Lean thinking in the highways construction sector: Motivation, implementation and barriers

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Abstract

The interest in lean thinking in the UK's civil construction industry is on the rise. The research presented in the paper evaluates the adoption of lean thinking in the highways construction sector by investigating 7 motivation factors, 20 lean techniques and 16 barriers through in-depth interviews with 20 sector managers and a questionnaire survey of 110 responses. The findings show the existence of strong external motivational factors for lean thinking such as clients' push and companies' expectation of winning more contracts alongside lean's operational benefits. Limited adoptions of the lean techniques, mostly in the stepwise process improvement cycle, the Last Planner System and Visual Management, were determined. This raises concerns about "pseudo-lean" practices in the sector. Lack of standardisation, insufficient benefit capturing, insufficient know-how, insufficient control of the entire value stream and limited view to the techniques were found as the top barriers. Small and medium sized enterprises (SMEs) are significantly different than large main contractors and subcontractors with respect to their lean implementations and views to barriers before lean thinking within their organisations.

Keywords: lean thinking; motivation; implementation; barriers; construction; civils; survey; highways

1. Introduction

The aim of this research is to evaluate the adoption of lean thinking in the highways construction sector in the UK by investigating its motivation factors, the characteristics of the implementation of some lean tools and techniques, and the barriers before lean thinking in the sector. The origins of lean thinking can be found on the shop-floors of Japanese manufacturers and, in particular, innovations put in effect at Toyota Motor Corporation between the 1930s and the 1970s, which were first conceived as improvement opportunities to be built-up on mass automotive manufacturing practices in the US (Monden 1983; Shingo 1986; Ohno 1988; Fujimoto 1999). In parallel with Japan's successful post-war recovery and emergence as a global economic power, Japanese manufacturing techniques have been benchmarked by Western manufacturers since the 1970s (Drucker 1971; Sugimori et al. 1977). Although the diffusion of lean thinking had started in discrete manufacturing industries in the West in the 1980s, the publication of a business book, "The machine that changed the world" by Womack, Jones and Ross (1990), fuelled a debate in both the practitioner and academic communities concerning the applicability of the lean approach outside discrete, repetitive industries (Oppenheim 2011; Lyons et al. 2013; Costa and Godinho Filho 2016; Dora, Kumar, and Gellynck 2016; Colicchia, Creazza, and Dallari 2017).

The start of discussions on the applicability of lean thinking in the construction industry concurred with this broader diffusion period of lean in other industries. In parallel with this attention to lean thinking, its adoption in the construction industry started to be discussed extensively in the early 1990s (Koskela 1992, Koskela 1996; Ballard 1997; Tommelein 1998). The construction industry is shaped by low-entrance barriers and low-profit margins, temporary production configurations exposed to many uncontrollable parameters, a slow take-up of change and fragmented supply chains

(Behera, Mohanty, and Prakash 2015), which produce challenges before the diffusion of lean thinking in the industry (Ballard and Howell 1998; Thomas et al. 2002; Johansen and Walter 2007; Viana, Formoso, and Isatto 2017). Unlike some other industries (Storch and Lim 1999; Yusuf and Adeleye 2002; Achanga et al. 2006; Wilson and Roy 2009; Hodge et al. 2011; Panizzolo et al. 2012; Lyons et al. 2013; Martinez-Jurado and Moyano-Fuentes 2014), broader empirical research, investigating the adoption of lean thinking in different supply chains of the construction industry has generally remained scarce. Lack of sector level analyses is conspicuous as lean thinking in construction has mostly been investigated from a process improvement perspective through some lean techniques at the operational level (Alves and Tsao 2007).

With two high-profile industry reports published in the mid/ late 1990s, a climate of change highlighting lean thinking as one of the way-forwards was induced for the construction industry in the UK (Latham 1994; Egan 1998). For the past 10 years, the civil construction sector in the country has been increasingly adopting lean thinking in its operations with explicit requirements from the main public clients (Wolbers et al. 2005; Ansell et al. 2007; Chen et al. 2012; Drysdale 2013; Fullalove 2013; Daniel et al. 2017). Consequently, lean thinking in the civil sector has been driven by large service suppliers and client organisations to date with some reported benefits. Despite those efforts, not much is known as to the general characteristics of this surge in the interest in lean thinking.

The article has the following structure. In the next section, a review of lean thinking in the construction industry is presented, discussing the key literature in the area, alongside the main lean tools and techniques used in the construction phase, and the motivations for and barriers before lean thinking in construction. Following the general lean thinking discussion, the main characteristics of the highways construction supply chain in the UK, in which lean thinking has been treated as a strategic direction since the late 2000s, are outlined. After setting the research background, the research methodology and the data collection methods are presented. Following the research methodology section, the analysis of the data collected from the interviews and the survey questionnaire are presented and discussed. The article is concluded with a summary of the key findings and some recommendations.

2. Literature review

2.1. Lean thinking in the construction industry

The application and adaptation of the underlying concepts and principles of lean thinking to construction is referred to as Lean construction (LC) (Sacks et al. 2010). Those underlying concepts and principles are (1) elimination of the process wastes (Hodge, Goforth Ross, and Joines 2011; Thürer, Tomašević, and Stevenson 2017), (2) effective management of the value stream and establishing long-term alliances with the supply chain (Serrano Lasa, Castro, and Laburu 2009; Colicchia, Creazza, and Dallari 2017), (3) maintaining a continuous and reliable flow of the production and process elements (Storch and Lim 1999; Negrão, Godinho Filho, and Marodin 2017), (4) pull-based production planning and control (Slomp, Bokhorst, and Germs 2009; Zegarra and Alarcon 2017), (5) just-in-time delivery of materials and components (Bamber and Dale 2000; Chiarini 2017), and (6) instilling a continuous improvement culture (Lyons et al. 2013).

Lean thinking deployments are affected by industry characteristics (Storch and Lim 1999; Lyons et al. 2013; Vlachos 2015) and the construction industry possesses its own defining characteristics which necessitates an adaptation of the lean thinking principles and techniques rather than a direct adoption from manufacturing. The industry is shaped by temporary multi-organisations, fragmented supply chains and project delivery systems, regulatory intervention, different work trades moving around the capital asset (the product) leading to frequent time and space conflicts, lack of a real industry direction - the traditional *laissez-faire* policy justified by the industry's "flexibility", taxation and insurance policies leading to acute self-employment and labour casualisation, low entry barriers with small firms and self-employment dominating the industry scene, a strong focus on individual projects narrowing perspectives on general supply development, a high emphasis on initial delivery costs instead of whole life-cycle costs, suppliers tending to compete on cost efficiency rather than technical expertise, relationships between actors influenced by a culture of conflict (low-trust economy), economic climate affecting organisations' relations quickly (amicable/supporting vs. adversarial/aggressive), superficial supply chain integration practices, low-profit margins, a high risk aversion and a slow-take up of innovation and technology (Koskela 1992; Shirazi, Langford, and Rowlinson 1996; Vrijhoef and Koskela 2000; Dubois and Gadde 2002; Harvey 2003; Green and May 2005; McGuinness et al. 2006; Segerstedt and Olofsson 2010; Behera, Mohanty, and Prakash 2015; Viana, Formoso, and Isatto 2017; Zegarra and Alarcon 2017). According to Oppenheim (2011) and Oehmen et al. (2012), to successfully implement lean in complex systems like construction projects, (1) managers must treat people as important assets, (2) strive to maximise the project value, (3) optimise the value stream, (4) create a project flow, (5) create pull planning and control systems in the project and (6) pursue perfection. A list of the frequently discussed lean techniques deployed by the construction industry can be seen in Table 1. The Last Planner System is almost the only method specifically developed for the industry. Actually, there is evidence that many lean techniques developed in the manufacturing context seem to work well in construction with some adaptation.

There is evidence of the use of lean thinking within the construction industry for more than 25 years (Koskela 1992; Howell and Ballard 1998). LC aims to improve the performance of the construction industry from a production management perspective by analysing construction projects as temporary production systems (Howell 1999). A recent market report by McGraw-Hill (2013) documented the positive effect of lean in attaining higher construction project performance and customer satisfaction, alongside challenges associated with lack of lean knowledge and a limited understanding of lean thinking in the industry. After an in-depth study of ten successful building projects in the United States and Canada, Cheng (2016) concluded that Integrated Project Delivery (IPD), a relational contracting and partnering strategy, sets the terms and provides the motivation for collaboration and lean provides the means for construction teams to optimise their performance and achieve project goals, further highlighting the need to approach lean in construction with a firm supply chain management perspective. While LC is claimed to offer a new paradigm for construction production management, the field has also been criticised for lacking firm theoretical underpinnings and concrete definitions, for having an overriding positive bias based on enthusiastic arguments, for inherently being too process focused neglecting the supply chain dynamics and for superficial implementations in some lean techniques like the Last Planner System (Green 1999, 2002; Green and May 2005; Fearne and Fowler 2006; Jorgensen and Emmitt 2008; Eriksson 2010; Daniel et al. 2017).

According to Green and May (2005), lean construction implementation efforts can be divided into three different stages, with increasing degree of sophistication:

(1) Stage 1: waste and variability elimination from a technical and operational perspective using specific lean tools and techniques like good housekeeping (5S), visual management systems, Just-in-Time (JIT) production and IT systems that can be adopted in any construction project striving for operational efficiency. Most of the research in the field have consolidated around exploring Stage 1 (Alves and Tsao 2007).

(2) Stage 2: optimising the supply chain through eliminating adversarial relationships and enhancing cooperative relationships, teamwork and partnering among supply chain actors (Eriksson 2010).

(3) Stage 3: supply chain implementation. According to Alves and Tsao (2007) , supply-chain level lean thinking implementation research is the most scarce.

Lean Construction Institute (2017) defines lean thinking implementation in construction as a triangle with the following edges;

- Lean techniques at the operational level (operating systems),
- Integrated project delivery strategies (commercial) and
- Transformational change (organisational) mostly concerned with strategic decisions like the use of off-site/modular systems and leadership.

Regarding motivational factors for lean thinking in construction organisations, alongside an expectation of increase in operational performance, secondary factors like client and competitive pressures, and aspirations toward building a positive publicity/ image of the company were found important (Green 1999; Alarcon and Seguel 2002; Almeida and Salazar 2003; Barros Neto and Alves 2007; Mossman 2009; Arbulu and Zabelle 2012; McGraw-Hill 2013; Ogunbiyi, Goulding, and Oladapo 2014). At the operational level, employee resistance, lack of know-how, lack of management support, backsliding (going back to the old of ways of working), a temporary, short-sighted view to the implementation (viewed as “flavour of the month”), budget constraints (risk aversion), lack of proper planning and coordination in implementation, insufficient control of the entire value stream and training issues were identified as important barriers before the implementation of lean thinking in the construction industry (Diekman et al. 2004; Jorgensen, Emmitt, and Bonke 2004; LEI 2007; Leong and Tilley 2008; Arbulu and Zabelle 2012; Wandahl 2014; Sarhan and Fox 2013; Berroir, Harbouche, and Boton 2015; Pasquire, Sarhan, and King 2015a, 2015b; Ward 2015; Zanotti, Maranhão, and Aly 2017).

Table 1. Lean thinking techniques as applied in the construction industry.

