# Managing Radical Innovation in the Swedish Infrastructure Sector

*A Study of Industrialized Construction*

Johan Larsson

Luleå University of Technology
Department of Civil, Environmental and Natural Resources Engineering
Division of Industrialized and Sustainable Construction

***"Innovation is the whim of an elite before it becomes a need of the public."***

\- Ludwig von Mises

## PREFACE

This is the end of a five-year journey that began with an energetic and curious soul starting some research with various pre-conceptions (some of which proved to be wrong, or at least simplistic) and ended up encapsulated in this little book, my doctoral thesis. While the journey has been my own, it would not have been possible without support from a number of people and partners in crime.

Above all, I would like to express my gratitude to my supervisors Professor Thomas Olofsson, Professor Per-Erik Eriksson and Associate Senior Lecturer Gustav Jansson. I am thankful for your continuous guidance, support and motivation throughout the journey. Thomas, I am truly thankful for you taking me on board the ship and believing in me in both rain and shine. You are truly an inspiring person who always contributes to a positive atmosphere in everything you do. Per Erik, thank you for being a fantastic discussion partner, always tough but fair, and for teaching me the intricate art of research. Gustav, you have always challenged me, from thrilling squash matches to fruitful discussions that made me reflect upon work, and for that I am truly grateful. Equal gratitude also extends to all my supportive and inspiring colleagues at the Department of Industrialized and Sustainable Construction.

I would also like to express my appreciation to my financial sponsors SBuF and Trafikverket (BBT), and people who participated in my studies for giving me the opportunity to address both contractor and client dimensions of the studied processes, which has been essential for fulfilling the broad purpose. I would also like to acknowledge my former colleague, Peter Simonsson, for his mentorship during my early years and for providing support.

Moreover, I would like to express my gratitude to my “NCC people”, who have always had an open door. I would particularly like to acknowledge Magnus Alfredsson for his continuous support throughout the journey and always showing interest in my work. The ability to work closely with the industry is inspiring, and was probably essential for me to avoid insanity.

When you finally return to a haven after a long day at sea, it is always lovely to find people waiting for you. Therefore, I must especially thank you Lisa for always being there as my “harbor master” and lighting the way when the course was difficult to navigate, and of course my two crew-members Oliver and Elsa, you are simply the best!

*Johan Larsson, Luleå, January 2016*

# ABSTRACT

Industrialized construction has been a key enabler for managing increasing customer demands and addressing low productivity problems in the house building industry. It has also been proposed as a solution for low productivity in the infrastructure construction sector, but diffusion has been slow. The focus in industrialized construction is on maximizing the efficiency of the whole production system by implementing both novel products and processes in a traditionally project-based industry. Hence, industrialized construction should be considered and managed as a radical innovation involving multiple stakeholders throughout the supply-chain. Thus, the purpose of the research underlying this thesis was to increase understanding of the management of radical innovation in the infrastructure sector, as exemplified by industrialized construction.

To increase knowledge of the whole innovation process, an exploratory approach including both case studies and surveys was applied. A contractor perspective was adopted in an initial study, focusing on the development phase of industrialized construction. It revealed that industrialized construction is a comprehensive and multi-faceted activity that must be managed strategically rather than at a project level. However, early studies also revealed major challenges in the diffusion of the concept. Consequently, the research underpinning this thesis has also addressed the diffusion phase, which occurs in the Swedish infrastructure sector mostly in construction projects managed by a public client (often the Swedish Transport Administration, STA). Five studies were conducted during the course of the research, which have contributed insights into different aspects of the challenging management of radical innovation in the mature Swedish infrastructure sector.

The findings reveal that the radical innovation process involves a clear separation between the development and diffusion phases, but these are strongly intertwined. They also show that the major role of public clients (especially STA) in management of the diffusion of innovations developed by contractors exacerbates difficulties of diffusing industrialized construction in the infrastructure sector. Both the client and contractor need to acknowledge the nature of industrialized construction as a radical innovation with two separate phases. The contractor, who drives the development phase of a radical innovation, must apply an appropriate process that addresses needs of stakeholders (both internal and external) who may affect the diffusion phase, while the client must act as a problem owner and facilitate diffusion, due to the strength of the client's position. The findings further reveal major shortcomings in the current diffusion phase and show that procedures in Swedish infrastructure projects must be modified to facilitate increased diffusion of radical innovations such as industrialized construction.

