research have their shortcomings, the collaborative research between universities and construction organisations generate successful research activities due to complimentary skills of the both parties.

The UK construction research base has a number of issues which hinder its success. The UK construction industry has a lower level of R&D intensity than most other industries. Furthermore, investments in R&D work are lower compared to that in other countries like France and Japan (see Section 2.4.5). Literature suggested that the construction R&D output does not address the requirements of its targeted audience and lacks applicability for industrial needs. This has resulted in a reduction in the enthusiasm of the industrial partners to work on research projects. Furthermore, the lack of evaluation, validation and feedback mechanisms within construction R&D activities to assess the success of its activities has negative influences on construction R&D activities. Due to lack of evaluation, validation and feedback, funding bodies and industrial partners are not made aware of resource utilisation. Moreover, skills shortage, lack of effective communication and coordination between the parties involved, lack of commitment and contribution from industrial partners for R&D activities and poor dissemination of the research results within the industry are revealed as some of the crucial issues in the R&D activities (see Sections 2.4.5 and 2.6.5). In addition to this it was revealed that the issues within construction R&D are related to one another and directly or indirectly linked with the lack of evaluation mechanisms.

6.5 Objective 3: Evaluate the importance of performance measurement in construction research and development function

The importance of PM to construction R&D was identified by the expert interviews (see Section 4.4.1). They valued PM since it provides focus for effective research work. However, the expert interviewees highlighted the need for measuring the whole research process which can lead to a better outcome, rather than concentrating purely on the research output. Nevertheless, the interviewees highlighted the importance of formulating correct targets for PM as lack of such targets could mislead the research team and ultimately result in generation of inaccurate results and creation of flawed feedback.

In the exploratory stage of the study a number of benefits of PM in construction R&D function was derived (see Sections 5.4.1.1, 5.4.1.2 and see Figure 5.26) such as; facilitates the selection of the best option/ aim and objectives; improves the quality of the research work; identifies and ensures the contribution of the team; directs the team members towards targets; improves the transparency of the work; improves dissemination of research results; facilitates inter project comparisons; validates the achievements; improves communication; motivates the team; ensures proper progress of work; and increases the satisfaction of the stakeholders.

Besides the benefits of PM, the empirical investigation revealed a number of negative influences (see Sections 5.4.1.3 and 5.4.1.4). The implementation of PM applications within R&D work could result in wasting the resources employed by it when the results of PM are not integrated with the ongoing process or used as a reference for future projects. Thus, some argued that the effort put into PM could be used to achieve the objectives of the research work. Further, inclusion of incorrect performance targets could result in adding inaccurate feedback thus misleading the research team. Moreover, the biasness of the performance evaluator could also add inaccurate feedback. In addition to this, it was revealed that the PM results could be manipulated to provide a better picture of the performance. However, these negative influences of PM points to the need for setting correct targets for PM and the importance of making the applications of PM an integral part of the R&D work by incorporating the PM results.

6.6 Objective 4: Explore how performance of the construction research and development function is measured

Within the PM applications of construction R&D, the use of multiple performance measures was evident ranging from financial to non financial, and qualitative to quantitative. Some of the interviewees preferred to use quantitative measures over qualitative due to their ease of measurement and interpretation.

Case study respondents opted for the use of performance measures which satisfy the stakeholder (funding bodies and industrial partners) needs such as; measures of finance, time, quality; accomplishment of objectives and milestones of the project and identification of stakeholder requirements. As opposed to the indicators on the satisfaction of the stakeholders of the construction R&D activities, the indicators targeting the researchers (identification of the researchers' requirements, education and training of researchers, satisfaction of the researchers) have been utilised less. The performance indicators on the evaluation of post delivery success (development of new research directions, retention of the stakeholders, acquisition of new business relationships) were not extensively used within the case study.

As far as PM applications within the case study are concerned, lack of flexibility to accommodate performance indicators when and where deemed necessary during the research process have been identified as a drawback. Further, it was noticed that the PM applications are primarily dominated by the funding bodies' requirements and guidelines. Furthermore, informality and lack of a structured approach to measure the performance of construction R&D activities was evident from the case study resulting in providing insufficient information for the research team members to identify the extent of work required for PM.

6.7 Objective 5: Determine the critical success factors of construction research and development function

A number of CSFs were identified for the construction R&D function. At initiation and conceptualising phases, emphasis is placed on laying a proper foundation for the research work through establishment of a clear research problem which would address a current issue (see Section 5.4.2.2.1) and ensuring the clarity and focus of the research work for the smooth flow of the research work and to make valuable contributions for the parties concerned (see Section 5.4.2.4.1). When the research team joins the R&D project at the conceptualising phase and when the actual development of the research objectives start, the characteristics of the team members, their behavioural and motivational issues become vital for the success of construction R&D function (see Sections 5.4.2.4.4 and 5.4.2.6.4). Further, having adequate resources, especially the human resource, was highlighted at the conceptualising and development phases (see Sections 5.4.2.4.2 and 5.4.2.6.2). At the launch, effective dissemination of the work was emphasised so that the beneficiaries could be benefited from the research results and a good impact can be made by the research results (see Section 5.4.2.8.2). Throughout the R&D function, the importance of project coordination and resource management were emphasised (see Sections 5.4.2.10.1 and 5.4.2.10.2).

From the initiation to the launch of the R&D project, emphasis is placed on the stakeholders' (industrial partners and funding bodies) needs through proper identification of their requirements during the initiation and conceptualisation and satisfaction of their requirements during the development and launch phases (see Sections 5.4.2.2.2, 5.4.2.4.3, 5.4.2.6.1 and 5.4.2.8.1). As opposed to the prominence given to the satisfaction of the stakeholders, the empirical investigation on the case study revealed that less attention was given to satisfying the researchers' requirements. It can be argued that, as a whole, more emphasis is placed on providing value for the stakeholders as their satisfaction could lead to the creation of long term partnerships, guaranteeing continuous funding, rather than considering the requirements of the researchers. Furthermore, the principal investigator's role in leading the project and providing sufficient commitment to the project was elaborated (see Sections 5.4.2.2.3, 5.4.2.4.4 and 5.4.2.6.3).

In terms of the implementation/ consideration of the CSFs during the construction R&D function, it was revealed that CSFs are not sufficiently implemented when compared with the importance attached to them. The summary of the CSFs which were gathered from the empirical investigation is presented in Table 6.1.

Table 6.1: Critical success factors of the construction research and development function

Initiation Phase		
Solid upfront work	Understand the market and its dynamics Establish the research problem clearly Selecting a competent team	See Section 5.4.2.2.1
Consider stakeholder requirement	Consider funding bodies' requirements Consider industrial partners' requirements	See Section 5.4.2.2.2
Authority and commitment of the principal investigator	Commitment of the principal investigator Leadership of the principal investigator	See Section 5.4.2.2.3
Conceptualising Phase		
Team dynamics: ***Authority and commitment of the principal investigator*** ***Motivational and behavioural issues of the team members***	 Commitment of the principal investigator Leadership of the principal investigator Committed and cooperative team members	 See Section 5.4.2.4.4
Consider stakeholder requirement	Consider funding bodies' requirements Consider industrial partners' requirements	See Section 5.4.2.6.1
Clarity and focus of work	Check the feasibility of the project Establish clear and realistic goals/ deliverables/ milestones Establish clear method to measure success Allocation of responsibilities to team members inline with competencies Establish a plan to disseminate research results	See Section 5.4.2.4.1
Adequate resources and capabilities	Having a skilled team Adequate resources/financial support	See Section 5.4.2.4.2