No	Lean construction tools/ techniques	Definition	References: Manufacturing	References: Construction
1	The Last Planner System(LPS)	A collaborative task planning and control framework for the construction industry that emphasises collectively removing production blockages and self-planning (pull) of work by construction work trades. The proponents of the LPS claim the framework can more realistically integrate construction process flows and value capturing into the planning and control process than the commonly used Critical Path Method (CPM).		Ballard and Howell 1998; Kim and Ballard 2010; Seppänen, Ballard, and Pesonen 2010; Viana, Formoso, and Isatto 2017; Zegarra and Alarcon 2017
2	Visual Management	A management strategy that is based on using easy-to-understand sensory systems (i.e. visual performance boards) in close-range communication to increase process transparency, and to facilitate work control and information flow.	Parry and Turner 2006; Murata and Katayama 2010	Formoso, Santos, and Powell 2002; Tezel et al. 2015; Tjell and Bosch-Sijtsema 2015
3	5S	A systematic housekeeping methodology which is represented by its 5 distinctive steps all starting with s; sort, set-in-order, shine, standardise and sustain.	Abdulmalek and Rajgopal 2007; Bayo-Moriones, Bella-Pintado, and Merino-Díaz de Cerio 2010	Johansen and Walter 2007; Stehn and Höök 2008
4	Value Stream Mapping (VSM)	A material and information flow mapping technique, which is used to analyse the current and to design the future state of a production or service delivery from its beginning through to the customer.	Seth and Gupta 2005; Serrano Lasa, Castro, and Laburu 2009; Ben Fredj-Ben Alaya 2016	Yu et al. 2009; Rosenbaum, Toledo, and González 2013
5	Problem solving process (PDCA Cycle)	A work improvement cycle that is based on identifying and analysing process problems (plan), developing and testing potential solutions (do), measuring the effectiveness of the test solution(check) and implementing and standardising the solution (act).	Herron and Braiden 2006; Sokovic, Pavletic, and Pipan 2010	Salem et al. 2006; Yu et al. 2011
6	Continuous improvement cells	A small-group work improvement activity that is based on Quality Circles (QC).	Åhlström 1998; Kitazawa and Sarkis 2000	Nahmens and Ikuma 2009; Miron et al. 2016
7	Line of balance method (Location based planning)	A graphical work scheduling, control and balancing method, which is based on planning/ work balancing with respect to location and often used in linear construction projects (i.e. highways, high-rise buildings etc.)		Mendes and Heineck 1998; Soini, Leskelä, and Seppänen 2004

8	*Takt* time planning	Work planning based on the time set for the supply of a certain process (*takt*) that is derived from the customer demand. It forms the basis for single-piece flow in lean thinking	Seth and Gupta 2005; Millstein and Martinich 2014	Yu et al. 2009; Frandson, Berghede, and Tommelein 2013
9	First run studies	An alternative approach to work improvement through process observation and photo/video recording. It is often executed on critical construction tasks at the beginning of their execution to understand productivity rates for better work planning and work improvement opportunities, fine tuning the task design.		Ballard 1999; Hamzeh, Ballard, and Tommelein 2009
10	Work structuring	A term used to describe the effort of integrating product and process design throughout the project development process to optimise production on-site.		Tsao et al. 2004; Frandson, Seppänen, and Tommelein 2015
11	Set-up preparation and improvement	Systematic study of a work-setup to optimise each task involved in terms of efficiency and safety, which is also explained under the term Single-Minute Exchange of Dies (SMED)	Shingo and Dillon 1989; Mileham et al. 1999	Filho et al. 2005; Paez et al. 2005
12	Supply chain integration	A close alignment and coordination within supply chains through partnering, long-term contracts, training support for service providers, transparency in information flow, shared risk/ benefits and so on.	Fawcett and Magnan 2002; Flynn, Huo, and Zhao 2010	Dainty, Millett, and Briscoe 2001; Briscoe and Dainty 2005
13	Mistake-proofing (*Poka-Yoke*) systems	Tools and systems to control or warn people of process errors to prevent them from turning into mistakes (the permanent, undesirable condition of a process outcome) for improved process quality, safety and set-up preparation.	Shingo 1986; Saurin, Ribeiro, and Vidor 2012	Dos Santos and Powell 1999; Tommelein 2008
14	In-station quality - *Jidoka*	Providing machines and operators the ability to detect when an abnormal condition has occurred and immediately stop work. Together with Standard Operating Sheets (SOPs), Visual Management, Statistical Process Control (SPC) and mistake-proofing systems, it enables in-station quality or quality at source.	Bruun and Mefford 2004; Pettersen 2009	Kemmer et al. 2006; Heineck et al. 2009
15	Standard Operating Sheets (SOPs)	A visual documentation of a work process displaying the required material components, process steps and production rates. SOPs form one of the basis for work standardisation.	Schuring 1996; Shaw and Edwards 2006	Arbulu and Tommelein 2002; Nahmens and Ikuma 2011
16	Just-in-Time (JIT) material/ component flow	Maintaining a construction material and component flow in a way that matches the internal/external customer demand and the pace of production to optimise stocks and work-in-progress.	Sugimori et al. 1977; Golhar and Stamm 1991	Tommelein 1998; Pheng and Chuan 2001
17	Pull production system using *kanbans*	Controlling and harmonising production between work units based on the number of specific cards, tokens or signals called *kanbans.*	Sugimori et al. 1977; Mukhopadhyay and Shanker 2005	Tommelein 1998; Arbulu, Ballard, and Harper 2003; Ko and Kuo 2015
18	Pre-fabrication and modularisation	Extensively using pre-fabricated and modularised construction components to overcome the inherent production problems of on-site construction (i.e. low productivity, low output quality, high variability, health and safety hazards).		Gosling and Naim 2009; Gosling et al. 2016

19	Cell production units (Multi-functional construction work units)	Forming teams of different construction trades (i.e. plasterer. electrician, carpenter) to work together as a work unit in a particular construction site location to minimise work-in-progress and to maintain a continuous production flow.	Deif 2012; Saurin, Marodin, and Ribeiro 2011	Moser and Dos Santos 2003; Mariz et al. 2013
20	Information technologies to support lean construction deployments	Extensive use of digital technologies (i.e. mobile systems, distributed databases and cloud computing, sensor networks etc.), particularly the Building Information Modeling (BIM) technology, an object-based, parametric, virtual prototype of a construction asset that can be used from the asset's design to demolition to facilitate the information flow in lean construction deployments.		Sacks et al. 2010; Becerik-Gerber et al. 2011

2.2. Lean thinking in the highways construction supply chain in the UK

In the UK, lean thinking came under the spotlight mainly with the Egan report, "Rethinking Construction", which was produced in 1998 to address concerns raised by clients engaging services of construction companies (Egan 1998). The aim of the report was to stimulate a change in the culture, style and management of the industry. However, after the report, the dissemination of lean thinking across the construction industry in the country could not be realised as intended (Mossman 2009; Sarhan and Fox 2013). Since the late 2000s, adoption of some of the lean production planning and control techniques outlined in Table 1 has been championed by Highways England (HE), the highways supply chain's main public client in England, as a strategic decision to improve the overall performance of the supply chain and to meet HE's ambitious performance and cost saving targets set by the UK government (Ansel et al. 2007; Drysdale 2013; HE 2016).

HE first executed that strategy through engagement and contractual configurations with some large-sized main contractors (Tier 1s) and some specialised, large sized subcontractors operating in key delivery areas like soil works, paving/surfacing or traffic management (large Tier 2s) (Chen et al. 2012; Drysdale 2013; Fullalove, 2013). Those large subcontractors are almost on par with large main contractors in terms of their annual turnovers and employee numbers. While those large contractors and specialised subcontractors form alliances to deliver series of projects within some framework arrangements with HE, small and medium sized construction and maintenance companies (SMEs), which are defined as companies operating with annual turnovers not more than 50 million GB £ and with employees not more than 250 (EC 2015), are employed by Tier 1s, often for short terms on the minimum price basis with fixed-priced contracts (Tezel, Koskela and Aziz 2017).

HE commonly imposes a cap contract price, from which deviations in the form of price overruns or savings are shared between Tier 1s and HE to incentivise Tier 1s to make operational cost savings and to encourage the development of lean thinking at the same time. Alongside this, HE is contractually imposing the use of some lean techniques like the Last Planner System (known as Collaborative Planning in the UK – see Figure 1a) (Daniel et al., 2017) or Visual Management (see Figure 1b) (Tezel and Aziz, 2017) in its contracts with Tier 1s. Also, Tier 1s and large subcontractors are monitored by HE for their lean maturity (Nesensohn et al., 2015). This active lean agenda drew management consultants into the sector. Those consultants are generally employed by large contractors and large subcontractors to develop on their current lean efforts and also they offer lean training services to the supply chain.

Although lean thinking is on the rise and becoming a strategic direction in the UK's civil construction sector, there is a scarcity of empirical research evaluating its characteristics of implementation by covering the whole supply chain beyond discussing some specific lean tools like Collaborative Planning or Visual Management. Moreover, client-led, large-scale lean thinking implementation efforts in the construction industry are relatively recent phenomena and little research has been identified focusing on the lean thinking deployment conditions of specific construction sectors (e.g. civil, building, energy etc.) in this regard.

Figure 1(a). A Collaborative Planning board for planning and control at a highways construction project. The project has been divided into production areas and each subcontractor has been colour-coded. The Last Planner System is called the Collaborative Planning System in the UK.

Figure 1(b). A visual planning and control board devised as part of the Visual Management effort at a highways construction project for electrical construction works. The production progress, plan and issues can be tracked visually.

3. Methodology

With the fundamental aims of understanding the motivation factors behind the surge in the adoption of lean thinking, the characteristics of the adoption of lean tools and techniques, and their associated barriers in the civil construction supply chain, a mixed-method study of exploratory nature was designed. Following a literature review on lean in the construction industry, 20 senior managers (4 from HE, 5 from large contractors, 4 from large subcontractors, 7 from SMEs) from England's highways sector were interviewed face-to-face for circa 45 – 60 minutes between December 2015-May 2016 (see details of the interviews in Table 2). The interviews were semi-structured and open-ended. The primary advantages of open-ended interviews are that that they can provide more detailed information on a subject matter than survey studies and their potential to reveal rich-insights for exploratory research (Rapley 2001; Berg 2004). The interviewees were identified in collaboration with HE from managers actively engaging with the lean implementation in highways projects. Particular attention was given to interviewing managers from all the supply chain roles, from the client (HE) to SMEs, in order to capture a more complete picture of the issue, which is as an important aspect for interview reliability (Miles and Huberman 1994; Shao and Müller 2011). Also, to further increase interview reliability and validity, the interview protocol was reviewed by peers and supervisors, and the data and the analysis were linked to the existing literature as much as possible (Miles and Huberman 1994; Shao and Müller 2011).

Table 2. Details of the interviewees.

No	Interviewee management role	Experience in the sector	Organisation's role in the supply chain	Main operational area
1	Senior manager	> 20 years	SME	Civil works
2	Senior manager	> 20 years	SME	Civil works
3	Senior manager	> 20 years	SME	Telecommunication works
4	Senior manager	> 30 years	SME	Telecommunication works
5	Senior manager	> 30 years	Large subcontractor	Aggregate/ surfacing
6	Senior manager	> 20 years	Large subcontractor	Aggregate/ surfacing
7	Senior manager	> 20 years	Large contractor (Tier 1)	General contracting/ project management
8	Senior manager	> 30 years	Large contractor (Tier 1)	General contracting/ project management
9	Senior manager	> 20 years	Large contractor (Tier 1)	General contracting/ project management
10	Senior manager	> 30 years	Large subcontractor	Traffic management
11	Senior manager	> 30 years	SME	Civil works
12	Senior manager	> 20 years	Large subcontractor	Surfacing
13	Senior manager	> 20 years	Large contractor (Tier 1)	General contracting/ project management
14	Senior manager	> 30 years	Large contractor (Tier 1)	General contracting/ project management
15	Senior manager	> 20 years	SME	Electrical works

16	Senior manager	> 20 years	SME	Surfacing
17	Senior manager	> 20 years	Client (HE)	Lean/ process improvement department
18	Senior manager	> 30 years	Client (HE)	Lean/ process improvement department
19	Senior manager	> 30 years	Client (HE)	Lean/ process improvement department
20	Senior manager	> 20 years	Client (HE)	Lean/ process improvement department

To validate, rank and perform further analysis on the findings from the literature review and the interviews, a questionnaire survey was designed due to its ability to cover large number of respondents, its cost effectiveness and for a higher generalisability of results (Ngai, Cheng and Ho 2004; Yang and Wu 2009). The questionnaire includes;

- 7 motivation factors behind the lean implementation identified from the literature review and the interviews, for which the respondents were allowed to choose more than one motivation factor,
- 20 questions investigating the degree of the implementation of the main lean production planning and control techniques (Table 1) in construction organisations, where the respondents could choose either "implemented", "some efforts towards implementation", "seen useful but no real action", "known but not seen useful" or "not known" by their evaluation of the condition of the techniques at their companies and
- 16 lean thinking barriers related questions on a Likert-type scale of 1 to 5, where 1 represents "strongly disagree" and 5 represents "strongly agree".

After the first draft of the questionnaire, a pilot study was conducted with the aim of testing the level of ease at which respondents would be able to complete the questionnaire. The pilot study examined the clarity of the language, the appropriateness and the logic of the questions, the layout, the degree of depth, the ease of navigation and user friendliness of the whole questionnaire. Additionally, it also gave the opportunity to ask the respondents if there were other statements beyond the ones in the final questionnaire. The pilot study involved 12 senior managers (with the highways sector experience more than 20 years) from 4 Tier 1 companies, 4 large subcontractor companies and 4 SMEs. Although no additional items were required to be included in the final list, the companies recommended re-wording some of the questions. These suggestions were implemented in the design of the final questionnaire.