The STA has recognized the need to increase rates of innovation, both by initiating an innovation program and by increasing the rate of design-build contracts, to resolve the issue of low productivity. Diffusion of industrialized construction has been slow. However, the insights regarding management of the radical innovation process presented in this thesis could be beneficial for industry representatives seeking to raise rates of the implementation of such innovation. The thesis addresses various aspects of the radical innovation process and emphasizes the difficulty of diffusing innovations in the current industry climate. The more comprehensive understanding of the system thereby provided may increase the ability of stakeholders, especially the STA, to make appropriate long-term decisions to facilitate increases in productivity.

**Keywords**

Industrialized construction, Radical innovation, Innovation management, Infrastructure, Project-based industry, Construction innovation, Process platforms

## SAMMANFATTNING

Industriellt byggande har används för att adressera både låg produktivitet och ökade kundkrav inom husbyggande. Industriellt byggande som koncept har på senare tid även inom anläggningsbyggande lyfts fram som en möjlig åtgärd för den låga produktiviteten men har till stor del varit svår att implementera. Fokus inom industriellt byggande är att öka produktiviteten i hela värdekedjan genom strategisk utveckling och implementering av nya produkter och processer in den annars projektbaserade byggsektorn. Detta innebär att industriellt byggande måste ses och ledas som en radikal innovation vilken involverar en mängd aktörer längs hela värdekedjan. Syftet med denna forskning har således varit att öka förståelsen för att leda radikala innovationer såsom industriellt byggande inom infrastruktursektorn. En ökad förståelse för både möjligheterna och utmaningar vid ledning av radikal innovation såsom industriellt byggande bidrar till att aktörer kan fatta rätt långsiktiga beslut och vidta rätt åtgärder.

En explorativ strategi inkluderat både fallstudier och enkäter har används för att öka förståelsen för den outforskade innovationsprocessen inom infrastruktursektorn. Forskningen hade initialt ett entreprenörsperspektiv med fokus på att utveckling av industriella produkter och processer. Det stod dock tidigt klart att industriellt byggande är ett komplext och mångfacetterat koncept som måste ledas strategiskt och som påverkar den ofta starka statliga beställaren. Följaktligen har forskningen också behövt adressera implementeringsfasen som oftast sker in byggprojekt ledda av Trafikverket, som den största statliga beställaren av infrastruktur i Sverige. De fem studier som utförs inom detta forskningsprojekt har alla adresserat olika aspekter av den komplexitet som finns vid utveckling och implementering av radikala innovationer såsom industriellt byggande inom den mogna infrastruktursektorn.

Resultatet visar att den radikala innovationsprocessen innefattar en tydlig separation mellan utvecklingsfasen och implementeringsfasen men att de i högsta grad påverkar varandra och till stor del måste ses som sammanflätade. Det faktum att implementering av entreprenörsutvecklade innovationer leds av en statlig beställare, oftast

Trafikverket, understycker svårigheten att sprida exempelvis industriellt byggande. Både entreprenören och beställaren samt till viss del även andra aktörer måste förstå industriellt byggande som en radikal innovation som involverar denna tydliga separation mellan de två faserna. Entreprenören som leder utvecklingen måste applicera en passande process där intressenter (både interna och externa) som påverkas av utfallet involveras redan i tidiga skeden för att underlätta implementeringen. Beställaren på grund av sin starka ställning måste anta rollen som problemägare och vidta åtgärder för att underlätta implementering vilket ökar incitamentet för strategisk utveckling separerad från byggprojekt. Resultatet avslöjar dock stora brister i den nuvarande procesen som kontrollerar byggprojekt drivna av Trafikverket. Förfarandet som används måste förändras för att öka andelen radikala innovationer såsom industriellt byggande vilket ses som lösningen på låg produktivitet.

Sammanfattningsvis måste poängteras att Trafikverket har uppmuntrat innovationer genom att både öka andelen totalentreprenader samt startat ett innovationsprogram (BBT), vilket denna forskning är en del av, för att lösa den låga produktiviteten. Det har dock varit svårt att implementera radikala innovationer och den ökade förståelse för innovationsprocessen som denna avhandling bidrar med kan vara till nytta för aktörer inom infrastruktursektorn. Den belyser olika aspekter av den radikala innovationsprocessen och betonar komplexiteten vid implementeringen i det rådande industriklimatet. En ökad förståelse för hela systemet ökar möjligheten för aktörer, i synnerhet beställaren, att fatta korrekta långsiktiga beslut för att möjliggöra för ökad implementering av innovationer.

## LIST OF PUBLICATIONS

**Peer-reviewed journal articles (Papers I-IV are appended to the thesis and referred to in the text by the corresponding Roman numerals)**

**Paper I:**

Larsson, J., Eriksson, P.E., Olofsson, T. and Simonsson, P. (2014) "Industrialized construction in the Swedish infrastructure sector: core elements and barriers". *Construction Management and Economics*, *32*(1-2), 83-96.