Development Phase		
Adequate resources and capabilities	Having a skilled team Adequate resources and financial support Having a well established operational procedure	See Section 5.4.2.6.2
Team dynamics: ***Motivational and behavioural issues of the team members*** ***Authority and commitment of the principal investigator***	Committed and cooperative team members Secure momentum/ motivation of the team Share a common understanding about the work Flexibility and responsiveness to change Leadership of the principal investigator Commitment of the principal investigator	See Section 5.4.2.6.3 and Section 5.4.2.6.4
Stakeholder satisfaction	Meet industrial partners' requirements Meet funding bodies' requirements	See Section 5.4.2.6.1
Launch Phase		
Adequate resources and capabilities	Having a well established dissemination/ marketing plan	See Section 5.4.2.8.3
Stakeholder satisfaction	Meet funding bodies' requirements Meet industrial partners' requirements	See Section 5.4.2.8.1
Effective dissemination of work	Launch the output within the planned time frame Effective dissemination of the results	See Section 5.4.2.8.2
Management		
Project coordination	Continuous reviews Effective collaboration Effective communication Effective planning, controlling, and organising of activities	See Section 5.4.2.10.1
Resource management	Effective resource management Management of the people	See Section 5.4.2.10.2

6.8 Objective 6: Develop a performance measurement system that enables management to assess the success of the construction research and development function

This section presents the conceptual framework and the refined PMS developed through the empirical investigation of the study. Through a comprehensive literature review (see Chapter 2) and a series of expert interviews (see Section 3.2.3), the conceptual framework for this study was created to illustrate the main concepts of the study, their interrelationship and the conditions under which these relationships are true (see Figure 4.2 for the conceptual framework). The framework denotes the lifecycle of a new venture (product, process or management methodology) from initiation, conceptualisation, development to launch and elaborates on the need for management activities for the success of the new venture. Further, the conceptual framework shows the issues and the CSFs within the construction R&D function. It was argued that through the implementation of PM focusing on the CSFs, the issues within the construction R&D function could be minimised and improve the stakeholder satisfaction. The satisfaction of the stakeholders will lead to provide the contribution from the stakeholders, which will strengthen the construction R&D activities. The appropriateness of the conceptual framework in representing the impact of PM in the construction R&D function to improve the stakeholder satisfaction was strengthened in the empirical investigation of the study. The empirical investigation identified the benefits of PM (see Sections 5.4.1.1 and 5.4.1.2 and Figure 5.26), the CSFs of the construction R&D function (see Section 5.4.2), the need for focusing PM on the CSFs (Section 2.7.1, 4.4.2 and 5.4.1.5) and showed how the PM within construction R&D function could minimise the issues associated with it while improving the satisfaction of the stakeholders.

By extracting the concepts *"CSFs"* and *"PM"* from the conceptual framework, the PMS was populated to measure the success of the construction R&D activities (Figure 5.32). Further, performance measures were developed to represent the performance indicators of construction R&D function (see Table 5.19). In addition to the PMS, the study developed a success map as shown in Figure 5.33. The success map consists of three perspectives namely; stakeholder satisfaction, internal business processes and learning and growth. The success map illustrates the resources, infrastructure, and capabilities of researchers needed to support the R&D processes that will deliver value to the industrial partners and funding bodies which will eventually satisfy their requirements. By satisfying the stakeholders the research institution will earn their loyalty, secure future funding, gain continuous engagement in research work.

6.9 Contribution to theory

This study merged literature from five main areas: construction R&D (see Section 2.3 and Section 2.4), PM in general (see Section 2.5), PM in R&D in other disciplines (see Section 2.6), PM in construction R&D (see Section 2.6.5) and CSFs (see Section 2.7). By merging the concepts and theories of the aforementioned subject areas, the study provided a better understanding of the PM in the construction R&D function. In addition, the study identified a number of variables such as CSFs, performance indicators and performance measures which need to be considered to improve the performance of the construction R&D function. The section below identifies the areas in which this study contributed to theory.

6.9.1 Identification of critical success factors for construction research and development function

A number of studies have been carried out in various disciplines on the CSFs of research activities (Cooper and Kleinschmidt, 2007; Sun and Wing, 2005; Sawhney and Prandelli, 2000; Shim and Lee, 2001; Cooper, 1999; Lester, 1998). However, in these studies different methods were used to generate CSFs and were based on different units of analysis. For instance, some of the studies were on the CSFs at project level (see Cooper and Kleinschmidt, 2007), business unit level (Cooper, 1999), process level (see Sun and Wing, 2005) and at the early stage of product development (Lester, 1998) while some studies link the phases of product development with the CSFs (see Sun and Wing (2005). Therefore, even though these studies provide a common view about CSFs, they are not comparable, and are from different disciplines, hence cannot be applied directly to the construction R&D function. Thus, this study contributes to the theory by deriving construction R&D specific CSFs and integrating them with the phases of the R&D function from initiation, conceptualising, development to launch and for the management of R&D activities.

6.9.2 Benefits of performance measurement in construction research and development

The general literature on the application of PM has revealed and categorised a number of benefits of PM such as; influencing the subordinate's behaviour; identification of the current position in the market; customer/people satisfaction; increased productivity; business improvement and strategy implementation etc (see Franco-Santos et al, 2007; Martinez, 2005; Kuwaiti and Kay, 2000; Neely, 1998; Van Hoek, 1998). In addition to the aforementioned benefits, the PM studies carried out on R&D revealed the advantages of PM as increasing the accountability of the proper usage of R&D investments and proper resource allocation and utilisation within organisations (see Yawson et al, 2006; Bremser and Barsky, 2004; Pearson et al, 2000; Kerssens-van Drongelen et al, 2000; Kerssens-van Drongelen and Bilderbeek, 1999; Werner and Souder, 1997; Brown and Svenson, 1988).

Accordingly, this study contributes to the theory by drawing up the benefits of PM in construction R&D function such as facilitates the selection of the best option/ aim and objectives; improves the quality of the research work; identifies and ensures the contribution of the team; directs the team members towards targets; improves the transparency of the work; improves dissemination of research results; facilitates inter project comparisons; validates the achievements; improves communication; motivates the team; ensures proper progress of work; and increases the satisfaction of the stakeholders.

6.9.3 Definition for performance measurement in construction research and development

Section 2.5.1, identified three factors which need to be considered when measuring the performance: efficiency and effectiveness of actions which determine the attainment of organisational goals and other influential factors; delivering value to the stakeholders and the need for infrastructure such as data acquisition, collection, sorting, analysing, interpreting and disseminating. The empirical investigation of this study highlighted the value of stakeholders (industrial partners and funding bodies) for the construction R&D function (see Sections 5.4.2, 5.4.3 and 5.4.4.2). Failure to satisfy their needs could have repercussions such as a lack of funding and lack of continuous research work; lack of contribution from the industrial partners thereby resulting in research results with low applicability. Thus, this study contributes to theory by defining PM for the context of construction R&D as follows:

"measuring the efficiency and effectiveness of actions which determine the attainment of organisational goals and other influential factors through data acquisition, collation, sorting, analysing, interpreting and disseminating to deliver value to the stakeholders of construction R&D activities"

6.10 Contribution to practice

6.10.1 Facilitating the implementation of critical success factors

This study developed a PMS which could assist in measuring the performance of the construction R&D function. Through the PMS development process, the study identified a number of CSFs applicable from initiation to launch phases and at the management of construction R&D function. Subsequently, these CSFs are interpreted and analysed to show their implications in the construction R&D function. Thus, the interpretations on CSFs provide practical insight into why they are important and how they could enhance the construction R&D work. Understanding the implications of CSFs could lead the research team to facilitate the effective implementation of CSFs within construction R&D function by providing supporting factors for their implementation.