HE's database was used to pinpoint relevant managers to send the questionnaire to, who are familiar with the lean adoption in the highways supply chain. This kind of purposive sampling strategies in survey studies can be necessary to obtain relevant results when investigating innovative, emerging or niche phenomena (Winch et al. 2012; Stanworth 2012, Shishank and Dekkers 2013). The questionnaire was sent electronically. Of the outgoing 289 surveys, 110 responses were collected between June – October 2016 with 38% response rate, which is acceptable in academic studies (Baruch, 1999; Barlett, Kotrlik and Higgins 2001). Among the respondents, 49 managers are from Tier 1s (45% of the respondents), 43 managers are from SMEs (40% of the respondents), 13 managers are from large Tier 2s (11% of the respondents) and 5 managers are from management consultants (4% of the respondents). 67 of the respondents are senior managers (61% of the respondents), 35 of the respondents are middle managers (32% of the respondents) and 8 managers are junior managers (7% of the respondents) (see details of the respondents in Table 3). The questionnaire was analysed using the SPSS (Statistical Package for the Social Sciences) software. The research process can be seen in Figure 2.

Table 3. Details of the survey questionnaire respondents.

Supply chain role	**Years of experience**				
Management role	0 - 10 years	10- 20 years	20 - 30 years	> 30 years	**Total**
Consultant	1	2		2	5
Middle Manager	1	1			2
Senior Manager		1		2	3
Large contractor (Tier1)	12	19	8	10	49
Junior Manager	8				8

Middle Manager	3	15	3	2	23
Senior Manager	1	4	5	8	18
Large subcontractor	7	1	3	2	13
Middle Manager	6	1			7
Senior Manager	1		3	2	6
SME	3	17	17	6	43
Middle Manager		2	1		3
Senior Manager	3	15	16	6	40
Grand Total	23	39	28	20	110

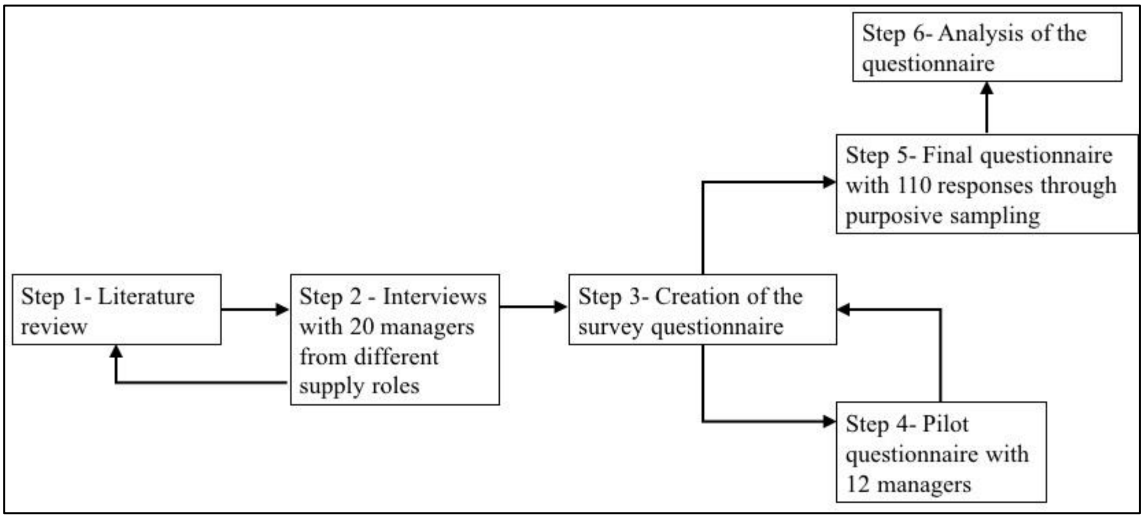

Figure 2. Research process

4. Data analysis

4.1. Interview results

The interview findings revealed that companies in the civil construction supply chain were motivated for their lean implementation by seven main factors; (1) LC will help companies improve their operations/ processes, which is the expected outcome of those lean implementations. Additionally, (2) LC implementations will help companies win more contracts in the future, (3) LC can help companies promote their organisations for a better publicity/ image, (4) clients are asking companies to implement some LC techniques within their organisations. Similarly, (5) clients are asking companies to participate in their LC implementations/ plans in a supporting role, which was found more valid for large subcontractors and SMEs, (6) companies are contractually obliged by their clients to implement some LC techniques and (7) companies' competitors are also implementing some LC techniques and consequently, companies do not want to lag behind.

Regarding the lean techniques, the ones that were frequently referred to were the Last Planner System (or Collaborative Planning as known in the UK), Visual Management and the stepwise process improvement cycle (PDCA), which is mostly used to eliminate the process wastes. The findings were not surprising as those techniques are also frequently highlighted by the main client (HE), sometimes incorporated in contracts and are the main subjects of LC trainings in the supply chain. Other initiatives associated with LC such as the use of BIM, the use of prefabricated and modular construction components, and supply chain integration practices were also mentioned. However, beyond the lean initiative, those associated practices have already been on the agenda of the supply chain actors, due to various other reasons like the UK government's BIM mandate on construction companies (Gledson and Greenwood 2016) or the main clients' notable attention to off-site/modular construction (Gosling et al. 2016). As for the adoption of the techniques, large Tier 1 contractors and large subcontractors were found to be leading with marginal efforts at SME organisations.

The referred barriers before lean thinking by the interviewees were (1) lack of standardisation in the application, (2) problems associated with benefit measurement or demonstrating the business case, (3) insufficient know-how, and (4) the supply chain's narrow view of the techniques as means to impress clients rather than actual means for improvement in processes/ operations. Also, the interviewees underlined (5) lack of metrics for the techniques, (6) employee resistance, (7) backsliding or going back to the old ways of working after a while, (8) lack of a long term vision, (9) budget constraints (high risk aversion), (10) problems in retaining experience and know-how associated with the techniques, (11) lack of continuous lean training in the supply chain, (12) insufficient management support, (13) insufficient planning and coordination in the' implementation, (14) fragmented implementation of the techniques, (15) insufficient control of the entire value stream, particularly the design phase and (16) the techniques being seen as temporary "flavour of the month" by the supply chain. The interview findings matched well with the literature review and were used as the basis for the questionnaire survey study.

4.2. Questionnaire results

4.2.1. Motivation factors

The seven motivation factors were compiled by the respondents' supply chain roles (see Table 4). Each motivation factor was ranked by the number of respondents that had chosen the corresponding motivation factor within a supply chain role group and in total. According to this ranking, the top three motivation factors are:

(4) clients' push for LC (clients are asking companies to implement some LC techniques),

(5) companies' expectation to win more contracts in the future and

(6) companies' belief that LC will help them improve their processes/ operations are the top three motivation factors in total.

Also, as the data are of nominal type and multiple-choice, a non-parametric Chi-square test (H_0: LC motivation response does not depend on the supply chain role) investigating if there is any statistically significant difference in the perception of the motivation factors by the main supply chain roles (3 groups – large contractors, large subcontractors and SMEs) at 95% confidence was executed for each motivation factor (see Table 4). Consultants were excluded due to their small number of responses (5). As all the Chi-square test significance (Sig.) values were found bigger than 0.05, H_0 was not rejected at 95% confidence; meaning the perception for the motivation factors does not depend on the supply chain roles and the existence of some consensus among the supply chain actors with respect to the motivation factors. The views of consultant organisations however were found to differ more significantly (see Figure 3 for relative response percentages) from the rest of the respondents. In particular, contrary to the rest of the respondents, consultants do not seem to think companies are motivated for LC mainly for the expected process/ operations benefits (see Figure 3).

Table 4. Motivation factors for the LC implementation.

LC deployment motivations	Large contractors			Large subcontractors			SMEs			Consultants			Total			Chi-square test		
	No. of respondents	% of respondents	Rank within group	No. of respondents	% of respondents	Rank within group	No. of respondents	% of respondents	Rank within group	No. of respondents	% of respondents	Rank within group	No. of respondents	% of respondents	Overall rank	Chi-square value	Sig.[a]	H_0[b]
Companies believe LC will help them improve their operations/ processes	30	61%	3	9	69%	3	30	70%	2	1	20%	7	70	64%	3	5.11	0.16	Not rejected
Companies believe LC implementations will help them win more contracts in the future	32	65%	2	10	77%	2	29	67%	3	4	80%	1	75	68%	2	1.66	0.65	Not rejected
LC is a popular term that can help companies promote their organisations for a better publicity/ image	14	29%	7	2	15%	6	16	37%	5	2	40%	6	34	31%	7	2.59	0.46	Not rejected
Clients are asking companies to implement some LC techniques.	34	69%	1	11	85%	1	33	77%	1	3	60%	3	81	74%	1	1.96	0.59	Not rejected
Clients are asking companies to participate in their LC implementations/ plans	27	55%	4	9	69%	3	28	65%	4	4	80%	1	68	62%	4	3.08	0.38	Not rejected
Companies are contractually obliged to implement some LC techniques.	22	45%	5	2	15%	6	11	26%	6	3	60%	3	38	35%	5	7.40	0.06	Not rejected
Competitors are also implementing some LC techniques and companies do not want to lag behind	18	37%	6	3	23%	5	11	26%	6	3	60%	3	35	32%	6	3.60	0.31	Not rejected

a. Significant at 95% confidence interval = 0.05

b. H_0: LC motivation response does not depend on the supply chain role (Large contractors, large subcontractors and SMEs)

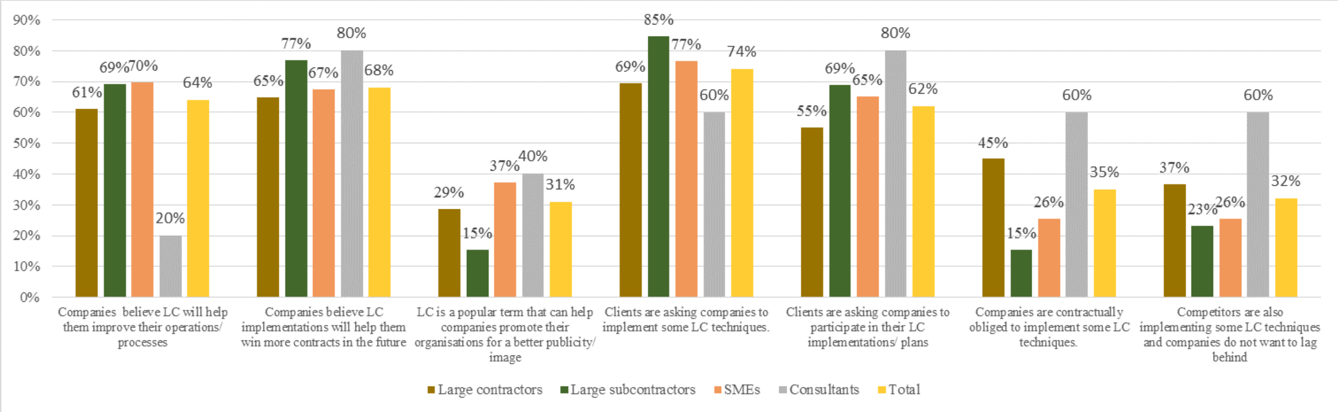

Figure 3. Percentage (%) of the motivation factors chosen by each supply chain group

4.2.2. Lean techniques

The responses as to the condition of the twenty lean techniques were compiled by the respondents' supply chain roles (i.e. large contractors, large subcontractors, SMEs and consultants) (see Table 5). The condition percentages of the total responses by each lean technique can be seen in Figure 4. As the data are of nominal type, a pairwise non-parametric Chi-square test (H_0: There is no difference with respect to the implementation of the LC techniques between the two groups of companies) investigating if there is any statistically significant difference in the implementation of the techniques by the three main supply chain roles (*i.e.* large contractors, large subcontractors and SMEs) at 95% confidence was executed for each lean technique (see Table 5). Consultants were excluded due to their small number of responses (5). When the significance (Sig.) values were found smaller than 0.05, H_0 was rejected at 95% confidence and the significance values were shown in italic and bold in Table 5; meaning there is a statistically significant difference in the implementation of a lean technique between two groups of companies.

The results show that with respect to the condition of the lean techniques, there is no statistically significant difference between large contractors and large subcontractors. However, the conditions at both group of companies significantly differ from the conditions at SMEs. Most of the techniques seem to be unknown to SMEs (see Table 5). The top five implemented techniques in the supply chain (see Figure 4) are

(1) extended prefabrication and modularisation,
(2) the process improvement cycle (PDCA),
(3) the Last Planner System,
(4) Visual Management and
(5) supply chain integration efforts, which are in line with the findings from the interviews and the literature review.

However, with the Last Planner and Visual Management, there are notable “not seen usable” percentages (22% and 20% respectively) as well, which supports the argument for the need for a better demonstration of the business case for those techniques. Also, some techniques like mistake-proofing or in-station quality seem to have not been implemented at all and to be mostly unknown by the supply chain. Consultants as external actors also acknowledged that although there are efforts for the implementation of some lean techniques such as the PDCA process improvement and problem solving cycle, the Last Planner System or Visual Management, the lack of know-how is a challenge in the supply chain.