**Paper II:**

Larsson, J., Lu, W., Krantz, J. and Olofsson, T. (2015) "Discrete event simulation analysis of product and process platforms – a bridge construction case study". *Journal of Construction Engineering and Management*. (Online Publication Date 25 November 2015)

**Paper III:**

Larsson, J., Eriksson, P. E., Olofsson, T., and Simonsson, P. (2015). "Leadership in civil engineering: Effects of project managers' leadership styles on project performance". *Journal of Management in Engineering*, *31*(6).

**Paper IV:**

Larsson, J. and Larsson, L. "Exploring capabilities to manage innovation projects in production". Submitted for publication in *International Journal of Technology Management*.

**Paper A:**

Krantz, J., Larsson, J., Lu, W. and Olofsson, T. (2015) "Assessing embodied energy and greenhouse gas emissions in infrastructure projects". *Buildings, 5*(4), 1156-1170.

**Peer-reviewed conference articles**

**Paper B:**
Rwamamara; R., Simonsson, P. and Ojanen (curr. Larsson), J. (2010) "Advantages of industrialized methods used in small bridge construction". *Proceedings of the 18th Annual IGLC Conference (International Group for Lean Construction)*, July 14-16, Haifa, Israel.

**Paper C:**
Larsson, J. and Emborg, M. (2011) "A Study of the future concrete bridge construction in Sweden". *Proceedings of the XXI Nordic Concrete Research Symposium*, May 30-June 1, Hämeenlinna, Finland.

**Paper D:**
Larsson, J. and Simonsson, P. (2012) "Decreased complexity of bridge construction through prefabrication: A case study". *Proceedings of the 20th Annual IGLC Conference,* July 18-20, San Diego, USA.

**Paper E:**
Larsson, J. and Simonsson, P. (2012) "Barriers and drivers for increased use of off-site bridge construction in Sweden". *Proceedings of the 28th Annual ARCOM Conference,* September 3-5, Edinburgh, UK.

**Paper F:**
Jensen, P., Larsson, J., Simonsson, P. and Olofsson, T. (2013) "Improving buildability with platforms and configurators". *Proceedings of the 21st Annual IGLC Conference,* July 29-August 2, Fortaleza, Brazil.

**Paper G:**
Larsson, J., Olofsson, T. and Lu, W. (2014) "Platform concepts in bridge construction". *Proceedings of the 2014 ICCCBE conference,* June 23-25, Orlando, USA.

**Paper H:**
Krantz, J., Lu, W., Shadram, F., Larsson, J. and Olofsson, T. (2015) "A model for assessing embodied energy and GHG emissions in infrastructure projects". *Proceedings of the 2015 ICCREM Conference,* August 11-12, Luleå, Sweden.

**Paper Ib:**
Larsson, L., Larsson, J., Stahre, J. and Öhrwall Rönnbäck, A. (2015) "Innovation for competitive manufacturing". *Proceedings of the XXVI ISPIM Conference,* June 14-17, Budapest, Hungary.

**News article**
Larsson, J. (2012) "Future development potential for concrete bridge construction in Sweden". *TKS Beton, 4,* 92-94. (In Czech).

**Licentiate thesis**
Larsson, J. (2012). "Mapping the Concept of Industrialized Bridge Construction – Potentials and Obstacles". Luleå University of Technology, ISBN 978-91-7439-543-3.

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## APPENDICES

# 1 INTRODUCTION

*This chapter presents background information for the research the thesis is based upon, followed by the purpose of the research and specific research questions addressed, and then ends by describing the disposition of the thesis and summarizing the appended papers.*

## 1.1 Background

Technology development and innovations are seen as crucial for firms' survival in today's increasingly competitive environment, and meeting customer demands in line with swiftly changing global trends (e.g. Hart, 1997; Panuwatwanich et al., 2009). Innovations are often described as the creation and use of substantial changes or improvements in a process, product or system that is perceived as new to the receiver (Slaughter, 1998; Boer and During, 2001; Tushman and Nadler, 1986). Boer and During (2001) point out that innovation always involves a process, starting with an idea that is *developed* then subsequently *diffused*, and thus must be managed as such. The diffusion may be internal, within the organization where the idea originated, external within the market, or a combination of both (Boer and During, 2001). However, any innovation has two core phases: development, followed by its realization through diffusion (Tidd and Bessant, 2013). The capacity to managing these phases successfully depends on both organizational capability and the innovative climate of the industry (Rothwell, 1992; Pellicer et al., 2014; Cooper, 1998; Boer and During, 2001).