6.10.2 Use of performance measurement system as a tool within construction research and development function

The PMS developed through the study provides the performance indicators and measures that need to be considered during the construction R&D function to measure the performance. Thus, through the implementation of the PMS, this study contributes to practice by assisting the performance improvement within construction R&D function.

6.10.3 Satisfaction of the stakeholders

Under the identification of CSFs, the study identified the need for consideration of stakeholder requirement at the initiation and conceptualisation phases and satisfying the stakeholder requirements at the development and launch phases (see Section 5.4.2). Further, the findings on the implementation of CSFs revealed that the CSFs related to stakeholders are implemented more than other CSFs in the construction R&D function (see Section 5.4.3). Furthermore, when questioned about the performance measures used during the construction R&D function, the measures relating to the satisfaction of the stakeholders were utilised when compared with other performance measures (see Section 5.4.4.2). Therefore, this study contributes to the practice by highlighting the importance of satisfying the stakeholders in the construction R&D activities.

6.11 Limitations of the study

This section discusses the limitations of the study. Throughout the study, attention was paid to increasing the acceptability of the research findings, hence a number of measures were taken to increase reliability, validity and credibility of the study (see Section 3.6). The study followed a rigorous research process while increasing the depth of the study through various measures such as use of multiple data collection methods, considering different perspectives regarding the same research issue, and collecting the data at different time periods. The study employed a single case study research approach, thus one of the limitations of the study is with the external validity of the study's findings. However, the researcher provided clear descriptions about the unit of analysis of the study, detailed descriptions about the phenomenon being studied and details about the participants involved so that the findings of the study can be generalised to suitable domains.

Another limitation of the study is associated with the limited progress that can be made in implementing the PMS within a construction R&D project to identify the impact of it towards the success of construction R&D activities. However, the researcher assessed the impact of the PMS by carrying out a series of interviews with principal investigators and researchers who had experience of being involved in R&D projects.

6.12 Further research

6.12.1 Implementing the performance measurement system developed through the study

One of the limitations of the study is non-implementation of the PMS in an on going R&D project. Thus, as further research the PMS can be implemented within a construction R&D project to validate and to identify the impact of the PMS.

6.12.2 Similar studies with different units of analysis and contexts

For this study, the unit of analysis was fixed at the issue: the construction R&D function, and gathered the data from the stakeholders involved in. However, future studies could be carried out by fixing the unit of analysis on the organisations that carry out R&D work such as universities, construction organisations. Further, this study focused on collaborative construction R&D activities lead by the universities. In contrast, future studies can be carried out for collaborative research work lead by the construction organisations.

6.12.3 Application of the performance measurement system in other disciplines

The PMS can be modified to apply to other disciplines such as facilities management, knowledge management to identify the impact of performance improvement.

6.13 Summary of contribution to knowledge

This chapter summarised the main findings of the study obtained from literature, expert opinion and case study investigation. Though PM in construction R&D was asserted as important, limited literature was found in this area. This gap was identified and addressed through this study while contributing to the knowledge as follows:

- identifying the ways in which PM could influence construction R&D function;
- identifying the CSFs of construction R&D function; and
- developing a structured approach to measure the performance of construction R&D function

APPENDIX A THE LIST OF JOURNAL AND CONFERENCE PUBLICATIONS BY THE AUTHOR

- Kulatunga, U, Amaratunga, D, and Haigh, R 2007, Performance measurement in construction research and development, *International Journal of Productivity & Performance Management*, Vol. 56. No. 8, pp. 673 – 688
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2008, Performance measurement in construction Research & Development: The use of case study research approach, *International conference on building education and research (BEAR)*, 11th – 15th April, Sri Lanka
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2007, Structuring the unstructured data: the use of content analysis, *Proceedings of 6th international postgraduate research conference in the built and human environment*, 27th – 28th March, The University of Salford, UK
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2006, Performance Measurement of Construction Research and Development: Evaluation of Performance Measurement Frameworks, *The construction and building research conference of the Royal Institution of Chartered Surveyors*, 7th - 8th September, University College, London
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2006, Design Parameters of Research and Development Performance Measurement Systems, *CIB W 65: Construction in the 21st century, local and global challenges,* 18th – 20th October, Rome, Italy
- Kulatunga, U, Amaratunga, D, Haigh, R 2006, Performance measurement in construction research and development, in Neely A, (Ed) *Performance Measurement and Management - Public and Private*, The University of Cranfield, UK
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2006, The role of research and development in achieving excellence in construction, *International conference on building education and research (BEAR)*, 10th – 13th April, Hong Kong
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2006, Measuring Performance and the impact of Research and Development in the Construction Industry: Research Methodological Perspectives, *Proceeding of 6th international postgraduate research conference in the built and human environment*, 6th-7th April, Delft, The Netherlands
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2006, Performance measurement of research and development: A literature review, *1st International CIB student chapters postgraduate conference*, 26th - 28th March, Turkey
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2005, Research and development, skills requirement achieving excellence in construction, *ARCOM Doctoral research workshop*, 30th November, The University of Northumbria, UK

- Kulatunga, U., Amaratunga, D., and Haigh, R. 2005, Literature review on the status of "research and development" in construction and its performance measurement, *Proceeding of 2nd Scottish conference for the postgraduate researchers of the built and natural environment,* 16th-17th November, The University of Glasgow, UK
- Kulatunga, U., Amaratunga, D., and Haigh, R. 2005, Performance measurement applications within the UK construction industry: A Literature review, *Proceedings of 5th international postgraduate research conference in the built and human environment*, 14th – 15th April, The University of Salford, UK

APPENDIX B SUMMARY OF THE SUCCESS FACTORS

	Critical success factors for new product development
Cooper and Kleinschmidt (2007/ 1996)	High quality new product process Well defined R&D strategy for the business unit Adequate resources such as people and money R&D spending for new product development High quality new product project team Senior management commitment An innovative climate and culture The use of cross functional project teams Senior management accountability
Poolton and Barclay (1998)	Top management support for innovation Long-term strategy with innovation focus Long-term commitment to major projects Flexibility and responsiveness to change Top management acceptance of risk Support for an entrepreneurial culture
Lester (1998)	Senior management commitment The culture of the organisation Cross-functional teams Focus on adding value to the efforts of the venture team Provide strategy and fundamental guidelines Share a common understanding of the process Innovation requires expertise, skills, and motivation Generate good ideas Team formation events A detailed project tactical plan Clear goals and milestone measurements Shift to an external focus to run the new product venture Understanding in the venture team Communication to management The insight gained through reassessment efforts
Lynn et al (1999)	Have a structured new product development process Have a clear and shared vision on the team Develop and launch a product within the proper time frame Refine a product after launch and having a long-term view Possess the optimal team skills Understand the market and its dynamics Secure top management support for the team and the team’s vision Apply lessons learned from past projects

	Critical success factors for new product development
	Secure good team chemistry Retain team members with relevant experience
Cooper (1999)	Solid upfront homework to define the product and justify the project Build in the voice of the customer Seek differentiated, superior product Sharp, stable, and early product definition A well planned, adequately researched, and proficiently executed launch Build tough go/kill decision points into your process Dedicated, supported cross-functional teams with strong leaders An international orientation: international teams, global products Provide training on new product management Define standards of performance expected Cut back the number of projects underway Install a process manager
Sun and Wing (2005)	Idea generation and conceptual design Clearly defined target market Innovativeness of the product to the market Leadership of project leader Support by R&D skilled people Idea generation by brain storming Cross-functional co-operation Flexible and responsive to change Customer focus Cross level communication The team has a clear vision of the market Project budgets established Senior management commitment The willingness to take risk on NPD Technology capable Screen ideas by historical analogy <u>Definition and specification</u> Implement quality standards Clear project goal The project team has a clear vision of project Leadership of project leader Consider issues in early stage Define the performance of the products Develop a feasibility study of the NP A well established operational procedure