Table 5. Condition of the lean construction techniques

LC techniques	Large contractors					Chi-square test statistic		Large subcontractors					Chi-square test statistic		SMEs					Chi-square test statistic		Consultants					Total				
	Imple-mented	Some efforts	No real action	Not seen useful	Not known	Sig[a]. vs. Large subc.	Sig[a]. vs. SMEs	Imple-mented	Some efforts	No real action	Not seen useful	Not known	Sig[a]. vs. Large cont.	Sig[a]. vs. SMEs	Imple-mented	Some efforts	No real action	Not seen useful	Not known	Sig[a]. vs. Large cont.	Sig[a]. vs.Large subc.	Imple-mented	Some efforts	No real action	Not seen useful	Not known	Imple-mented	Some efforts	No real action	Not seen useful	Not known
The Last Planner System	25	15	3	6	0	0.96	***0.00***[b]	7	3	1	2	0	0.96	***0.00***[b]	2	4	14	14	9	***0.00***[b]	***0.00***[b]	0	3	0	2	0	34	25	18	24	9
Visual Management	21	13	8	7	0	0.82	***0.00***[b]	4	4	2	3	0	0.82	***0.01***[b]	1	5	9	10	18	***0.00***[b]	***0.01***[b]	0	3	0	2	0	26	25	19	22	18
5S	10	12	16	11	0	0.22	***0.00***[b]	2	1	6	3	1	0.22	***0.00***[b]	0	0	6	5	32	***0.00***[b]	***0.00***[b]	0	1	2	2	0	12	14	30	21	33
Value Stream Mapping	5	4	10	7	23	0.2	***0.00***[b]	0	0	5	0	8	0.2	***0.00***[b]	0	0	0	2	41	***0.00***[b]	***0.00***[b]	0	0	1	0	4	5	4	16	9	76
Process improvement and problem solving (PDCA)	22	17	9	1	0	0.78	***0.02***[b]	6	4	2	1	0	0.78	0.34	13	8	14	2	6	***0.02***[b]	0.34	3	2	0	0	0	44	31	25	4	6
Continuous improvement cells/ teams	12	18	8	9	2	0.12	***0.00***[b]	3	4	3	0	3	0.12	***0.01***[b]	0	4	10	5	24	***0.00***[b]	***0.01***[b]	0	2	1	1	1	15	28	22	15	30
Line of Balance Method	3	4	13	3	26	0.77	0.1	1	1	2	0	9	0.77	0.28	0	2	5	5	31	0.1	0.28	0	0	2	0	3	4	7	22	8	69
Takt time planning	2	8	8	2	29	0.49	***0.00***[b]	1	0	2	0	10	0.49	***0.01***[b]	0	0	0	0	43	***0.00***[b]	***0.01***[b]	0	0	0	0	5	3	8	10	2	87
First run studies	0	4	9	0	36	0.64	***0.01***[b]	0	1	1	0	11	0.64	0.12	0	0	1	0	42	***0.01***[b]	0.12	0	0	0	0	5	0	5	11	0	94
Work structuring	3	6	9	2	29	0.6	***0.00***[b]	1	0	2	0	10	0.6	***0.01***[b]	0	0	0	0	43	***0.00***[b]	***0.01***[b]	0	0	0	0	5	4	6	11	2	87
Set-up preparation and improvement	7	9	11	7	15	0.52	***0.01***[b]	1	4	4	0	4	0.52	***0.01***[b]	2	2	3	4	32	***0.01***[b]	***0.01***[b]	0	2	0	1	2	10	17	18	12	53
Supply chain integration	15	29	5	0	0	0.46	***0.00***[b]	3	7	3	0	0	0.46	***0.02***[b]	5	9	29	0	0	***0.00***[b]	***0.02***[b]	0	3	2	0	0	23	48	39	0	0
Poka-yoke systems	0	2	7	1	39	0.72	***0.02***[b]	0	0	1	0	12	0.72	***0.04***[b]	0	0	0	0	43	***0.02***[b]	***0.04***[b]	0	0	0	0	5	0	2	8	1	99
In-station quality	0	3	7	1	38	0.64	***0.02***[b]	0	0	1	0	12	0.64	***0.04***[b]	0	0	0	0	43	***0.02***[b]	***0.04***[b]	0	0	0	0	5	0	3	8	1	98
Standard operating sheets	12	10	18	2	7	0.63	***0.03***[b]	2	3	4	0	4	0.63	0.6	2	10	18	0	13	***0.03***[b]	0.6	0	2	3	0	0	16	25	43	2	24
Just-in-Time material/ component flow	0	8	13	10	18	0.23	***0.01***[b]	0	0	5	1	7	0.23	0.09	0	0	5	5	33	***0.01***[b]	0.09	0	0	2	2	1	0	8	25	18	59
Pull-production system using kanbans	0	5	7	9	28	0.19	***0.00***[b]	0	0	3	0	10	0.19	***0.01***[b]	0	0	1	0	42	***0.00***[b]	***0.01***[b]	0	0	1	1	3	0	5	12	10	83
Extended pre-fabrication and modularisation	36	12	0	1	0	0.32	***0.00***[b]	7	5	0	1	0	0.32	***0.01***[b]	9	8	22	4	0	***0.00***[b]	***0.01***[b]	1	4	0	0	0	53	29	22	6	0
Cell production units	0	8	5	6	30	0.15	***0.00***[b]	0	0	3	0	10	0.15	***0.01***[b]	0	0	1	0	42	***0.00***[b]	***0.01***[b]	0	0	1	0	4	0	8	10	6	86
Use of BIM to support LC practices	16	18	6	0	9	0.49	***0.00***[b]	3	3	3	0	4	0.49	***0.01***[b]	0	2	7	2	32	***0.00***[b]	***0.01***[b]	0	1	2	0	2	19	24	18	2	47

a. Significant at 95% confidence interval = 0.05

b. H_0: No difference with respect to the implementation of the LC technique between the two groups of companies rejected.

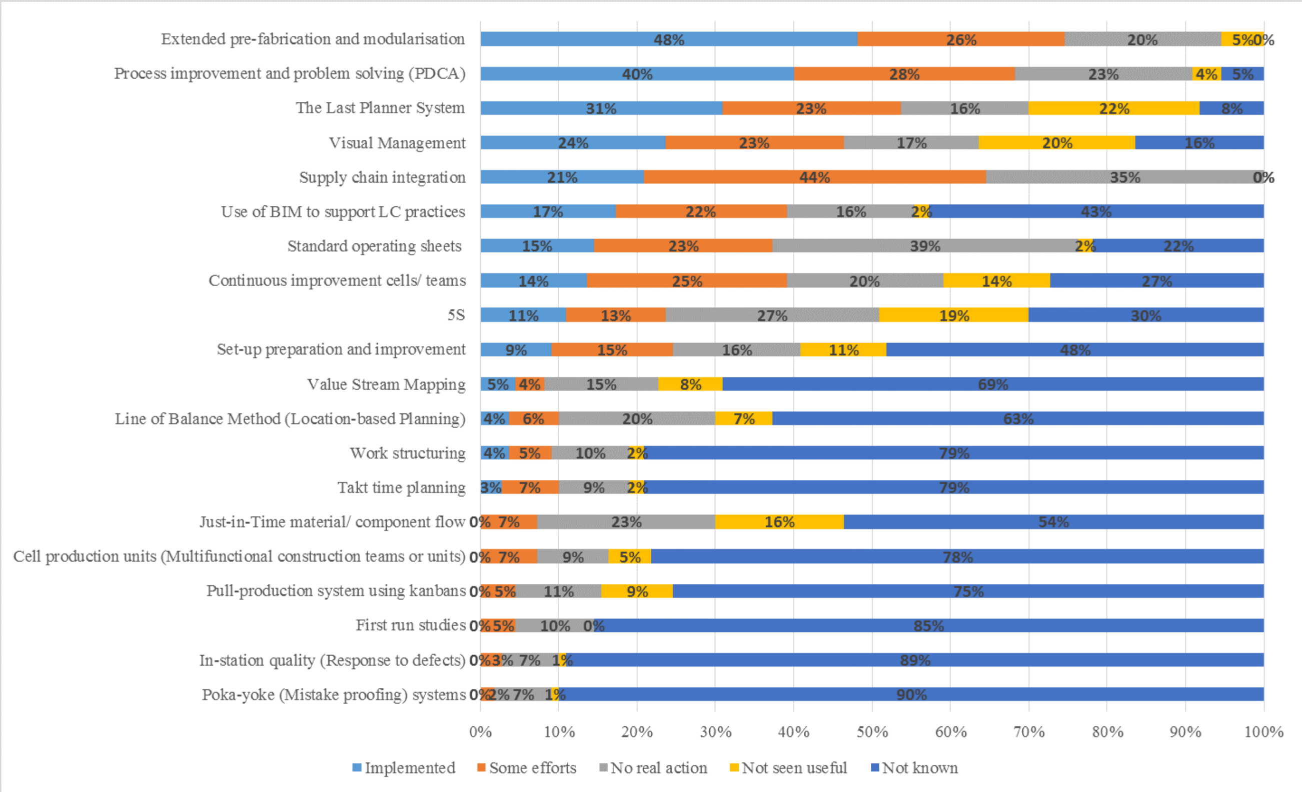

Figure 4. Percentages (%) of the conditions of the lean techniques. Each technique's percentages for the "applied", "some efforts", "no real action", "not seen useful" and "not known" conditions are shown.

4.2.3. Barriers before lean thinking

The respondents' evaluation on the Likert scale from 1 ("strongly disagree") to 5 ("strongly agree") for the fifteen barriers before the implementation of lean thinking was compiled by the respondents' supply chain roles (*i.e.* large contractors, large subcontractors, SMEs and consultants) (see Table 6). The barrier evaluation response percentages (%) by each supply chain role can be seen in Figure 5 as percentage contours.

Since the data were not drawn from a particular probability distribution, normal distribution was not assumed and the non-parametric Mann-Whitney test (H_0: There is no difference between the two groups of companies with respect to their evaluation of the barriers) was performed pairwise at 95% confidence for each barrier (see Table 6).

Consultants were excluded due to their small number of responses (5). When the significance (Sig.) values were found smaller than 0.05, H_0 was rejected at 95% confidence and the significance values were shown in italic and bold; meaning there is a statistically significant difference in the evaluation of a barrier between two groups of companies. Also, in Table 6, each barrier was ranked within a group and in total by their agreement scores calculated by using the following formula:

$$\left(\frac{\sum_{i=1}^{N} R_i}{NS}\right) \qquad (1)$$

where R_i is the rating given by the i^{th} respondent ranging from 1 to 5; i= 1, 2, 3.......N; N is the total number of respondents within a group (49, 13, 43 and 5) or in total (110); and S is the highest possible agreement rating, which is 5. The top five most agreed barriers in total were found as:

(1) lack of standardisation in the implementation,

(2) insufficient benefit measurement,

(3) insufficient know-how,

(4) insufficient control of the entire value stream and

(5) a short-sighted view to the techniques as means to "impress the client"

With respect to the different groups' views as to the barriers, there is no statistically significant difference between large contractors and large subcontractors. However, the barrier evaluations from both group of companies significantly differ from the evaluations from SMEs. In particular, barriers such as budget constraints (risk aversion), lack of longer term vision and insufficient management support seem to more important for SMEs than large contractors and large subcontractors. Some more operational barriers like backsliding (going back to the old ways of working after a while) or fragmented implementation of the tools seem to be of lesser importance for SMEs than large contractors and large subcontractors. On the other hand, no significant difference was found between the three groups of companies with respect to their views on;

- lack of standardisation,
- insufficient benefit measurement,
- insufficient know-how,
- employee resistance,
- problems in retaining experience and know-how,
- viewed as a means to impress the client,
- lack of continuous training,
- insufficient control of the value stream and
- insufficient planning and coordination in the implementation

Consultants were found to be in general agreement with the overall rankings emphasising barriers like insufficient know-how, lack of standardisation in implementation, insufficient benefit measurement, backsliding and insufficient planning and coordination (see Figure 5).

Table 6. Barriers before lean thinking in the highways sector.