Innovation may range in magnitude from incremental to radical, but must always contribute to increased value of some kind. Radical innovations are always accompanied by higher risks and uncertainties than incremental innovations, and often require the introduction of new skills throughout the organization (Tushman and Nadler, 1986; McDermott and O'Connor, 2002). While incremental innovations are typically extensions or modifications of existing products or processes, often continuously generated and implemented, radical innovations involve the development or introduction of significantly novel technologies in markets, either new or existing, that require dramatic changes (McDermott and O'Connor, 2002). McDermott and O'Connor (2002) further state that effective management of radical innovations is often critical for the long-term survival for firms in many industries. Any innovation process involves a range of activities ranging from rather simple to very difficult tasks, often performed by collaborating organizations and people with different competences. Thus, all innovation processes can be characterized by certain levels of uncertainty, complexity, diversity, and interdependence (Boer and During, 2001).

## 1.2 Innovation in construction

Like other industries, firms in the construction industry are exposed to steep increases in competition and customer demands, and hence require innovation (e.g. Panuwatwanich et al., 2008). Furthermore, increases in the rate of innovations may boost productivity (Winch, 2003). This could be highly significant as low productivity has been highlighted as a problem facing much of the construction industry in governmental reports and research publications from many countries including Great Britain and the USA (e.g. Egan 1998; Teichholz et al., 2001). In Sweden there is also an urgent need to raise productivity and client satisfaction in the construction industry (both building and infrastructure sectors), which has triggered a number of government investigations (SOU, 2002, 2009 and 2012). However, the mainstream literature on improving the construction industry has focused primarily on the housing sector (e.g. Gann, 1996; Pan et al., 2012; Jonsson and Rudberg, 2013), despite the great importance of the infrastructure sector.

Measures to increase the productivity of the infrastructure sector are particularly important from a societal perspective, since large amounts of public funds are spent on investments in the sector that are crucial for national development and economic growth (Caerteling et al., 2011). Previous research has found that productivity is a key challenge in the sector, and that many infrastructure projects suffer from cost and schedule overruns (Flyvbjerg et al., 2004; Cantarelli et al., 2012). However, introducing extensive innovations in much of the construction industry, particularly the infrastructure sector, has been difficult. Frequently mentioned reasons for this include the industry's project-based, engineering-to-order, fragmented and strongly institutionalized characteristics (e.g. Latham, 1994; Fairclough, 2002). Effects of each of these characteristics are considered below.

Construction is a *project-based industry*, in which temporary teams are frequently formed to execute projects involving the construction of one-off products. The short-term nature of the teams and their activities promotes short-term thinking and tight coupling between actors, activities and operations within a project (Dubois and Gadde, 2002). It also inevitably leads to *fragmentation* as multiple stakeholders are gathered to execute construction projects, but then disperse to form new teams for their next projects (Alashwal et al., 2011). Dave and Koskela (2009) point out that this fragmentation obscures the role of learning in construction organizations (and responsibilities for ensuring that it occurs), since it reduces collective knowledge capture and sharing. Thus, these two construction characteristics hinder long-term thinking and transfer of knowledge between projects, causing complications from a long-term innovation perspective.

Generally *engineer-to-order* production strategies are applied in construction projects, characterized by an early order-penetration-point during the early design stage (Olhager, 2003; Gosling and Naim, 2009). Partly due to early entrance, the client also often has a strong position in construction projects. Further, Gann and Salter (2000) found that clients can play an important role in increasing (or restricting) the degree of innovation, partly by putting pressure on stakeholders to improve, and partly by helping them to manage unpredicted changes in (for example) demands and regulations. This is clearly evident in the infrastructure sector where public clients, often the Swedish Transport Administration (STA) in Swedish cases, manage projects from initiation to completion. For other stakeholders in the supply-chain to significantly influence a construction project, they have to be involved in the early design stage before limitations obstructing the diffusion of innovations are set by the client (Segerstedt and Olofsson, 2010; Widén et al., 2013).

Further, Kadefors (1995) found that due to its project-based structure, the construction industry is subject to strong *institutionalization* owing to the need for coordination and communication in the often temporary and complex project organizations involving multiple actors. Institutionalization refers to the cultural rules that provide foundations for the ways people act and think about the world, such as governmental regulations, norms, contracts and procurement systems. These rules foster homogenized behaviour within the industry, which could hamper the openness needed for creating an innovative climate.

Due to the highlighted characteristics of the industry, the most common innovations in construction are incremental and arise to solve problems within construction projects (Winch, 1998; Taylor and Levitt, 2004). Construction innovations have historically been more related to products than processes, perhaps because the focus in early phases of a construction project is on design of the product rather than its realization (Gann et al., 2000). However, development of more radical innovations requires separation from specific construction projects because of difficulties in enabling innovations that occur at project-level to persist and diffuse across the industry (Winch, 1998; Egan, 1998). This appears to be a very rare process across long timeframes (Tatum, 1987; Latham, 1994). Hence, changes in both organizational capabilities and industry climate may be necessary to increase rates of innovation in construction according to Tatum (1987), and general product innovation literature (Cooper, 1998; Rothwell, 1992).