	Critical success factors for new product development
	Cross-functional co-operation Technical support by R&D people Senior management commitment Senior management delegation Provide training on NP management to staff <u>Prototype and development</u> Project is well scheduled & strictly monitored Internal communication within the project team Clear understanding of the operation Technical support by project and/or tooling staff Internal testing on product Product review meeting Produce pilot product Cross-functional cooperation Meet customer needs as per previous spec. Senior management commitment External laboratory test Shorten time for prototyping Shorten time for tool building Commercialisation Delivery of the NP to customers on time Right time to launch Competitive product cost Availability of sales force, distribution resources A well established marketing plan The project team has a clear vision of market Senior management commitment Availability of production resources & persons Meet product specification Quick responsiveness to customer requirements Market testing Strong advertising promotion efforts Cross-functional co-operation

APPENDIX C INTERVIEW GUIDELINES DURING THE EXPLANATORY STAGE

Development of a Performance Measurement Framework for Collaborative Research and Development Work

Purpose of the interview

- To refine the Performance Measurement framework
- To evaluate the impact of the Performance measurement framework towards the success of construction R&D activities

Section A: Refinement of the Performance Measurement framework

Based on the construction performance measurement framework what is your view on the below factors:

- completeness of the critical success factors?
- completeness of the performance indicators?
- identification of the performance measures and sources?
- ease of understanding of the framework?
- applicability to construction R&D projects?

Section B: Evaluation of the impact from the Performance Measurement System towards the success of construction R&D work.

As a Principal investigator/ Researcher when you apply this PMS to a completed or an ongoing research project (which involves industrial partners and funding bodies), do you expect improvements in terms of:

- resource identification and utilisation;
- addressing the requirements of the parties involved;
- get the commitment of the team members;
- controlling and monitoring the activities;
- effective dissemination of the work;
- improving feedback, communication and coordination of activities;
- improving the performance of construction R&D activities.

Thank you for your valuable time.

APPENDIX D CASE STUDY BRIEF

Influences of Performance Measurement towards the Construction Research and Development

Aim and Objectives of the Study

The aim of this study is to evaluate how the use of Performance Measurement could enhance the efficiency and effectiveness of construction R&D projects. This involves:

- Understanding the way construction R&D projects being initiated, developed and delivered
- Identifying the success factors of construction R&D project
- Identifying the drawbacks/ improvement areas of the current performance measurement practices
- Identifying the benefits of performance measurement towards construction R&D project

Benefits to you

- Based on the strengths and weaknesses of the current R&D practices and evaluation systems further improvements can be identified
- The performance measurement framework develop during the study can be beneficial to you in evaluating the successfulness of the construction R&D projects

Your Commitment

This study involves conducting series of interviews.

- The interviews will last approximately one hour
- Check the validity of the transcript prepared by the researcher

Confidentiality

The information collected during the case studies will be used for the sole purpose of this study. The findings of the study will not be attributed to any specific interviewee or to the case study organisation.

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APPENDIX E INTERVIEW GUIDELINES DURING THE EXPLORATORY STAGE

Influences of Performance Measurement towards Construction Research and Development

Interview Protocol

This study is on identifying the influences of Performance Measurement towards construction Research and Development (R&D). Accordingly, research projects initiated by universities with the collaboration of construction organisations and research funding bodies will be taken as the scope of the study. The information will be gathered from the main parties involved in the R&D project namely the research providers (Principal investigator, Researchers) and industrial partners.

The interview protocol consists with two sections.

Section A: Information about the interviewee

Section B: The interview questions

The interview questions are based on your experience on a current or recently completed R&D project with particular reference to its performance measurement.

The collected information will remain confidential and will be used for the sole purpose of this study. The subsequent reports and research papers written based on this study will be structured in such a way that no individual can be identified. Comments will not be attributed to any single person of the case study organisations. Further, the interview transcripts will be sent back to the interviewees for their review and acceptance.

Thank you in advance for participating in this study. If you have any queries, do not hesitate to contact me.

Contact details of the researcher

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SECTION A: INTERVIEWEE'S BACKGROUND INFORMATION

Interview Type: Principal investigator ☐ Researcher ☐ Industrial partner ☐	Interview Number: ☐
Location:	
Date:	Time:
Name:	Designation:
Organisation:	
Contact Details	
Postal Address:	
Telephone:	Fax:
Email:	

SECTION B: INTERVIEW QUESTIONS

1. Initiation of the R&D project

This involves the idea generation to select the most suitable option for a research

- Who are the parties involved at the initiation of the R&D project?
- Who identifies the activities needed for the R&D project?
- In your opinion, what are the areas which can be improved during the idea generation?
- What are the success factors during the initiation stage of the R&D project?

Conceptualising the R&D project

Conceptualising stage involves the formulation of aims and objectives, identification of the resources and analysis of the feasibility of the R&D project

- How are the aims and objectives/ resource requirements of the R&D project being identified?
- Is the feasibility of the R&D project being evaluated?
- Are the aims and objectives of the R&D project being communicated?
- In your opinion, what are the areas which can be improved during the conceptualising stage?
- What are the success factors during the conceptualising stage of the R&D project?

2. Development of the research project

The development stage involves the actual development and piloting the new

- How are the deliverables/milestones of the R&D project being identified? (by considering whose needs)
- If the research output significantly deviates from the established deliverables/milestones, what are the actions that have been taken?
- What are the reasons for not achieving the established deliverables/milestones?
- In your opinion, what are the areas which can be improved during the development stage?
- What are the success factors during the development stage of the R&D project?

3. Launching the R&D project results

Launching stage the dissemination of the project results

- How are the project results being delivered?
- In your opinion what are the areas which can be improved at the delivery stage?
- What are the success factors during the launch of the R&D project?
- Do you think the R&D activities initiated by universities are properly transferred to the industry?

- If not what are the reasons?
- If yes, in what ways?

4. Management of the R&D project

This section is based on your experience on the management of the R&D project

Resource management

- What are the resources needed for the R&D project?
- How is the resource requirement for the R&D project being identified?
- How is the proper resource utilisation being evaluated?
- In your opinion, how can the proper resource utilisation within the R&D project be improved?
- What are the success factors for resource management of the R&D project?

Coordination

- How is the R&D project being coordinated?
- What are the problems/ difficulties when coordinating the R&D project?
- What are the main reasons for the problems you identified?
- How can these reasons be prevented and improve the R&D performance?
- In your opinion, how can the proper coordination of R&D project be improved?
- What are the success factors for coordination of the R&D project?

5. Performance measurement of R&D project

This section is based on your experience on the performance measurement of the R&D project

- Are performance indicators/ measures used within the R&D project? What are they?
- How are the norms for the above performance indicators/ measures being set out?
- What measurement techniques are used?
- What are the drawbacks/ shortcomings of the current performance measurement applications?
- Are there any other performance indicator/ measure that you think should be used within the R&D project?
- Why are they not in place at the moment?
- Are the results of the performance measurement being communicated to the parties involved in the R&D project?
- In your opinion, how can the performance measurement of the R&D project be improved?
- What are the benefits of performance measurement in the R&D project?
- What can be the negative impacts of R&D performance measurement?

6. The status of construction R&D

This section is on your general perception regarding the construction R&D

- In your opinion, who should lead the construction R&D activities?
- Why?

Thank you for your valuable time spent on this interview.