	Large contractors								Large subcontractors								SMEs								Consultants						Total					
							Mann-Whitney test scores								Mann-Whitney test scores								Mann-Whitney test scores													
Barriers for lean thinking	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rank within group	Sig[a]. vs. Large subcontr.	Sig[a]. vs. SMEs	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rank within group	Sig[a].vs. Large contractors	Sig[a]. vs. SMEs	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rank within group	Sig[a]. vs. Large contractors	Sig[a]. vs. Large subcontr.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rank within group	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Overall rank
Lack of standardisation in implementation	25	20	2	2	0	1	0.85	0.38	7	5	1	0	0	1	0.85	0.44	19	17	7	0	0	3	0.38	0.44	3	2	0	0	0	2	54	44	10	2	0	1
Insufficient benefit measurement	25	15	5	4	0	2	0.76	0.89	7	4	2	0	0	2	0.76	0.84	20	19	4	0	0	2	0.89	0.84	2	3	0	0	0	3	54	41	11	4	0	2
Lack of metrics	20	19	7	3	0	6	0.90	***0.01***[b]	5	5	3	0	0	5	0.90	0.10	10	13	14	4	2	11	***0.01***[b]	0.10	1	2	2	0	0	8(9)	36	39	26	7	2	7
Insufficient know-how	13	32	4	0	0	4	0.52	0.07	4	6	3	0	0	6	0.52	0.11	22	18	3	0	0	1	0.07	0.11	4	1	0	0	0	1	43	57	10	0	0	3
Employee resistance	10	15	13	6	5	12	0.23	0.10	1	4	3	3	2	12	0.23	0.99	8	6	12	10	7	14	0.10	0.99	0	2	2	1	0	14	19	27	30	20	14	13
Backsliding	20	15	10	4	0	8	0.31	***0.00***[b]	3	5	4	1	0	8(9)	0.31	***0.04***[b]	5	10	14	14	0	13	***0.00***[b]	***0.04***[b]	2	2	1	0	0	4(5)	30	32	29	19	0	9
Budget constraints (risk aversion)	0	5	14	17	13	16	0.29	***0.00***[b]	0	2	5	4	2	15	0.29	***0.00***[b]	14	17	8	4	0	5	***0.00***[b]	***0.00***[b]	0	0	3	2	0	15	14	24	30	27	15	15
Lack of longer term vision	7	9	13	11	9	14	0.86	***0.00***[b]	0	4	4	3	2	13(14)	0.86	***0.00***[b]	12	15	13	3	0	8	***0.00***[b]	***0.00***[b]	0	2	3	0	0	12 (13)	19	30	33	17	11	12
Viewed as "flavour of the month"	16	17	12	4	0	11	0.06	***0.00***[b]	2	3	4	3	1	11	0.06	0.15	4	6	11	13	9	15	***0.00***[b]	0.15	1	2	1	1	0	10(11)	23	28	28	21	10	11
Problems in retaining experience and know-how	22	19	4	4	0	3	0.17	0.11	4	4	3	2	0	8(9)	0.17	0.92	16	12	5	7	3	10	0.11	0.92	1	3	1	0	0	6(7)	43	38	13	13	3	6
Viewed as a mean to 'impress client'	19	19	9	2	0	7	0.42	0.40	6	5	1	1	0	4	0.42	0.20	15	15	5	6	2	9	0.40	0.20	1	1	2	1	0	12(13)	45	37	16	10	2	5
Lack of continuous training	8	10	12	11	8	13	0.62	0.12	1	2	5	3	2	13(14)	0.62	0.52	3	7	10	14	9	16	0.12	0.52	0	1	1	2	1	16	12	20	28	30	20	16
Lean techniques not connected to each other (fragmentation)	18	19	5	7	0	9	0.73	***0.00***[b]	4	5	3	1	0	7	0.73	***0.03***[b]	6	8	20	6	3	12	***0.00***[b]	***0.03***[b]	0	4	1	0	0	8(9)	28	36	29	14	3	10
Insufficient management support	2	9	12	13	13	15	0.47	***0.00***[b]	1	1	2	5	4	16	0.47	***0.00***[b]	16	18	8	1	0	4	***0.00***[b]	***0.00***[b]	1	2	1	1	0	10(11)	20	30	23	20	17	14
Insufficient control of the entire value stream	20	19	8	2	0	5	0.45	0.40	7	4	1	1	0	3	0.45	0.25	17	13	5	6	2	7	0.4	0.25	2	1	2	0	0	6(7)	46	37	16	9	2	4
Insufficient planning and coordination	17	16	12	4	0	10	0.23	0.91	3	4	3	2	1	10	0.23	0.27	14	16	8	4	1	6	0.91	0.27	2	2	1	0	0	4(5)	36	38	24	10	2	8

a. Significant at 95% confidence interval = 0.05
b. H_0: No difference with respect to the views as to the barriers for lean thinking between the two groups of companies rejected.

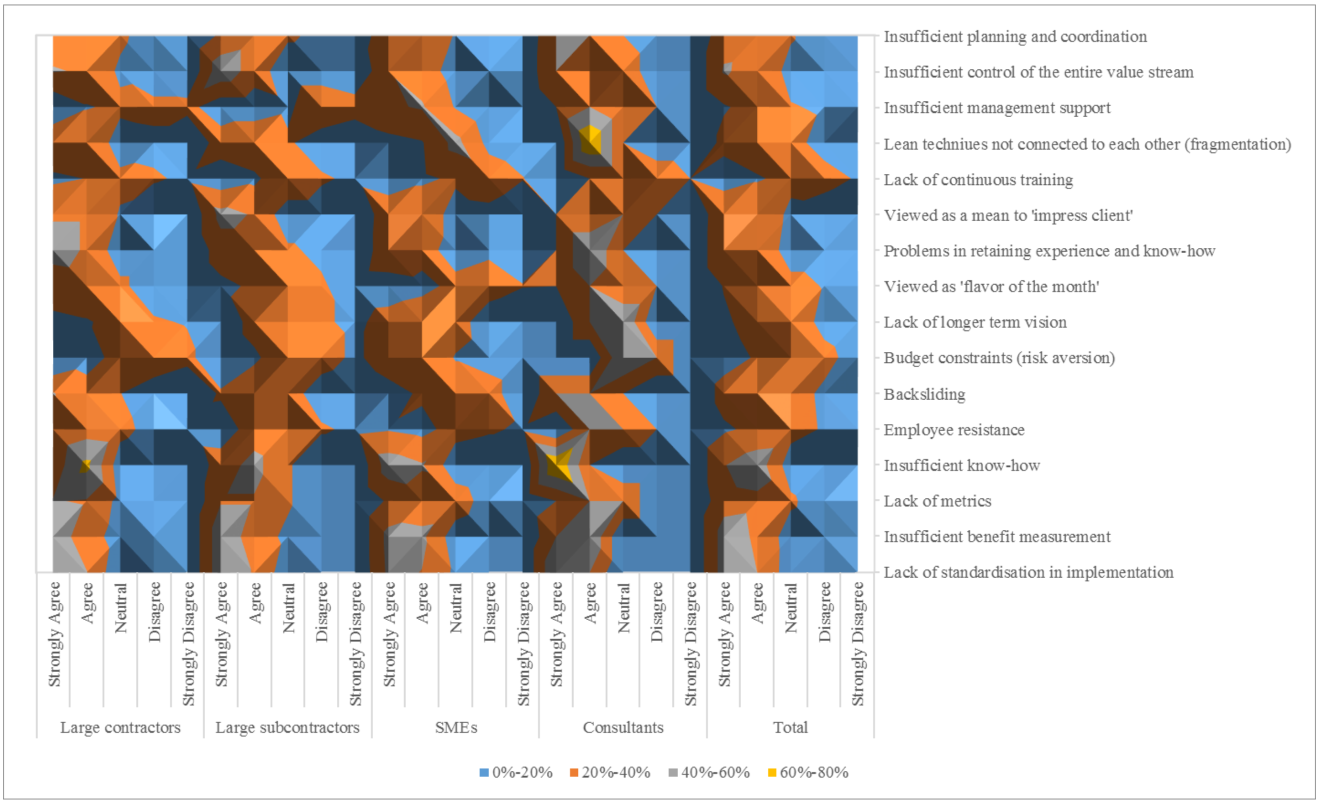

Figure 5. Response (%) contours of each supply chain group for the barriers. The colours at the intersection of a barrier (y-axis) and a supply chain role (x-axis) represent the number of respondents (%) for a particular agreement statement and a barrier.

5. Discussion

In addition to operational performance improvement expectations through lean thinking, external factors relating to project delivery (expectations toward more contract awarding after the adoption of lean thinking) and client pressure were found as strong motivation factors for the sector. Client or top-management pressures for lean thinking often pushed construction organisations to adopt a shallow implementation approach, typically conceived and mandated by the management and without proper stakeholder engagement (Arbulu and Zabelle 2012; Zanotti, Maranhão, and Aly 2017). Barros Neto and Alves (2007) noted from their analysis of Brazilian construction companies that construction companies often start implementing lean thinking with a few lean techniques, the most common of which is the Last Planner System. The current lean thinking adoption in the sector also seems to have started with and concentrated mostly around the process improvement cycle, the Last Planner System and Visual Management with many other techniques being marginally implemented or even completely unknown. This kind of fragmented lean adoptions were found common also in the manufacturing industry (Negrão, Godinho Filho, and Marodin 2017). For the existing implementations, insufficient standardisation, know-how, lack of metrics and the need to see the business case for lean thinking were identified as the pending barriers, further indicating a shallow implementation. Recent investigations of the Last Planner System (Daniel et al. 2017) and Visual Management (Tezel and Aziz 2017) in the highways sector revealed the effect of client pressure in their adoption by companies and that their implementations were commonly unstandardized and partial across companies, with some steps or opportunities in those techniques being completely omitted or ignored. In the manufacturing industry, shallow, partial or selective lean thinking implementations, particularly at the earlier stages of a lean transformation, are sometimes classified as "pseudo-lean" (McCarthy et al. 1997; Baldwin et al. 2005; Dalal 2010). Although the defining characteristics of the term "pseudo-lean" in the construction industry is not fully known yet, which presents a research opportunity in the field; the authors assert there is evidence for "pseudo-lean" practices in the highways sector; similar to the ones seen in the manufacturing industry. This assertion is further justified by the fact that the adoption of even some fundamental lean techniques like Value Stream Mapping (VSM) (Seth, Seth, and Dhariwal 2017) has remained scarce in the sector. Given the different degrees or characteristics of lean thinking adoption in the construction industry, the generic, three-legged lean implementation definitions (Green and May 2005; LCI 2017) need to be refined further and expanded with sub-categories or stages. In that respect, an in-depth evaluation of lean thinking in the sector over a few case studies will be useful.

The motivation factor related to the expectation as to winning more contracts can have interesting implications depending on if the expectation is fulfilled or not. If the expectation is not fulfilled, the shallow implementations leading to "pseudo-lean" practices may lose momentum, leaving mostly the intrinsically motivated companies deploying lean thinking for its positive implications on their operations. If the expectation is fulfilled, the "pseudo-lean" may broaden in parallel with the broadening lean thinking deployment in the sector.

Except for the motivation factors and some specific barriers, SMEs were found to significantly differ from large contractors and subcontractors in terms of their lean thinking implementations and barrier perceptions, which is in many ways similar to findings from other industries (Dora, Kumar, and Gellynck 2016; Hu et al. 2016; Manfredsson 2016; Zhou 2016) . There is no agreement in the literature whether there is a difference in the applicability of lean thinking between large organisations and SMEs (Shah and Ward 2003; Achanga et al. 2006; Rose, Deros, and Ab-Rahman. 2013). Further, some researchers believe lean thinking should be applied fully at SMEs, while others claim partial or selective implementations should be acceptable and will yield gradual performance improvements at SMEs (Golicic and Medland 2007; Anand and Kodali 2009).

From this study, SMEs' operational lean implementations and know-how were found very limited (see Table 5). SMEs are also more concerned with strategic issues like lack of top management support and budget constraints (risk aversion). Given those strategic barriers, SMEs need to see the business case for lean thinking more than other supply chain actors. To mitigate those concerns, large contractors should consider going farther beyond Stage 1 (Green and May 2005)., the operational lean thinking phase, toward Stage 3 (Green and May 2005), a strategic change in the overall project governance with SMEs for relational contracting and partnering strategies like IPD. IPD type relational contracting strategies were found useful in disseminating innovative approaches (i.e. BIM, lean thinking or sustainable construction) to smaller subcontractors (Matthews and Howell 2005; Kent and Becerik-Gerber 2010; Lahdenperä 2012). On the other hand, it is promising that most of the companies have some efforts toward supply chain integration (see Figure 4). Souza (2015) reports from in-depth analyses of a large main contractor and the main client from the highways sector in the UK that there is a long-term strategic vision in those organisations toward their suppliers, particularly toward their strategic suppliers; however, this vision is hampered by short-sighted commercial practices and contracting mechanisms. The main client (HE) should also consider engaging directly with SMEs for lean thinking instead of leaving the engagement solely to large contractors. Some pilot SME organisations can be nominated for extensive lean thinking deployments to create the business case for SMES in the supply chain. Also, HE or large contractors can lead the formation of innovation sharing groups among SMEs to help build lean thinking knowledge and expertise, which was noted as an effective practice to disseminate lean thinking in the construction industry (Bertelsen 2004; Barros Neto and Alves 2007; Heineck et al. 2009).