However, the construction industry is far from homogeneous in terms of the rate of introducing innovations. In some parts of the housing sector, production companies have used innovations such as industrialized processes and prefabrication for decades, resulting in higher possibilities for continuous productivity improvements (Gann, 1996; Höök and Stehn, 2008; Segerstedt and Olofsson, 2010; Johnsson, 2013). These industrialization strategies taken from the manufacturing industry have been seen as solutions for improving construction productivity. Due to the perceived need to increase productivity in the infrastructure sector, STA has launched a long-term research and innovation program to identify ways to increase industrialization throughout the supply-chain (Trafikverket, 2012).

## 1.3 Industrialized construction as a radical innovation

Both industrialized construction and innovation can be regarded as products and processes, new to the unit of adoption, which involve risks in both development and diffusion (Kamar et al., 2013). Thus, various authors have argued that industrialized construction is a significant innovation in construction that must be managed as such (e.g. Pan et al., 2012; Kamar et al., 2011, Atkin, 2014). Lessing et al. (2015) regarded industrialized construction as a strategically different process and product-oriented alternative to project-based construction using traditional methods and principles. As described in detail in the theoretical framework (section 2.3), it involves and affects the whole supply-chain not just a single organization. Thus, industrialized construction is a radical innovation that requires modification of the whole supply-chain for success. For example, a major element of industrialized construction, prefabrication or off-site fabrication (Lessing et al., 2015; Gibb, 2001; Atkin, 2014; Li et al., 2014), often triggered by demands for increased productivity, also affects the product because components are manufactured in factories. Hence, prefabrication affects multiple stakeholders (technical consultants, contractors, clients and suppliers) throughout the supply-chain, which increases the difficulty, risks and uncertainty during both its development and diffusion.

Viewing industrialized construction as a radical innovation also has advantages since there is extensive literature on innovation management, which could provide vital information for understanding the difficulties involved, for both researchers and practitioners. However, previous literature suggests that there are significant differences in managing innovations between traditional manufacturing and project-based industries such as construction (e.g. Gann and Salter, 2000; Keegan and Turner, 2002; Blindenbach-Driessen and van den Ende, 2006). Further, the noted characteristics of construction (project-based structure, fragmentation, engineering-to-order and institutionalization) found in prior literature all increase the barriers for successfully introducing the radical innovations required to increase productivity.

## 1.4 Problem discussion

Innovations, incremental or radical, in construction are usually diffused within construction projects rather than within the organizations developing the innovations (Winch, 1998). This has profound consequences for the introduction of radical innovations in the infrastructure sector because the development and diffusion phases are managed by different actors. Radical innovations may be developed by agents such as contractors or suppliers involved in a construction project, but the client (often STA, as the main public client for infrastructure projects in Sweden) must initiate and manage any subsequent diffusion as a "system integrator" (Segerstedt and Olofsson, 2010). Thus, due to the characteristics of construction and its strong position as the major public client, STA could severely hinder the diffusion of radical innovations such as industrialized construction, and its role should be carefully considered. Traditionally, most activities in infrastructure projects have been specified in Design-bid-build (DBB) contracts, so the product design is essentially determined before the contractor enters the project (SOU, 2010). Hence, the vast experience and knowledge of the contractor(s) are not taken into account during the most creative phase of the construction project. This procedure reduces the chance for contractors, as developers, to introduce industrialized construction practices and minimizes incentives for contractors to invest in development separated from construction projects.

Previous research on industrialization in the infrastructure sector is scarce and has largely focused on the development phase from a contractor's perspective without considering the strong position of the client during the diffusion phase (e.g. Harryson, 2002; Simonsson, 2011). Simonsson (2011) explored the possibility of using production methods (e.g. prefabrication), standardization and lean tools to increase buildability and productivity in infrastructure projects. Harryson (2002) adopted a more conceptual approach, presenting a framework for industrialization including three cornerstones: process development, product development and productivity development. However, little attention has been paid to the diffusion phase, although several authors have stressed its importance and intricacy (e.g. Peres et al., 2010; Widen et al., 2014).