APPENDIX F INTERVIEW TRANSCRIPT

SECTION B: INTERVIEW QUESTIONS

Initiation of the R&D project

- Who are the parties involved at the initiation of the R&D project?

I think that depends on who the project aimed at, I think majority of time it's purely driven by the academics.

- Who identifies the activities needed for the R&D project?

Investigators have to satisfy the requirements of the beneficiaries as well as the funding bodies. The funding body as a separate organisation may have different objectives that to actual beneficiaries of a research project. So as the investigators we have to make sure that both the objectives are taken care of within your research project. To answer your question, partly the beneficiaries; party the research objective it self, what is the actual question it self; and apart from that the funding organisations.

- What are the success factors during the initial stage of the R&D project?

At the very beginning, the first and foremost thing that we are doing is to ensure that the project is funded by the funding organisation. In order to make sure that actually we have to go through a rigorous bidding process. In order to do that actually we have to make a balance between what the funding organisation requires from their perspective as well as what are the actual research questions. So when compiling the research bid, we are addressing both the issues in a balanced way. That is the key I think.

Conceptualising the R&D project

- How are the aims and objectives/ resource requirements of the R&D project being identified?

First and foremost the major input for the aims and objectives of the projects comes from the research questions, from where we are formulating the research proposal. In fact that's from the perspectives of beneficiaries, what they really require from the research project. Apart from that there may be drivers from the investigators point of view, if the investigator is attached to a particular research institute, research institute's long term goals may have an impact towards the aims and objectives of the research project. On top of that again the function of the funder is coming to the action. We have to address their objectives as well if there are specific causes for proposals for a particular funder. We have to look at their perspectives, what are they really looking at, so part of aims and objectives accommodate their objectives as well. So it's a combination of investigators point of views, the research institute's point of view and funders and not to forget about the ultimate beneficiaries.

- Are the aims and objectives of the R&D project being communicated to you? How is it communicated?

As a researcher yes, I can answer it in two ways, as a person who involved in initial bidding. Yes I always tend to make explicit quotations about what the aims and objectives are within the research proposal. So who ever get involved in the research project later on will come to know about the aims and objective because those are specifically mentioned within the documentation. So yes, I make sure that it is transparent through out the whole profile.

As well as a researcher, yes I was given the documentation related to the project and day to day guidance, revisiting aims and objectives every day with regular meetings to refresh our minds to what really we are doing. So yes, I am quite aware of what we are doing in terms of aim and objectives.

- In your opinion, what are the areas which can be improved during the conceptualising stage?

I think, ideally speaking the aims and objectives of a research project should have a major bearing towards the beneficiaries. The beneficiaries should determine what the aim and objectives of a research project are. But as this has a financial component attached, the funding organisations often determine a larger portion of aim and objectives. I think we should make a clear distinguish between what the industry wants and what the actual funders want. We have to have a proper mechanism in place to ensure both the parties are satisfied at the same time, while not forgetting the major impact is towards the beneficiaries. So their problems should be taken into consideration when formulating aims and objectives.

- What are the success factors during the conceptualising stage of the R&D project?

It should be very simple, and should be achievable. Should be a method devised to find out whether these aims and objectives are achieved through the process. For e.g. if you have set up an objective to accomplish something at the end of third week, there should be set of measurement to determine whether the objectives have been achieved during that particular period, rather than going by ad-hoc means and there should be proper measures to determine whether the objectives have been achieved or not.

Development of the research project

- How are the deliverables/milestones of the R&D project being identified? (by considering whose needs)

The deliverables are identified based on the aims and objective of the project obviously. At the same time we are making sure that the outcomes are directly related to the problems that we are addressing and directly going towards the direct beneficiaries. So we are identifying ok, what the problem is and who are the targeting groups and what are the outcomes and how the outcomes address the problems identified and how that is transferred to the identified beneficiaries.

Yes about milestones, each and every research project we have a time frame in mind. Generally it is a good practice to have a set of small activities combine together to formulate the big project. We are terming it in our research projects as work packages. In work package what you do is, you get a set of activities to be completed within a certain time period, and that work package is designed as a mini project. So while achieving all the aims and objectives and their timelines and milestones everything, ultimately we are making sure that the big project aims and objectives are met within the given time periods. So to answer your question effectively when we are determining the milestones, we are doing it by going through a process what is known as the work package process.

- If the research output significantly deviates from the established deliverables/milestones, what are the actions that have been taken?

Well, research is really a plan, plans basically go wrong. I think it's not a major issue, if a plan deviated from its original plan. What we do is, we identify each and every research project, if something changes significantly from what we intended, we are identifying what are the causes for that reason. Then we are trying to establish, whether that cause is significant body of knowledge towards the research project as a negative impact. If that is so, then that it self is a major outcome. Because of these reasons, we couldn't deliver the identified objectives or the identified deliverables, instead we have delivered these ones.

To take remedial actions, I don't think that remedial actions are appropriate here. Because, it is appropriate if you are governed by the principle that we should achieve all the aims and objectives set initially. No I think we are not governing by that principle. We are governing by the principle that we are doing a research project, we have initial aims and objectives, but if that is going to change later on due to reasons, then when the reasons are identified properly that doesn't matter anymore. We have delivered an appropriate product at the end of the day. Comparing that to the first objective or first intention to the final product is done by going through the justification process. I think a remedial action may not be necessary.

- Don't you think that it will be a problem for the funders or beneficiaries?

Well that we have to make sure. The general practice during the execution of a research project is to have a contract in place. So there are mechanisms within the contract, if you are deviating from your original aims and objectives, deliverables, these actions should be taken. For e.g. for one of the projects that I am involved in, if there are significant changes, we have to inform them during a certain period. And that is classified as a major addendum to the contract. So we are formulating a different document saying that this is an addendum to the contract. So the addendum and the previous contract form the new contract. So the funding organisations are also dynamic and the research institute also dynamic and the investigator also dynamic. Every body is looking at every body's perspectives. I don't think that as long as they keep on the dynamic situation, that there will be a problem. The problem comes if the funder is so static and not willing to change his mind. I think that won't work anymore because everything is changing.

- What are the reasons for not achieving the established deliverables/milestones?

One that I think straight away is funding problems. If that is sorted out initially, then a major problem is solved. The other things could be the time limitations. Due to unforeseen circumstances, if it is a collaborative project specifically with all the partners' things can go wrong. Another example could be, partners, institutions might change over time. So their objectives may change overtime. So your research directions may change over time. That could be another effect. Individuals may change, say a principal investigator from a research project changes from one person to another during the life span of the project that individual character will influence towards the research project. Even though that it shouldn't be there, there is certain individuality. That may be another reason.

- In your opinion, what are the areas which can be improved during the development stage?

One good practice that I have seen so far is the work package concept. If you are not using the same terms, the idea is to set mini projects within the big project. And set short term objectives for the mini projects. So the final project will come out successfully. So if you are going wrong with one particular mini project, you can always medal within that mini project, so that the major effect towards the main project is minimal. Another one could be when setting milestones is be realistic. When funding we tend to think quite extensively about what the funders wants. Don't put a time line just to satisfy them. Think carefully whether we can deliver this project within the given timelines.

- What are the success factors for development stage of the R&D project?

During the execution the first and foremost thing that I would emphasise is the collaboration. There are so many parties involved within the research project. You have to make sure that effective communication is established between all the parties. There are so many approaches that we can take. Actually one innovative approach that we took is to make a virtual research environment which we have hosted within the University. And that works very well I think. Apart from that there are traditional ways and means of making the project progress with the collaboration with proper communication channels like emails, regular meetings.

And also at the same time it's important to make sure that your short term objectives are met during short term milestones. Set your short term milestones to ensure that at the end of the day you are achieving the overall objectives of the research project.