A concern that was highlighted repeatedly by the interviewees was the disconnection between the design and construction (production) phase and construction companies' limited ability to affect the product design process in the sector. Also, this disconnection has negative implications on the on-site production system design practices through lean thinking. The survey also confirmed that concern with high agreement scores given to the "insufficient control of the entire value stream" barrier.

The need for integrating design and construction for an extensive deployment of lean thinking in the construction industry has been frequently underlined (Bertelsen 2004; Freire and Alarcon 2002; Jorgensen and Emmitt 2009). In order to deepen the current adoption of lean thinking, this link between the design and construction for lean should be established.

Some further suggestions for lean thinking in the sector based on the findings are:

- Control metrics and performance indicators for the lean techniques should be devised. The need for developing relevant control metrics and performance measurement strategies for lean thinking implementations in construction was identified as essential (Cheng 2016),
- The current training curricula should be revised to cover issues associated with strategic deployment of lean thinking and the lesser known techniques as well,
- The training should highlight how different lean techniques are linked with each other at the operational phase to overcome the fragmentation in the application (the techniques being applied in silos),
- Pilot projects on the lesser known techniques, which can potentially be executed in cooperation with academia, will be useful,
- Standard checklists and guidelines for the lean techniques should be prepared and disseminated to the supply chain. This will also help support retaining lean know-how. However, as underlined by Tatum (1987), construction project teams can be viewed as “skunk work” organisations that have autonomy to innovate. Therefore, this innovation capacity should not also be crippled with excessive standardisation,

- Efforts for capturing both soft and hard benefits of the adoption of lean thinking should be given precedence.

6. Conclusion

Low-profit margins and high performance targets prompt construction organisations to consider lean thinking as a way-forward. The explorative research presented in the paper aimed at evaluating the condition of lean thinking in the highways construction sector, which has embarked on adopting lean thinking at the supply chain level, under the leadership of some large contractors and the main public client. The findings show the existence of strong external motivational factors for lean thinking alongside the expected operational benefits. Limited adoptions of the lean techniques, mostly around the process improvement cycle, the Last Planner System and Visual Management, were identified. It was also found that there are efforts in supporting lean thinking with other related technologies and concepts like BIM and off-site/ modular construction. Given the strong influence of the external motivation factors and the findings suggesting a generally shallow, partial or selective lean adoption condition, concerns about the existence of "pseudo-lean" in the sector are raising. Lack of standardisation, insufficient benefit capturing, insufficient know-how, insufficient control of the entire value stream and limited view to the techniques (viewed as a mean to "impress the client") were identified as the top five most strongly agreed barriers by the supply chain. Also, SMEs were found to be significantly different than large contractors and large subcontractors with respect to their implementation of the lean tools and their perception of the barriers. However, SMEs are generally in agreement with the rest of the supply chain in terms of the motivation factors for lean thinking.

As a limitation, the study does not investigate practices associated with the current product design management in the sector. An evaluation of the applicability of lean thinking in the product design phase and how design and construction can be linked in the highways sector by using lean thinking requires further research. Also, there is a need for a better understanding of what defines “pseudo-lean” or different lean maturity levels in the construction industry. The lack of understanding on how lean thinking can be deployed in construction SMEs offers another research opportunity. Currently, with many civil construction companies trying to adopt lean thinking in the UK, there is a ground for deeper research over case studies on the issue to further investigate and to develop on the findings.

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References

Abdulmalek, F. A., and J. Rajgopal. 2007. “Analyzing the Benefits of Lean Manufacturing and Value Stream Mapping via Simulation: A Process Sector Case Study.” *International Journal of Production Economics* 107 (1): 223-236.

Achanga, P., E. Shehab, R. Roy, and G. Nelder. 2006. “Critical Success Factors for Lean Implementation within SMEs.” *Journal of Manufacturing Technology Management* 17 (4): 460-471.

Åhlström, P. 1998. “Sequences in the Implementation of Lean Production”. *European Management Journal* 16 (3): 327-334.

Alarcon, L. F., and L. Seguel. 2002. “Developing Incentive Strategies for Implementation of Lean Construction.” *In Proceedings of the 10th Annual Conference of International Group for Lean Construction.* Gramado: IGLC.

Almeida, J. C., and G. F. Salazar. 2003. “Strategic Issues in Lean Construction.” *In Proceedings of the 11th Annual Conference of the International Group for Lean Construction.* Blacksburg: IGLC.

Alves, T. C. D. L., and C. C. Tsao. 2007. “Lean Construction–2000 To 2006.” *Lean Construction Journal* 3 (1): 46-70.

Anand, G., and R. Kodali. 2009. "Development of a Framework for Lean Manufacturing Systems." *International Journal of Services and Operations Management* 5 (5): 687-716.

Ansell, M., M. Holmes, R. Evans, C. Pasquire, and A. Price. 2007. "Lean Construction Trial on a Highways Maintenance Project." *In Proceedings of the 15th Annual Conference of the International Group for Lean Construction*. East Lansing: IGLC.

Arbulu, R., G. Ballard, and N. Harper. 2003. "Kanban in Construction." *In Proceedings of the 11th Annual Conference of the International Group for Lean Construction.* Blacksburg: IGLC.

Arbulu, R., and I.D. Tommelein. 2002. "Value Stream Analysis of Construction Supply Chains: Case Study on Pipe Supports Used in Power Plants." *In Proceedings of the 10th Annual Conference of International Group for Lean Construction.* Gramado: IGLC.

Arbulu, R., and T. Zabelle. 2006. "Implementing Lean in Construction: How to Succeed." *In Proceedings of the 14th Annual Conference of the International Group for Lean Construction.* Santiago: IGLC.

Baldwin, J.S., P.M. Allen, B. Winder, and K. Ridgway. 2005. "Modelling Manufacturing Evolution: Thoughts on Sustainable Industrial Development." *Journal of Cleaner Production* 13 (9): 887-902.

Ballard, G. 1997. "Lookahead Planning: The Missing Link in Production Control." *In Proceedings of the 5th Annual Conference of the International Group for Lean Construction.* Gold Coast: IGLC.

Ballard, G. 1999. "Improving Work Flow Reliability." *In Proceedings of the 7th Annual Conference of the International Group for Lean Construction.* Berkeley: IGLC.

Ballard, G., and G. Howell. 1998. "Shielding Production: Essential Step in Production Control." *Journal of Construction Engineering and Management 124* (1): 11-17.

Bamber, L., and B. G. Dale. 2000. "Lean Production: A Study of Application in a Traditional Manufacturing Environment." *Production Planning and Control* 11 (3): 291-298.

Barlett, J.E., J.W. Kotrlik, and C.C. Higgins. 200. "Organizational Research: Determining Appropriate Sample Size in Survey Research." *Information Technology, Learning, and Performance Journal* 19 (1): 43-50.

Baruch, Y. 1999. “Response Rate in Academic Studies: A Comparative Analysis.” *Human Relations* 52 (4): 421-438.

Barros Neto, J.D.P., and T.D.C.L. Alves. 2007. “Strategic Issues in Lean Construction Implementation.” *In Proceedings of the 15th Annual Conference of the International Group for Lean Construction*. East Lansing: IGLC.

Bayo-Moriones, A., A. Bello-Pintado, and J. Merino-Díaz de Cerio. 2010. “5S Use in Manufacturing Plants: Contextual Factors and Impact on Operating Performance.” *International Journal of Quality and Reliability Management* 27 (2): 217-230.

Becerik-Gerber, B., F. Jazizadeh, N. Li, and G. Calis. 2011. “Application Areas and Data Requirements for BIM-Enabled Facilities Management.” *Journal of Construction Engineering and Management 138* (3): 431-442.

Behera, P., R. P. Mohanty, and A. Prakash. 2015. “Understanding Construction Supply Chain Management.” *Production Planning and Control 26* (16): 1332-1350.

Ben Fredj-Ben Alaya, L. 2016. “VSM a Powerful Diagnostic and Planning Tool for a Successful Lean Implementation: A Tunisian Case Study of an Auto Parts Manufacturing Firm.” *Production Planning & Control* 27 (7-8): 563-578.

Berg, B.L. 2004. *Qualitative Research Methods for the Social Sciences*. London: Pearson Education.

Berroir, F., L. Harbouche, and C. Boton. 2015. “Top Down vs. Bottom Up Approaches Regarding the Implementation of Lean Construction through A French Case Study.” *In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction.* Perth: IGLC.

Bertelsen, S. 2004. “Lean Construction: Where are We and How to Proceed.” *Lean Construction Journal* 1 (1): 46-69.

Briscoe, G., and A. Dainty. 2005. “Construction Supply Chain Integration: An Elusive Goal?” *Supply Chain Management: An International Journal* 10 (4): 319-326.

Bruun, P., and R. N. Mefford. 2004. “Lean Production and the Internet.” *International Journal of Production Economics* 89 (3): 247-260.

Chen, C., S. Housley, P. Sprague, and P. Goodlad. 2012. “Introducing Lean into the UK Highways Agency's Supply Chain.” *Proceedings of the Institution of Civil Engineers* 165 (5): 34-39.

Cheng, R. 2016. *Motivation and Means: How and Why IPD and Lean Lead to Success*. Minneapolis: Lean Construction Institute.

Chiarini, A. 2017. "An Adaptation of the EOQ Formula for JIT Quasi-Pull System Production." *Production Planning & Control* 28 (2): 123-130.

Colicchia, C., A. Creazza, and F. Dallari .2017. "Lean and Green Supply Chain Management through Intermodal Transport: Insights from the Fast Moving Consumer Goods Industry." *Production Planning & Control* 28 (4): 321-334.

Costa, L.B.M., and M. Godinho Filho. 2016. "Lean Healthcare: Review, Classification and Analysis of Literature." *Production Planning & Control* 27 (10): 823-836

Dainty, A. R., S. J. Millett, and G. H. Briscoe. 2001. "New Perspectives on Construction Supply Chain Integration." *Supply Chain Management: An International Journal 6* (4): 163-173.

Dalal, A.F. 2010. "Keep It Simple." *Quality Progress* 43 (9): 24-28.

Daniel, E.I., C. Pasquire, G. Dickens, and G. Ballard. 2017. "The Relationship between the Last Planner System and Collaborative Planning Practice in UK Construction." *Engineering, Construction and Architectural Management* 24 (3): 407-425.

Deif, A. M. 2012. "Dynamic Analysis of a Lean Cell Under Uncertainty." *International Journal of Production Research* 50 (4): 1127-1139.

Diekman, J., M. Krewedl, T. Stewart, and S. Won. 2004. *Application of Lean Manufacturing Principles to Construction: Technical Report 191-11 for Construction Industry Institute.* Austin*:* The University of Texas at Austin.

Dora, M., M. Kumar, and X. Gellynck. 2016. "Determinants and Barriers to Lean Implementation in Food-Processing SMEs–A Multiple Case Analysis." *Production Planning & Control* 27 (1): 1-23.

Dos Santos, A., and J. Powell. 1999. Potential of Poka-Yoke Devices to Reduce Variability in Construction. *In Proceedings of the 7th Annual Conference of the International Group for Lean Construction.* Berkeley: IGLC.

Drucker, P. 1971. "What We Can Learn from Japanese Management." *Harvard Business Review* March–April: 110–122.

Drysdale, D. 2013. "Introducing Lean Improvement into The UK Highways Agency Supply Chain." *In Proceedings of the 21st Annual Conference of the International Group for Lean Construction.* Fortaleza: IGLC.

Dubois, A., and L. E. Gadde. 2002. "The Construction Industry as A Loosely Coupled System: Implications for Productivity and Innovation." *Construction Management and Economics* 20 (7): 621-631.

Egan, J. Sir. 1998. *Rethinking Construction*: *Report of the Construction Task Force to the Deputy Prime Minister, Department of the Environment, Transport and the Regions*. Norwich: Construction Task Force.

Eriksson, E. P. 2010. “Improving Construction Supply Chain Collaboration and Performance: A Lean Construction Pilot Project.” *Supply Chain Management: An International Journal* 15 (5): 394-403.

EC (European Commission). 2015. “User Guide to The SME Definition.” *EC*. Accessed August 15, 2017. https://ec.europa.eu/docsroom/documents/15582/attachments/1/translations/en/renditions/pdf

Fearne, A., and N. Fowler. 2006. “Efficiency versus Effectiveness in Construction Supply Chains: The Dangers of ‘Lean’ Thinking in Isolation.” *Supply Chain Management: An International Journal* 11 (4): 283-287.

Filho, A. N. D. M., F. M. M. Filho, A. N. D. Miranda, and M. I. A. D. Miranda. 2005. “Improving The Root Pile Execution Process through Setup Time Reduction.” *In Proceedings of the 21st Association of Researchers in Construction Management Conference*. London: ARCOM.