The Productivity Committee, supported by the Swedish Ministry of Enterprise, Energy, and Communications, has recently examined barriers and drivers for innovations, such as industrialization, in the Swedish infrastructure sector (SOU, 2012). It concluded that norms, regulations and STA's unwillingness to introduce unproven solutions hinder the diffusion of innovations. Further, the Committee emphasized the importance of finding a suitable balance between radical and incremental innovations for sustainably developing the sector and increasing its productivity. The client (STA) shows the motivation and ambition to change the industry, but much greater understanding of the system of managing radical innovations is needed in the infrastructure sector (Winch, 1998).

The practical challenges of managing radical innovations and theoretical gaps outlined above show there is a clear need for greater understanding of the development and diffusion of radical innovations in the project-based infrastructure sector. These challenges, gaps and needs are addressed in this thesis and the studies it is based upon, as outlined in the following section.

## 1.5 Research purpose and questions

As core phases of the innovation process, it is clearly important to increase knowledge of development and diffusion phases to improve understanding of the difficulty of managing radical innovations. Consequently, the studies this thesis is based upon have considered activities and roles of both the largest public client and a major contractor active in the Swedish infrastructure sector.

The overall purpose of the research has been to increase understanding of managing radical innovations in the infrastructure sector, as demonstrated by industrialized construction. To fulfil this purpose, specific goals (encapsulated in three research questions) were to understand industrialized construction, and subsequently address the development and diffusion phases.

Industrialization is said to be an appropriate way to improve both products and processes in the infrastructure sector. To increase understanding of ways to appropriately manage the innovation process, greater understanding of the concept of industrialized construction is required. Hence, research question 1 was posed:

**Research question 1:** How is industrialized construction, as a radical innovation, received?

However, both of the main recognized phases of the radical innovation process in the infrastructure sector (development and diffusion) are strongly affected by diverse management-related factors, which determine the capability to innovate within the sector. Thus, to improve understanding of the nature of the radical innovation process, and how it could be managed (particularly within the sector), two further questions were posed:

**Research question 2:** How could the development phase be managed to facilitate diffusion?

**Research question 3:** How is the diffusion phase managed and what challenges can be identified?

## 1.6 Thesis disposition

The thesis comprises six chapters outlining various aspects of the research (outlined below) and four appended papers, which are listed in the next section together with a brief description of each author's contribution.

Thesis chapters

**Chapter 1** introduces the phenomena considered, then describes the purpose of the underlying research and the questions addressed.

**Chapter 2** presents the theoretical framework used for guiding the research and interpreting the findings.

**Chapter 3** presents the research journey, strategy and methods used. Research quality is also discussed.

**Chapter 4** summarizes findings from the conducted studies.

**Chapter 5** discusses the findings in relation to the research purpose and research.

**Chapter 6** presents conclusions, considers theoretical and managerial implications of the findings, then discusses limitations of the research and aspects that require further research.

## 1.7 Appended papers I-IV

**Paper I:**
Larsson, J., Eriksson, P.E., Olofsson, T. and Simonsson, P. (2014) "Industrialized construction in the Swedish infrastructure sector: core elements and barriers". *Construction Management and Economics*, *32*(1-2), 83-96.

*Author contribution*
This paper was published in a special issue of *Construction Management and Economics* entitled Industrialized building. My contribution was in formulating the fundamental ideas, together with Eriksson, conducting one of the presented studies together with Simonsson, and writing the paper (as main author) with Eriksson.

**Paper II:**
Larsson, J., Lu, W., Krantz, J. and Olofsson, T. (2015) "Discrete event simulation analysis of product and process platforms – a bridge construction case study". *Journal of Construction Engineering and Management*. (Online Publication Date 25 November 2015)

*Author contribution*
My contribution to this paper was in formulating the main ideas together with the co-authors, carrying out the reported case study at the company, conducting the related workshops and interviews, then writing the paper as main author, together with the other authors, particularly Lu.

**Paper III:**
Larsson, J., Eriksson, P. E., Olofsson, T., and Simonsson, P. (2015). "Leadership in Civil Engineering: Effects of Project Managers' Leadership Styles on Project Performance". *Journal of Management in Engineering*, *31*(6).

*Author contribution*
My contribution here was in formulating fundamental ideas together with Eriksson, conducting the questionnaire survey together with Simonsson, then analysing the data and writing the paper (as main author) together with Eriksson.

**Paper IV:**
Larsson, J. and Larsson, L. "Exploring capabilities to manage innovation projects in production". Submitted for publication in *International Journal of Technology Management*.

*Author contribution*
The multiple case study underlying the empirical findings were conducted and analysed by both authors, who collaborated during the whole process and contributed equally during the writing, but I was the main author.