To summarise what I have said, you have a plan to measure whether you have achieved you mile stones or not. Then you can set up short term milestones, and try to be realistic with your milestones.

Launching the R&D project results

- How are the project results being delivered?

Through conferences, publications in refereed journals may be presented in workshops.

- In your opinion what are the areas which can be improved at the delivery stage?

It goes to the short term planning I think. If it is possible to breakdown the project and plan it to such a level of sophistication, that would be preferable than having something that still dependent on future work. Unfortunately with R&D, the unknown is always in the future. It's always influential on what is being done to date.

Unless you recall the whole process, in other words literature review A is backed up with literature review B and may be C and D and you record the back responses happening because of changes else where, which I think requires more honestly in the research process currently encouraged. But clearly what needs improved is the connection of delivery of aims and objectives against the project plan.

- Do you think the R&D activities initiated by Universities are properly transferred to the industry?

No I don't think so. One thing is the research is not initiated by the industry. That's the starting point. Second, when it comes to the construction projects specifically, publications matters a lot. But, tangible outcomes are the key concerns of practitioners. Are we delivering enough outputs towards the construction industry in that aspect? When you take say soft ware industry, aircraft, ultimate output of those researches is a usable product to the industry itself. But in construction we hardly see any usable product being produced. To be used by the construction industry taken straight out from the research output. So that aspect is lacking. There should be a proper bridge between the research institutions and the industry. That gap is becoming bigger and bigger. Academics are concentrating on their own world of research and practitioners including clients are suffering from their own problems. I think that's again the lack of communication.

Management of the R&D project

Resource management

- What are the resources needed for the R&D project?

First and foremost researchers. Their time, their dedication. Then there are quite a number of capital investments like equipments. And main important thing is the time of the investigators. Generally, research investigators are a part of the research institute. They are not dedicated for a given research project at a given time. But they have to make sure that they are given proper attention, appropriate attention to each and every element that they have to deliver within the institute. If they have five research projects, they have to manage their time to give proper and appropriate attention to each individual project. Otherwise, without a leadership, a research project will collapse. Researchers alone cannot concentrate on the success of the research project. There has to be guidance. That guidance has to be come from principal investigator. That's one of the key elements that we have to be concerned about. Not winning the projects, not winning the bids, but managing it is quite important.

- How is the resource requirement for the R&D project being identified?

The practice that I have gone through is, when we formulate the research bid we identify what are the resources required. And we account for that financially within the research bid. But it may have an impact like this. Say for en e.g. if the funding body has a certain budget, when they are calling for proposals, the investigators might be guided by that budget to say they have a budget limit of this much and we'll go for that budget limit. That may lead to either under resource or over resource a project. Say a researcher may be assigned to a research project just to come to the financial limits that the funding organisations have. Or else if you are going out of the budget , then where a researcher is actually required for a project they may be cutting him down during the budget. That could be detrimental. So the idea would be to identify what are the things that the funding organisations sets up in terms of financial budgets, and then determine your resources based on the actual resources of the project. And then later on if it is not feasible within the given guidelines, scale down your project as a whole not as an element of resources. The research project is not actually scaled down to reflect the actual budget but the project remains big where as the resources being taken out from the projects, quite often to accommodate the financial constraints given by finding organisations. Later on you will realise that the project cannot be proceeded with the given resources limits.

- How is the proper resource utilisation being evaluated?

Resource utilisation is generally a concern of the funding organisation most of the time. So they have their own mechanisms. During quarterly reports, interim reports, the investigators will have to forward their financial expenditure for that particular period. That gives the funding organisation a snap shot what is the resource utilisation at that period. So they can either agree with that or make suggestions to change it. Any way the short term reports, is a key important factor to monitor the resource utilisation.

- In your opinion, how can the proper resource utilisation within the R&D project be improved?

One way would be to make sure that you are at them very beginning, you are realistic about the resource requirements. Don’t be governed by or don’t be guided by the guidelines published by external factors like funding organisations. Do not over resource or under resource your research projects. In order to determine the actual resource requirements, you have to have a bottom up approach. Think about the deliverables, think about the activities, think about the resource requirements, and then compile your actual resource requirements. It has to come up from the bottom. You can’t determine ok, we have this much of resources, and based on that we are going to do this. No, that won’t happen. Think about the actual deliverables required for the project, then work towards the top.

<u>Coordination</u>

- How is the R&D project being coordinated?

There could be so many variance of research coordination. It could be an internal research project, it could be an external research project, it could be a collaboration. When coordinating, you have to determine who are the stakeholders. Could it be internal organisations it self, could it be the industry based beneficiaries, funding organisations. So when you take that into account, first of all, you have to make sure that there is a proper mechanism in place for proper communication. Communication is the key for proper coordination. So if the communication channels are established, another good practice would be to have short term deliverables, short term milestones, and short term meetings. If you have all these things in place, you know what to deliver in given short term time. So at short meetings, you can determine whether the project is achieving its desired objectives.

- What are the problems/ difficulties when coordinating the R&D project?

The geography is the major concern. If the project is an international collaboration, communicating between the partners would be a quite a big task. Their time zones could be different from one to the others and some partners simply do not dedicate themselves towards the project. They may be engaged with other research projects, and they are not realising that there should be a certain input from all the partners towards the success of the project. So we have to educate all the partners equally about the importance of getting involved in the research project as much as we require.

Another thing would be the language barrier when it comes to so many aspects. Data collection, collecting actual perceptions, collaboration, all these could be a matter when it comes to the language barrier.

- In your opinion, how can the proper coordination of R&D project be improved?

By thinking all these barriers, we have developed this virtual research environment, at the moment it is in the initial stages, but from the output we can see that it's working very well. That reduces the impact of language barrier, the time differences between different geographical locations. Again the communication is the key.

- What are the critical success factors for coordination of the R&D project?

I think when you think about it, all the factors will ultimately leads towards communication. It's the communication.

Performance measurement of R&D project

- Are performance indicators/ measures used within the R&D project? what are they?

To get some examples, we have something called Logical Framework, within which we established what are the parameters that we are going to measures for each and every objective and the outcome. First of all we write down in a spreadsheet or in a document like that the major outcome of the research project. And under each outcome we specify, under which objective particular outcome is being evaluated. Then in front of that we are giving measures, what are the key factors to be considered when measuring these things. One example would be the development of module specification. This could be an output for a research project. The objectives would be to enhance the module pool between various institutions. And a numerical measurement could be number of modules contributed by each partner towards the central pool. So that's a numerical indication of how the activity is performed and how successful it is. Within that a metric could be the number of responses or number of modules that we have received. The second one would be a qualitative one to say that, giving it a quality rating for each module, what is the actual quality of the module. So we have this framework. And that is transparent to the investigators and to the funding body, so the funding body is assessing the investigators based on that logical framework to find out under this outcome every performance measures are being taken care of and under each performance measure, the metrics or the sub elements are been addressed. If that is done, then they can consider the outcome is achieved. Once the collection of outcomes are achieved, they can justify that the objective is achieved, by accumulating all the objectives, they can justify that the aim is achieved. So the performance is actually what you achieved at the end of the day from what you have intended.

- How are the norms for the above performance indicators/ measures being set out?

We are very explicit about the norms. The norms were written down in the logical framework. That we do at the time of the preparation of the research proposal. With that again it's a bottom up approach. We have to address these outputs, while doing so we have to go through this process, so we are identifying a process through which at the end of it we are achieving a certain outcome. But the process when we are analysing it, you will identify these are some spin over effects, so those spin over effects will contribute towards actual performance measures. Not only spin over effects, during the process we identify ok, for these particular objectives, these are the sub elements that we are going to address. So by setting up that you can determine these are my performance measures.