Flynn, B. B., B. Huo, and X. Zhao. 2010. “The Impact of Supply Chain Integration on Performance: A Contingency and Configuration Approach.” *Journal of Operations Management* 28 (1): 58-71.

Formoso, C. T., A. D. Santos, and J. Powell. 2002. “An Exploratory Study on the Applicability of Process Transparency in Construction Sites.” *Journal of Construction Research* 3 (1): 35-54.

Frandson, A., K. Berghede, and I. D. Tommelein. 2013. “Takt Time Planning for Construction of Exterior Cladding.” *In Proceedings of the 21st Annual Conference of the International Group for Lean Construction.* Fortaleza: IGLC.

Frandson, A., O. Seppänen, and I.D. Tommelein. 2015. “Comparison between Location based Management and Takt Time Planning.” *In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction.* Perth: IGLC.

Freire, J., and L. F. Alarcón. 2002. “Achieving Lean Design Process: Improvement Methodology.” *Journal of Construction Engineering and Management* 128 (3): 248-256.

Fujimoto, T. 1999. *The Evolution of a Manufacturing System At Toyota*. Oxford: Oxford University Press.

Fullalove, L.H. 2013. "Examples of Lean Techniques and Methodology Applied to UK Road Schemes." *In Proceedings of the 21st Annual Conference of the International Group for Lean Construction.* Fortaleza: IGLC.

Gledson, B., and D. Greenwood. 2016. "Surveying the Extent and Use of 4D BIM in the UK." *Journal of Information Technology in Construction* 21: 57-71.

Golhar, D. Y., and C. L. Stamm. 1991. "The Just-In-Time Philosophy: A Literature Review." *The International Journal of Production Research* 29 (4): 657-676.

Golicic, S. L., and S. S. Medland. 2007. "Size Might Matter: A Case Study of Lean Implementation in an SME." *In Proceedings of the Society for Marketing Advances.* Kuala Lumpur: Society for Marketing Advances.

Gosling, J., and M. M. Naim. 2009. "Engineer-To-Order Supply Chain Management: A Literature Review and Research Agenda." *International Journal of Production Economics* 122 (2): 741-754.

Gosling, J., M. Pero, M. Schoenwitz, D. Towill, and R. Cigolini. 2016. "Defining and Categorizing Modules In Building Projects: An International Perspective." *Journal of Construction Engineering and Management*, 142 (11): 04016062.

Green, S. 1999. "The Missing Arguments of Lean Construction." *Construction Management and Economics*, 17 (2): 133-137.

Green, S. 2002. "The Human Resource Management Implications of Lean Construction: Critical Perspectives and Conceptual Chasms." *Journal of Construction Research* 3 (1): 147-165.

Green, S., and S. May. 2005. "Lean Construction: Arenas of Enactment, Models of Diffusion, and The Meaning of 'Leanness'." *Building Research and Information* 33 (6): 498-511.

Hamzeh, F. R., G. Ballard, and I. D. Tommelein. 2009. "Is The Last Planner System Applicable to Design?—A Case Study." *In Proceedings of the 17th Annual Conference of the International Group for Lean Construction.* Taipei: IGLC.

Harvey, M. 2003. "Privatization, Fragmentation and Inflexible Flexibilization in the UK Construction Industry." In *Building Chaos: An International Comparison of Deregulation in the Construction Industry,* edited by Bosch, G., and P. Philips, 188-209. London: Routledge.

Heineck, L. F., P. E. Pereira, S. L. Kemmer, T. D. C. Alves, and J. D. P. Barros Neto. 2009. "Incentives and Innovation to Sustain Lean Construction Implementation." *In Proceedings of the 17th Annual Conference of the International Group for Lean Construction.* Taipei: IGLC.

Herron, C., and P. M. Braiden. 2006. "A Methodology for Developing Sustainable Quantifiable Productivity Improvement in Manufacturing Companies." *International Journal of Production Economics* 104 (1): 143-153.

HE (Highways England). 2016. "Lean Support to Highways England." *HE.* Accessed August 15, 2017. http://www.highwaysindustry.com/wp-content/uploads/2016/04/Lean_Strategy_Document_2015-2020__2_.pdf

Hodge, G. L., K. Goforth Ross, J. A. Joines, and K. Thoney. 2011. "Adapting Lean Manufacturing Principles to the Textile Industry." *Production Planning and Control* 22 (3): 237-247.

Howell, G., and G. Ballard. 1998. "Implementing Lean Construction: Understanding and Action." *In Proceedings of the 6th Annual Conference of the International Group for Lean Construction.* Guaruja: IGLC.

Hu, Q., S. J. Williams, R. Mason, and P. Found. 2016. "The Change of Production Systems through Consultancy Involved Projects: A Multiple Case Study in Chinese SMEs." *Production Planning & Control* 27 (7-8): 550-562.

Johansen, E., and L. Walter. 2007. "Lean Construction: Prospects for the German Construction Industry." *Lean Construction Journal* 3 (1): 19-32.

Jorgensen, B., and S. Emmitt. 2008. "Lost in Transition: The Transfer of Lean Manufacturing to Construction." *Engineering, Construction and Architectural Management* 15 (4): 383-398.

Jorgensen, B., and S. Emmitt. 2009. "Investigating the Integration of Design and Construction from A "Lean" Perspective." *Construction Innovation* 9 (2): 225-240.

Jorgensen, B., S. Emmitt, and S. Bonke. 2004. "Revealing Cultures and Sub-Cultures During the Implementation of Lean Construction." *In Proceedings of the 12th Annual Conference of the International Group for Lean Construction*. Helsingør: IGLC.

Kemmer, S. L., M. A. Saraiva, L. F. Heineck, A. V. L. Pacheco, M. D. V. Novaes, C. A. M. A. Mourão, and L. C. R. Moreira. 2006. "The Use of Andon in High Rise

Building." *In Proceedings of the 14th Annual Conference of the International Group for Lean Construction*. Santiago: IGLC.

Kim, Y. W., and G. Ballard. 2010. "Management Thinking in The Earned Value Method System and The Last Planner System." *Journal of Management in Engineering* 26 (4): 223-228.

Kent, D.C., and B. Becerik-Gerber. 2010. "Understanding Construction Industry Experience and Attitudes Toward Integrated Project Delivery." *Journal of Construction Engineering and Management* 136 (8): 815-825.

Kitazawa, S., and J. Sarkis. 2000. "The Relationship between ISO 14001 and Continuous Source Reduction Programs." *International Journal of Operations and Production Management* 20 (2): 225-248.

Ko, C. H., and J. D. Kuo. 2015. "Making Formwork Construction Lean." *Journal of Civil Engineering and Management* 21 (4): 444-458.

Koskela, L. 1992. *Application of the New Production Philosophy to Construction*: *Technical Report Vol. 72*. Stanford: Stanford University.

Koskela, L. 1996. "Towards the Theory of (Lean) Construction." *In Proceedings of the 4th Annual Conference of the International Group for Lean Construction.* Birmingham: IGLC.

Lahdenperä, P. 2012. "Making Sense of the Multi-Party Contractual Arrangements of Project Partnering, Project Alliancing and Integrated Project Delivery." *Construction Management and Economics* 30 (1): 57-79.

Latham, M. Sir. 1994. *Constructing the Team*: *Final Report of the Government/Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry*. London: HMSO.

LCI (Lean Construction Institute). 2017. "Lean Articles". *LCI*. Accessed August 15, 2017. https://www.leanconstruction.org/learning/lean-articles/

LEI (Lean Enterprise Institute). 2007. "New Survey: Middle Managers Are Biggest Obstacle to Lean Enterprise." *LEI*. Accessed August 15, 2017. https://www.lean.org/WhoWeAre/NewsArticleDocuments/lean_survey_07.pdf

Leong, M. S., and P. Tilley. 2008. "A Lean Strategy to Performance Measurement - Reducing Waste by Measuring 'Next' Customer Needs." *In Proceedings of the 16th Annual Conference of the International Group for Lean Construction*. Manchester: IGLC.

Lyons, A. C., K. Vidamour, R. Jain, and M. Sutherland. 2013. "Developing an Understanding of Lean Thinking in Process Industries." *Production Planning and Control* 24 (6): 475-494.

Manfredsson, P. 2016. "Textile Management Enabled by Lean Thinking: A Case Study of Textile SMEs." *Production Planning & Control* 27 (7-8): 541-549.

Mariz, R. N., F. A. Picchi, A. D. Granja, and R. S. S. Melo. 2013. "Production Cells in Construction: Considering Time, Space and Information Linkages to Seek Broader Implementations." *Journal of Engineering, Project, and Production Management*, 3 (1): 46-55.

Martínez-Jurado, P. J., and J. Moyano-Fuentes. 2014. "Key Determinants of Lean Production Adoption: Evidence from the Aerospace Sector." *Production Planning and Control* 25 (4): 332-345.

Matthews, O., and G. Howell. 2005. "Integrated Project Delivery: An Example of Relational Contracting." *Lean Construction Journal* 2 (1): 46-61.

McCarthy, I., M. Leseure, K. Ridgway, and N. Fieller. 1997. "Building A Manufacturing Cladogram." *International Journal of Technology Management* 13 (3): 269-286.

McGraw-Hill Construction. 2013. *Lean Construction: Leveraging Collaboration and Advanced Practices to Increase Project Efficiency*. Bedford: McGraw-Hill.

Mendes J. R., and L. F. M. Heineck. 1998. "Preplanning Method for Multi-Story Building Construction Using Line-Of-Balance." *In Proceedings of the 6th Annual Conference of the International Group for Lean Construction.* Guaruja: IGLC.

Mileham, A. R., S. J. Culley, G. W. Owen, and R. I. McIntosh. 1999. "Rapid Changeover–A Pre-Requisite for Responsive Manufacture." *International Journal of Operations and Production Management* 19 (8): 785-796.

Miles, M.B., and A. M. Huberman. 1994. *Qualitative Data Analysis*. Thousand Oaks: Sage.

Millstein, M. A., and J. S. Martinich. 2014. "Takt Time Grouping: Implementing Kanban-Flow Manufacturing in an Unbalanced, High Variation Cycle-Time Process with Moving Constraints." *International Journal of Production Research* 52 (23): 6863-6877.

Miron, L., S. Talebi, L. Koskela, and A. Tezel. 2016. “Evaluation of Continuous Improvement Programmes.” *In Proceedings of the 24th Annual Conference of the International Group for Lean Construction.* Boston: IGLC.

Monden, Y. 1983. *The Toyota Production System*. Portland: Productivity Press.

Moser, L., and A. Dos Santos. 2003. “Exploring the Role of Visual Controls on Mobile Cell Manufacturing: A Case Study On Drywall Technology.” *In Proceedings of the 11th Annual Conference of the International Group for Lean Construction.* Blacksburg: IGLC.

Mossman, A. 2009. “Why Isn't the UK Construction Industry Going Lean with Gusto?” *Lean Construction Journal* 5 (1): 24-36.

Mukhopadhyay, S. K., and S. Shanker. 2005. “Kanban Implementation at A Tyre Manufacturing Plant: A Case Study.” *Production Planning and Control* 16 (5): 488-499.

Murata, K., and H. Katayama. 2010. “Development of Kaizen Case-Base for Effective Technology Transfer: A Case of Visual Management Technology.” *International Journal of Production Research* 48 (16): 4901-4917.

Nahmens, I., and L. H. Ikuma. 2009. “An Empirical Examination of the Relationship between Lean Construction and Safety in The Industrialized Housing Industry." *Lean Construction Journal* 1: 1-12.

Nahmens, I., and L. H. Ikuma. 2011. “Effects of Lean Construction on Sustainability of Modular Homebuilding.” Journal of Architectural Engineering 18 (2): 155-163.

Negrão, L. L. L., M. Godinho Filho, and G. Marodin. 2017. “Lean Practices and their Effect on Performance: A Literature Review.” *Production Planning & Control* 28 (1): 33-56.

Nesensohn, C., Bryde, D., Ochieng, E. and Fearon, D., 2015. Maturity and maturity models in lean construction. Australasian Journal of Construction Economics and Building, 14 (1) 45-59.

Ngai, E. W. T., T. C. E. Cheng, and S. S. M. Ho. 2004. “Critical Success Factors of Web-Based Supply-Chain Management Systems: An Exploratory Study.” *Production Planning and Control* 15 (6): 622-630.

Oehmen, J., B.W. Oppenheim, D. Secor, E. Norman, E. Rebentisch, J.A. Sopko, M. Steuber, R. Dove, K. Moghaddam, S. McNeal, and M. Bowie. 2012. “The guide to lean enablers for managing engineering programs.” Joint MIT-PMI-INCOSE Community of Practice on Lean in Program Management.