# 2 THEORETICAL FRAMEWORK

*This chapter presents the theoretical framework. It first introduces the concept innovation and outlines innovation management in project-based industries, then describes the innovation process and factors influencing it in these industries. The chapter ends with a description of the concept of industrialized construction.*

## 2.1 Innovation management in project-based industries

Innovations are characterized by uncertainty, complexity, diversity and interdependence (Boer and During, 2001) and require careful management to be successful. Hence, managing innovations is a intricate task that requires adequate technical resources and organizational capabilities (Tidd and Bessant, 2013). Patterns and factors that influence the success of managing innovation have been identified in numerous studies (e.g. Rothwell, 1992; Cooper, 1998; Boer and During, 2001). Rothwell (1992) distinguishes between project-related factors (essentially organizational capabilities to realize key steps in the innovation process), and industry conditions, which set the context in which the innovation process is managed. These factors intensively interact, thereby strongly affecting the innovative climate. Rothwell (1992) notes that most of these factors are influential in all industries, but their relative importance may vary between industries.

Literature on innovation management mostly concerns organizations that are functionally organized (traditional manufacturing), often with strict hierarchical organizational structures (Taylor and Levitt, 2004; Blindenbach-Driessen and van den Ende, 2006; Gann and Salter, 2000). However, project-based industries, such as construction, provide a different context for innovation and various authors (e.g. Tatum, 1987; Blindenbach-Driessen and van den Ende, 2006) have noted that they have not been adequately addressed in innovation management research, and modification of innovation theory may be required to do so.

Project-based organizations are fluidly structured to deliver often unique and complex solutions for their clients in specific projects (Gann and Salter, 2000). The solutions usually consist of products or systems integrated in a business-to-business arrangement. These types of organizations handle two distinctly different types of projects, *business projects* and *development projects* (Blindenbach-Driessen and van den Ende, 2006). Thus, innovation may occur via two distinctly different paths: via problem-solving in business projects or via development in firms followed by diffusion in business projects (Winch, 1998).

*Business projects*, such as construction projects, offer unique solutions to each client in an arrangement bounded by contractual agreements (Keegan and Turner, 2002). Clients normally initiate the projects, define their specifications, provide financial resources and benefit from the end delivery (Keegan and Turner, 2002). Business projects in project-based industries often include phases such as concept definition, design, construction, implementation testing and operation, but every phase is not necessarily included in all projects. Construction management literature has historically focused on innovations and performance within business projects (e.g. Winch, 1998; Egan, 1998). Due to the project-based setting, the focus has been on approaches to execute individual construction projects successfully in terms of budget, schedule, quality, and (hence) short-term efficiency. Factors determining success have been frequently debated in literature, often related to resource management (Chua et al., 1999), project management practices (Songer and Molenaar, 1997) and/or contracting and procurement practices (Ibbs et al., 2003).

Project management and control have often been emphasized as important aspects within business projects in the construction industry (Blindenbach-Driessen and van den Ende, 2006; Pries and Janszen, 1995). Keegan and Turner (2002) found that project managers are generally reluctant to develop innovations within business projects. They further found that the project control systems applied in business projects hinder the success of innovative activities undertaken in business projects. They also affect the diffusion of radical innovations, developed separately from the business projects, since any diffusion occurs in traditional business projects regardless of the innovations' origins.

The second type of projects undertaken by project-based organizations, *development projects*, are often conducted separately from business projects, in efforts to develop innovations that can be applied in numerous business projects and evolve over time (Blindenbach-Driessen and van den Ende, 2006). Successful realization of these innovation projects often requires coordinated changes in multiple organizations throughout the supply-chain (Taylor and Levitt. 2004).

This more structured approach to innovation has received relatively little attention in prior construction management literature, although a few authors have considered some aspects of it. Gann and Salter (2000) were among the first to explore development projects in construction. They found that project-based organizations, especially in the construction sector, do not execute innovation projects in distinct R&D departments, but instead in close connection with, and using the same resources as, business projects. They also pointed out that construction firms could separate innovation projects and business projects more strictly, but have to be cautious since it could hamper internal knowledge transfer.

A critical ability for performance in innovation projects, according to Cohen and Levinthal (1990), is to absorb (assimilate and internally utilize) knowledge effectively. Internal knowledge utilization refers to the transfer and exploitation of knowledge between projects (Blayse and Manley, 2004; Pellicer et al., 2014; Rothwell, 1992), e.g. exploiting new production equipment, using old equipment in a novel way, or efficiently monitoring technological developments to identify innovative opportunities (Pellicer et al., 2014). The information and knowledge of individuals can only be distributed internally and used in business once it has been converted into a transferable form (Jantunen, 2005).