So its research project's expectations are the major source of guidance towards the performance measures.

- What measurement techniques are used?

Qualitative and quantitative in combination. As mentioned in the logical framework we have both combinations. But when it comes to the funding organisations, they would like to see tangible, quantitative, solid aspects. So that it's very easy to measure. But sometimes, depending on the nature of the research project, it's hard to give quantitative evidence. Giving that simply distort the actual performance of the research project. Because, sometimes the performance of the project cannot be determined by quantitative methods. So in that case we are giving qualitative aspects as well. So what we do is making sure that each qualitative aspect has also some sort of tangible measures.

- What are the drawbacks/ shortcomings of the current performance measurement applications?

I don't have much experience of PM of research projects, the only experience that I am having is about this logical framework. One problem with that could be the logical framework is very hard to compile initially. When you go through the process, there could be so many instances where you can simply miss important measurement aspects. Since it is one simple document, not all the aspects will be documented within that document. It is during the process that you realise, ok these are the important factors that you have take into account in the measurement. But the logical framework simply doesn't accommodate that, at least within a certain given period. We can update the logical framework in our research projects, general practice is that we can't update it within a reporting year, between reporting years we can update the logical framework. Say after the first year you can revise your logical framework for the second year. They are flexible in someway, but not as much as we like.

- Are there any other performance indicator/ measure that you think should be used within the R&D project?

Ideally we should take the perspective of the beneficiaries for PM. Because ultimately they are the once whose going to get benefits. But I don't know any mechanisms, actually I am not aware of any such mechanisms available within traditional research environments to get the ultimate feedback from the beneficiaries. At least not within the life cycle of the research project. Perhaps after it. But there's no input to the research project in that instance. I think, when and where we deliver the outputs to the intended beneficiaries, if there's a mechanism to get the feedback from them about the effectiveness of it, then that could be a big measure towards the performance.

- In your opinion, how can the performance measurement of the R&D project be improved?

Well the above could be one thing. Frankly speaking, the performance measures at the moment, are determined by the funding organisations. So we are really pushed towards delivering or performing the projects in terms of those performance measures. We are always looking at the performance measures written down in the logical framework in this particular instance, and trying to address those issues, rather than concentrating on the actual issue. So I think the performance measures should come form the researcher and the investigator. It's true that some part is there, but I think it should be initiated by the researcher rather than the funding organisation. The investigator should take the sole responsibility of the performance measures.

- Don't you think that there should be some contribution from the beneficiaries?

Yes, beneficiaries feedback should be there as I mentioned. But it is not there as far as I am concerned for the research projects that I am engaged. At least I can't see any feedback from the beneficiaries. If there are barriers to implement that at least immediately what you should do is, your project has your own measurement frameworks. You determine your measurements, how the project should progress, because ultimately, you are the one who's going to execute and deliver your outcome to the beneficiaries.

- What are the benefits of performance measurement in the R&D project?

It helps extensively to keep your research focused, without that your research can go all over. So by having performance measures, which are short term most of the time when you break it down, you know that at the end of the day you are achieving your aims and objectives. That is the key thing. The other thing is with that you can identify, are there other things that we can do for the project, apart from the actual proposal it self. In order to achieve the performance measures, there may be so many other things outside the proposal that you can do towards the success of the project. The measures it self gives us the indication apart from the activities written down in the document, these things could lead to a better project. So, that could be another advantage. And the other thing is if things go wrong, it's immediately transparent. So it becomes apparent that, if something is against your performance measures then there could be something wrong. So you can take immediate actions which reduce the risk of construction R&D projects being unsuccessful.

- What can be the negative impacts of R&D performance measurement?

As I mentioned, one big negative impact may be the investigator only concentrate on the performance measures rather than the actual research questions. If that is the case performance wise the project may progress well. But the beneficiaries might get the minimal benefits. You have to be diplomatic in that case. Take performance measures as a tool, do not lead the performance measures to drive your project, rather get it as a guidance to see that your project is successful, but often what I am seeing is research projects are guided by performance measures which I think is not the best thing to do.

The status of construction R&D

- In your opinion, who should lead the construction R&D activities? Why?

There are two aspects to this I think. The theoretical aspect as well as the practical aspect. Theoretical aspect says the research institute identifies the problems within the construction industry. But does it happen. I think that construction practitioners are more aware of construction problems than academics. Well, when it comes to research and development, I am here referring to big research institutions, dedicated research institutes. There are R&D departments within construction organisations. That's a different perspective. I am talking about dedicated, academic R&D organisations like Universities. Construction also has different perspectives. Problems from clients' perspective, problems from contractors' perspective, those are not matching each other. Say if there is a problem from the construction industry, from the contractors' perspective, that could be well not a problem form the clients' perspective. So we have to be carefully selected whose problems we are addressing. Someone may say that clients should lead the construction, well at the end of the day the construction organisations are the key concern when it comes to construction industry. So to whom should we listen to? I think its bit of unclear area to who should lead the R&D in construction. I think the initiation or the identification should come form the industry. At least they should communicate it to the R&D institutions. What we see as problems as academics may not be necessarily the problems that the construction practitioners may think. But at the end of the day as academics the research we do should have an impact towards actual construction. Otherwise there's no value of it.

Thank you for your valuable time spent on this interview.

APPENDIX G QUESTIONNAIRE

Reference number

QUESTIONNAIRE

Research Title: Influences of Performance Measurement towards Construction Research and Development

This questionnaire is based on an ongoing PhD which seeks to evaluate how the use of Performance Measurement could enhance the effectiveness and efficiency of construction R&D projects. The questionnaire consists of the following sections.

Section 1: General information
Section 2: Critical success factors of construction R&D
Section 3: Performance measurement applications

Scope: The scope of the study is limited to research projects initiated by universities with the collaboration of industrial partners and research funding bodies.

Confidentiality: The information collected will be used for the sole purpose of this study and for academic publications. The findings of the study will not be attributed to any specific personnel.

Please return the completed questionnaire on or before:

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Section 1: General information

1. Your present job title:
2. Years of experience in research activities:

Section 2: Critical success factors of construction Research and Development

The following tables present the success factors during different stages of a research project. Based on your experience, please tick the most appropriate scale regarding the importance and consideration/implementation of success factors during research project.

Success factors are defined as the set of circumstances/factors which influence the attainment of the success criteria (e.g. time, quality, cost targets) of research projects.

1. Initiation Phase: *This involves the idea generation to select the most suitable option for a research project*

The extent of importance | **The extent of consideration/ implementation**

Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☒	☐	Understand the market and its dynamics	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Establish the research problem clearly	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Selecting a competent team	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Leadership of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Commitment of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider funding bodies' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider industrial partners' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider researchers' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Other (please specify)	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

2. Conceptualising Phase: *Conceptualising stage involves the formulation of aims and objectives, identification of the resources and analysis of the feasibility of the R&D project*

The extent of importance | **The extent of consideration/ implementation**

Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐	Check the feasibility of the project	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider funding bodies' requirement	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider industrial partners' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Consider researchers' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Establish clear and realistic goals/ deliverables/ milestones	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Establish clear method to measure success	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Allocation of responsibilities to team members inline with competencies	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Establish a plan to disseminate research	☐	☐	☐	☐	☐	☐

2. Conceptualising Phase: *Conceptualising stage involves the formulation of aims and objectives, identification of the resources and analysis of the feasibility of the R&D project*

The extent of importance							The extent of consideration/ implementation					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
						results						
☐	☐	☐	☐	☐	☐	Comprehensive briefing process	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Adequate resources/financial support	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having a skilled team	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Early involvement of industrial partners	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Leadership of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Commitment of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Committed and cooperative team members	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Recognition for team members	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Fast decision making process	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Absence of lengthy bureaucracy	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Other (please specify)	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