Ogunbiyi, O., J. S. Goulding, and A. Oladapo. 2014. “An Empirical Study of the Impact of Lean Construction Techniques on Sustainable Construction in The UK.” *Construction Innovation* 14 (1): 88-107.

Ohno, T. 1988. *The Toyota Production System: Beyond Large-Scale Production*. Portland: Productivity Press.

Oppenheim, B.W. 2011. *Lean for Systems Engineering with Lean Enablers for Systems Engineering*. New Jersey: John Wiley & Sons.

Paez, O., S. Salem, J. Solomon, and A. Genaidy. 2005. “Moving from Lean Manufacturing to Lean Construction: Toward a Common Socio-technological Framework.” *Human Factors and Ergonomics in Manufacturing and Service Industries* 15 (2): 233-245.

Panizzolo, R., P. Garengo, M. K. Sharma, and A. Gore. 2012. Lean Manufacturing in Developing Countries: Evidence from Indian SMEs.” *Production Planning and Control* 23(10-11): 769-788.

Parry, G. C., and C. E. Turner. 2006. “Application of Lean Visual Process Management Tools.” *Production Planning and Control* 17 (1): 77-86.

Pasquire, C., S. Sarhan, and A. King. 2015a. “A Critical Review of the Safeguarding Problem in Construction Procurement: Unpicking the Coherent Current Model.” *In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction.* Perth: IGLC.

Pasquire, C., S. Sarhan, and A. King. 2015b. “Exploring the Implementation of the Last Planner System through IGLC Community: Twenty One Years of Experience.” *In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction.* Perth: IGLC.

Pettersen, J. 2009. “Defining Lean Production: Some Conceptual and Practical Issues.” *The TQM Journal* 21 (2): 127-142.

Pheng, L. S., and C. J. Chuan. 2001. “Just-In-Time Management of Precast Concrete Components.” *Journal of Construction Engineering and Management* 127 (6): 494-501.

Rapley, T. J. 2001. “The Art (Fullness) of Open-Ended Interviewing: Some Considerations on Analysing Interviews.” *Qualitative research* 1 (3): 303-323.

Rose, A.N.M., B.M. Deros, and M.N. Ab-Rahman. 2013. “Lean Manufacturing Perceptions and Actual Practice Among Malaysian SMEs in Automotive

Industry." *International Journal of Automotive and Mechanical Engineering* 7: 820-829.

Rosenbaum, S., M. Toledo, and V. González. 2013. "Improving Environmental and Production Performance in Construction Projects Using Value-Stream Mapping: Case Study." *Journal of Construction Engineering and Management* 140 (2): 04013045.

Sacks, R., L. Koskela, B. A. Dave, and R. Owen. 2010. "Interaction of Lean and Building Information Modeling in Construction." *Journal of Construction Engineering and Management* 136 (9): 968-980.

Salem, O., J. Solomon, A. Genaidy, and I. Minkarah. 2006. "Lean Construction: From Theory to Implementation." *Journal of Management in Engineering* 22 (4): 168-175.

Sarhan, S., and A. Fox. 2013. "Barriers to Implementing Lean Construction in the UK Construction Industry." *The Built and Human Environment Review* 6 (1): 1-17.

Saurin, T. A., G. A. Marodin, and J. L. D. Ribeiro. 2011. "A Framework for Assessing the Use of Lean Production Practices in Manufacturing Cells." *International Journal of Production Research* 49 (11): 3211-3230.

Saurin, T. A., J. L. D. Ribeiro, and G. Vidor. 2012. "A Framework for Assessing Poka-Yoke Devices." *Journal of Manufacturing Systems* 31 (3): 358-366.

Schuring, R. W. 1996. "Operational Autonomy Explains the Value of Group Work in Both Lean and Reflective Production." *International Journal of Operations and Production Management* 16 (2): 171-182.

Segerstedt, A., and T. Olofsson. 2010. "Supply Chains in the Construction Industry." *Supply Chain Management: An International Journal* 15 (5): 347-353.

Seppänen, O., G. Ballard, and S. Pesonen. 2010. "The Combination of Last Planner System and Location-Based Management System." *Lean Construction Journal* 6 (1): 43-54.

Serrano Lasa, I., R. D. Castro, and C. O. Laburu. 2009. "Extent of the Use of Lean Concepts Proposed for a Value Stream Mapping Application." *Production Planning and Control* 20 (1): 82-98.

Seth, D., and V. Gupta. 2005. "Application of Value Stream Mapping for Lean Operations and Cycle Time Reduction: An Indian Case Study." *Production Planning and Control* 16 (1): 44-59.

Seth, D., N. Seth, and P. Dhariwal. 2017. “Application of Value Stream Mapping (VSM) for Lean and Cycle Time Reduction in Complex Production Environments: A Case Study.” *Production Planning & Control* 28 (5): 398-419.

Shah, R., and P. T. Ward. 2003. “Lean Manufacturing: Context, Practice Bundles, and Performance.” *Journal of Operations Management* 21 (2): 129-149.

Shao, J., and R. Müller. 2001. “The Development of Constructs of Program Context and Program Success: A Qualitative Study.” *International Journal of Project Management* 29 (8): 947-959.

Shaw, D., and J. S. Edwards. 2006. “Manufacturing Knowledge Management Strategy.” *International Journal of Production Research* 44 (10): 1907-1925.

Shingo, S. 1986. *Zero Quality Control: Source Inspection and The Poka-Yoke System*. Portland: CRC Press.

Shingo, S., and A. P. Dillon. 1989. *A Study of the Toyota Production System: From An Industrial Engineering Viewpoint*. Portland: CRC Press.

Shirazi, B., D. A. Langford, and S. M. Rowlinson. 1996. “Organizational Structures in the Construction Industry.” *Construction Management and Economics* 14 (3): 199-212.

Shishank, S., and R. Dekkers. 2013. “Outsourcing: Decision-Making Methods and Criteria During Design and Engineering.” *Production Planning and Control* 24 (4-5): 318-336.

Slomp, J., J. A. Bokhorst, and R. Germs. 2009. “A Lean Production Control System for High-Variety/Low-Volume Environments: A Case Study Implementation.” *Production Planning and Control* 20 (7): 586-595.

Soini, M., I. Leskelä, and O. Seppänen. 2004. “Implementation of Line-Of-Balance Based Scheduling and Project Control System in a Large Construction Company.” *In Proceedings of the 12th Annual Conference of the International Group for Lean Construction.* Helsingør: IGLC.

Sokovic, M., D. Pavletic, and K. K. Pipan. 2010. “Quality Improvement Methodologies: PDCA Cycle, RADAR Matrix, DMAIC and DFSS.” *Journal of Achievements in Materials and Manufacturing Engineering* 43 (1): 476-483.

Souza, D. V. S. D. 2015. “A Conceptual Framework and Best Practices for Designing and Improving Construction Supply Chains.” PhD diss., University of Salford.

Stanworth, J. O. 2012. “Deep Supply Relationships: Influencing Outcomes by Managing Supply Service Quality.” *Production Planning and Control*, 23 (7): 541-552.

Stehn, L., and M. Höök. 2008. “Lean Principles in Industrialized Housing Production: The Need for a Cultural Change.” *Lean Construction Journal* 20-33.

Storch, R. L., and S. Lim. 1999. “Improving Flow to Achieve Lean Manufacturing in Shipbuilding.” *Production Planning and Control* 10 (2): 127-137.

Sugimori, Y., K. Kusunoki, F. Cho, and S. Uchikawa. 1977. “Toyota Production System and Kanban System Materialization of Just-In-Time and Respect-For-Human System.” *The International Journal of Production Research* 15 (6): 553-564.

Tatum, C.B. 1987. “Process of Innovation in Construction Firm.” *Journal of Construction Engineering and Management* 113 (4): 648-663.

Tezel, A., and Z. Aziz. 2017. “Visual Management in Highways Construction and Maintenance in England.” *Engineering, Construction and Architectural Management* 24 (3): 486-513.

Tezel, A., L. Koskela, and Z. Aziz. 2017. “Lean Construction in Small-Medium Sized Enterprises (SMEs): An Exploration of the Highways Supply Chain.” *In Proceedings of the 25th Annual Conference of the International Group for Lean Construction.* Heraklion: IGLC.

Tezel, A., L. Koskela, P. Tzortzopoulos, C. T. Formoso, and T. Alves. 2015. “Visual Management in Brazilian Construction Companies: Taxonomy and Guidelines for Implementation.” *Journal of Management in Engineering* 31 (6): 05015001.

Thürer, M., I. Tomašević, and M. Stevenson. 2017. “On the Meaning of ‘Waste’: Review and Definition.” *Production Planning and Control* 28 (3): 244-255.

Tjell, J., and P. M. Bosch-Sijtsema. 2015. “Visual Management in Mid-Sized Construction Design Projects." *Procedia Economics and Finance* 21: 193-200.

Tommelein, I. D. 1998. “Pull-Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique.” *Journal of Construction Engineering and Management* 124 (4): 279-288.

Tommelein, I. D. 2008. “Poka Yuka or Quality by Mistake Proofing Design and Construction System.” *In Proceedings of the 16th Annual Conference of the International Group for Lean Construction*. Manchester: IGLC.

Tongco, M.D.C. 2007. “Purposive Sampling as a Tool for Informant Selection.” *Ethnobotany Research and Applications* 5: 147-158.

Tsao, C. C., I. D. Tommelein, E. S. Swanlund, and G. Howell. 2004. “Work Structuring to Achieve Integrated Product–Process Design.” *Journal of Construction Engineering and Management* 130 (6): 780-789.

Viana, D. D., C. T. Formoso, and E. L. Isatto. 2017. “Understanding the Theory behind the Last Planner System Using the Language-Action Perspective: Two Case Studies.” *Production Planning and Control* 28 (3): 177-189.

Vrijhoef, R., and L. Koskela. 2000. “The Four Roles of Supply Chain Management in Construction.” *European Journal of Purchasing and Supply Management* 6 (3): 169-178.

Vlachos, I. 2015. "Applying Lean Thinking in the Food Supply Chains: A Case Study." *Production Planning and Control* 26 (16): 1351-1367.

Wandahl, S. 2014. “Lean Construction with or without Lean: Challenges of Implementing Lean Construction.” *In Proceedings of the 22nd Annual Conference of the International Group for Lean Construction*. Oslo: IGLC.

Ward, S. A. 2015. “Critical Success Factors for Lean Construction Intervention.” PhD diss., University of Dundee.

Wilson, M. M., and R. N. Roy. 2009. “Enabling Lean Procurement: A Consolidation Model for Small-And Medium-Sized Enterprises.” *Journal of Manufacturing Technology Management* 20 (6): 817-833.

Winch, G., M. C. Meunier, J. Head, and K. Russ. 2012. “Projects as the Content and Process of Change: The Case of the Health and Safety Laboratory.” *International Journal of Project Management* 30 (2): 141-152.

Wolbers, M., R. J. E. Evans, M. Holmes, C. Pasquire, and A. D. F. Price. 2005. “Construction Management and Lean Thinking in Highways Maintenance.” *In Proceedings of the 21st Association of Researchers in Construction Management Conference*. London: ARCOM.

Womack, J., D. Jones, and D. Roos. 1990. *The Machine That Changed the World*. New York: Macmillan.

Yang, H. E., and C. C. Wu. 2009. “Effects of Image Interactivity Technology Adoption on E-Shoppers' Behavioural Intentions with Risk As Moderator.” *Production Planning and Control,* 20 (4): 370-382.

Yu, H., M. Al-Hussein, S. Al-Jibouri, and A. Telyas. 2011. "Lean Transformation in A Modular Building Company: A Case for Implementation." *Journal of Management in Engineering* 29 (1): 103-111.

Yu, H., T. Tweed, M. Al-Hussein, and R. Nasseri. 2009. "Development of Lean Model for House Construction Using Value Stream Mapping." *Journal of Construction Engineering and Management* 135 (8): 782-790.

Yusuf, Y. Y., and E. O. Adeleye. 2002. "A Comparative Study of Lean and Agile Manufacturing with a Related Survey of Current Practices in the UK." *International Journal of Production Research* 40 (17): 4545-4562.

Zanotti, N. L., F. L. Maranhão, and V. L .C. Aly. 2017. "Bottom-up Strategy for Lean Construction on Site Implementation." *In Proceedings of the 25th Annual Conference of the International Group for Lean Construction.* Heraklion: IGLC.

Zegarra, O., L.F. Alarcon. 2017. "Variability Propagation in the Production Planning and Control Mechanism of Construction Projects." *Production Planning & Control* 28 (9): 707-726.

Zhou, B. 2016. "Lean Principles, Practices, and Impacts: A Study on Small and Medium-Sized Enterprises (SMEs)." *Annals of Operations Research* 241 (1-2): 457-474.

Lean thinking in the highways construction sector: Motivation, implementation and barriers

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