3. Development Phase: *This involves the actual development and piloting the new venture*

The extent of importance							The extent of consideration/ implementation					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐	Adequate resources/financial support	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having a skilled team	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having a well established operational procedure	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having a risk mitigation strategy	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Flexibility and responsiveness to change	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Leadership of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Commitment of the principal investigator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Committed and cooperative team members	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Share a common understanding about the work	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Recognition for team members	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Secure momentum/ motivation of the team	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Fast decision making process	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Absence of lengthy bureaucracy	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Testing the market	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet funding bodies' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet industrial partners' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet researchers' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Other (please specify)	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

3. Development Phase: *This involves the actual development and piloting the new venture*

The extent of importance							The extent of consideration/ implementation					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

4. Launching Phase: *This involves the dissemination of the project results*

The extent of importance							The extent of consideration/ implementation					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐	Having a well established dissemination/ marketing plan	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Launch the output within the planned time frame	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective dissemination of the results	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet funding bodies' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet industrial partners' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Meet researchers' requirements	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Comprehensive project review and feedback	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Refinement of the output after launch	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Other (please specify)	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

5. Project Management: *This involves the management activities needed for research projects.*

The extent of importance							The extent of consideration/ implementation					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐	Continuous reviews	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective collaboration	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective communication	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective planning, controlling, and organising of activities	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective resource management	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Effective management of the people	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Evaluating post delivery success	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having a separate project administrator	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	Having an external person to do reviews	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

5. Project Management: This involves the management activities needed for research projects.												
The extent of importance							**The extent of consideration/ implementation**					
Unimportant	*Of little importance*	*Moderately important*	*Important*	*Very Important*	*No Opinion N/A*		*Never*	*Rarely*	*Sometimes*	*Very often*	*Always*	*No Opinion N/A*
☐	☐	☐	☐	☐	☐	Other (please specify)	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐

Section 3: Performance measures in construction research projects

The following table presents the performance measures used in research projects. Please indicate the use of those performance measures within your research projects and the type of assessment(s) used.

Stakeholders refer to industrial partners and funding bodies participated for construction R&D activities.

Types of performance measures	Yes	No	The type of performance measure(s) used
Measures to identify the stakeholder requirements/ expectations from the project	☐	☐	
Measures on the comprehensiveness of the research proposal	☐	☐	
Measures to identify the market needs	☐	☐	
Measures on the feasibility of the project	☐	☐	
Measures to identify researchers' requirements/expectations	☐	☐	
Measures on the stakeholder involvement and commitment	☐	☐	
Measures on the project time	☐	☐	
Measures on the project finance (requirement, allocation, utilisation)	☐	☐	
Measures on the other resources (human, equipment etc.)	☐	☐	
Measures on the project team performance	☐	☐	
Measures on the project quality	☐	☐	
Measures on identifying the satisfaction of the stakeholders	☐	☐	
Measures on the accomplishment of the project objectives	☐	☐	
Measures on the accomplishment of the milestones	☐	☐	
Measures on the post delivery success	☐	☐	
Measures on the education and training of researchers	☐	☐	
Measures on the learning and growth of the stakeholders and researchers (knowledge gains/ knowledge creation, transfer and exploitation)	☐	☐	
Measures on identifying the satisfaction of the researchers	☐	☐	
Measures on the retention of the stakeholders	☐	☐	
Measures on the acquisition of new business	☐	☐	

Types of performance measures	Yes	No	The type of performance measure(s) used
relationships			
Measures on the development of new research directions	☐	☐	
Other (please specify)	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	

Any other comments:

Thank you for your valuable time spent on this questionnaire.

☐ *If you need a summary of the final survey report, please tick the box and provide your name and address below. Your responses will be treated in confidence.*

Name:

Address:

APPENDIX H COMPARISON OF THE QUALITY CRITERIA

Author	Criteria	Description	Techniques
Curtin and Fossey (2007)	Trustworthiness	The extent to which the findings are an authentic reflection of the personal or lived experience of the phenomenon under investigation	Thick description (detail descriptions of the context and circumstances surrounding the phenomenon to give a better understanding) Triangulation Member checking (involvement of the participants in the data analysing process) Collaboration (degree of collaboration between the researcher and the participants) Transferability (degree to which the findings can be applied to another setting) Reflexivity (direct acknowledgement of the researchers participation and influence through out the research process)
Yin (2003)	Construct validity	Establishing correct operational measures for the concepts being studied	Use of multiple sources of evidence, Key informants review the draft case study
	Internal validity	Establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguish from spurious relationships	Do pattern matching
	External validity	Establishing a domain to which the study's finding can be generalised	Use replication logic
	Reliability	Demonstrating that the operations of the study (such as the data collection procedure) can be repeated, with the same results	Use case study protocol, Consistent interview guidelines, Develop case study data base
Remenyi et al (1998)	Validity	Gaining the full access and knowledge and meanings of respondents	Respondents review the interview transcripts, Triangulation

Author	Criteria	Description	Techniques
	Reliability	Accept the particularise nature of research through good practice guidelines Elaborating the transparency of the work	Establish audit trail, Keeping evidence of work in easily retrievable manner, Maintaining log/journal about research design decisions and justifications
	Generalisability	Applicability of theories from one setting to another Enable one to attain an understanding of organisational processes	
	Credibility	Designing the research in such a manner that it accurately identify and describe the phenomenon to be investigated	In depth descriptions about the complexities of the research settings and drawing on empirical evidence
	Transferability	How the phenomenon being investigated ties to a broader case (external validity)	Stating the theoretical parameters clearly, Make clear the specific organisational processes about which generalisation will be made
	Dependability	Account for changes in the conditions of the phenomenon being investigated as well as research design changes which are made because of the better understanding of the research settings	
	Confirmability	Whether the research confirms general findings	Confirms the findings of the research by another similar study
Easterby-Smith et al (2002)	Validity	Study clearly gain access to the experience of those in the research setting	
	Reliability,	Transparency of the raw data	
	Generalisability	Concepts and constructs derived from the study have any relevance to another setting (external	

Author	Criteria	Description	Techniques
		validity)	
Silverman (2001)	Validity		Deviant case analysis, Constant comparative methods Comprehensive data treatment, Using appropriate tabulations
	Reliability	Degree of consistency	Standardised methods to write field notes, prepare transcripts, analysing the data by a third person, piloting the interviews,
	Genaralisability		Combining qualitative research with quantitative, measures of populations Purposive sampling Theoretical sampling
Whittemore et al (2001)	Credibility,		Reflexivity (expose the researcher's biases and personnel perspective, making clear the personnel stance in relation to the subject being studied, exposing the relationship with the participants of the study) Methodological triangulation, investigator triangulation Member checking Peer checking Audio/ video recording of interviews Providing sufficient methodological details to another researcher to repeat the study Making clear the rationale behind the sampling strategy

Author	Criteria	Description	Techniques
	Criticality,	Detailed account on how the researchers critically appraise their findings	Detailed descriptions of the data analysing process Investigator triangulation Searching for negative/unusual cases/views
	Authenticity	Extent to which the research reflect the experiences of the respondents	Member checking Quoting raw data Participants to act as researchers Allowing issues important to the participants rather than issues important to the researchers
	Integrity	Looks into the ethical issues of a study	Providing consent forms for the respondents
Mays and Pope (2000)	Validity Relevance		Triangulation Member checking Clear exposition of methods of data collection and analysis Reflexivity Attention to negative cases Fair dealing Sampling strategy (theoretical sampling)

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