However, successfully managing more structured innovation initiatives has been difficult in project-based industries, such as construction, and the uptake of innovations has been much slower than in other industries, according to (for example) Taylor and Levitt (2004). The distinctive features of the construction industry: project-based, engineering-to-order, fragmented and strongly institutionalized (described in Section 1.2), and its approach to innovation, suggest that factors for successful innovation management in the industry could also be distinctively different from those found in traditional manufacturing industries.

## 2.2 Innovation process

The innovation process *per se* is most crucial for the ability to realize innovation projects successfully. Realization of innovations is challenging and must be planned and adequately resourced, to gain not only acceptance (internal and external), but also optimal competitive advantage (Cooper, 1999; Tatum, 1987). This requires a high quality innovation process (Cooper, 1998; Pellicer et al., 2014) often designed as a funnel with go/kill decisions to yield positive outcomes.

In early generations of relevant research and modelling a linear view of the innovation process, driven by technology "pushes" and market "pulls", was adopted (Rothwell, 1994). Many of these linear models were developed after the Second World War, when markets screamed for innovations. However, this is seldom the case now, and newer generations of innovation models have shifted from a linear to a more comprehensive perspective, linking R&D with company goals, and more emphasis is placed on chain management in both general innovation literature (e.g. Rothwell, 1994) and construction innovation literature (e.g. Loosemore, 2015).

However, the innovation process always follows the same general patterns and the same main phases can be essentially recognised in each "generation" of models. For generalization purposes, the innovation process in this thesis is divided into four major phases — pre-development, development, diffusion and value capture — as described for instance by Cooper (1994) and Tidd and Bessant (2013) (Figure 1). The core phases of the process are however considered to be *development* and *diffusion*, or implementation according to the term used by Tidd and Bessant (2013) to describe both of these phases. Figure 1 illustrates the innovation process and their relation to the structure of project-based industries.

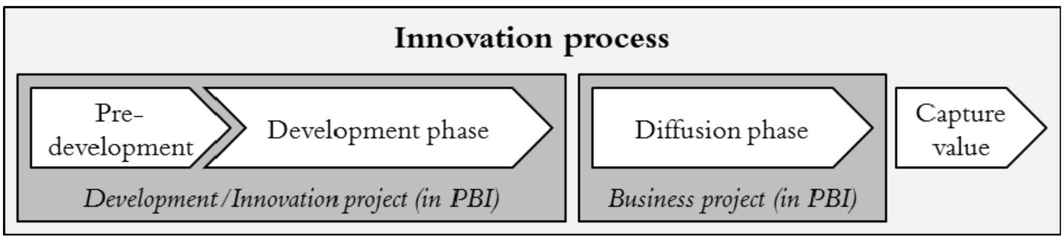


*Figure 1. The innovation process in a project-based industry (PBI) (Based on Cooper (1994), Tidd and Bessant (2013) and Blindenbach-Driessen and van den Ende (2006))*

Pre-development often includes an initial search for appropriate innovations before the process enters the development phase. Initiating triggers for innovation projects can be divided into push and pull factors, referring to opportunities and the need for change (e.g. to meet new regulations or changes in the competitive environment), respectively. According to Tidd and Bessant (2013), most innovations are driven by an interactive combination of both types of factors. Careful screening and planning before starting the development phase increases the chances for success of an innovation project (Rothwell, 1992).

In the *development* phase ideas are turned into new products, services or processes. The early stages of the development phase involve high uncertainty, which is gradually replaced by knowledge acquired through various activities (Tidd and Bessant, 2013). At the end of this phase (if successful), the solution can be diffused into its intended context, internally, externally or a combination of both. Development is the heart of the innovation process and poses fundamental challenges in project management (e.g. Tidd and Bessant, 2013; Brown and Eisenhardt, 1995; Murphy et al., 2011). This is because managers must maintain a sufficient contingency perspective to meet the constant shifts in knowledge, aims and associated issues throughout the process (Tidd and Bessant, 2013). In addition to a well-planned development phase, the solution often benefits from extensive testing before diffusion (Cooper, 1999).

When new products, services or processes are launched it is necessary to understand the intricate and dynamic phase of *diffusion*. Diffusion of innovations, both internally at organizational level and externally at market level, is a difficult and uncertain task. According to Tatum (1987), for project-based organizations the major steps in the diffusion phase (which are important for gaining a competitive advantage) are providing suitable resources, supplying tendering and planning inputs, and gaining experience and acceptance in use. Consequently, diffusion is especially difficult in project-based industries, where clients enter the diffusion process early, or even initiate it, and often require customized solutions tailored to their needs. This occurs in traditional business projects in project-based industries and thus involves multiple actors and inter-firm interactions (Winch, 1998).

The last phase of the innovation process is value capture, which is equally critical as innovations are (usually) undertaken to acquire some sort of value from them. This value may be an increase in market share, saving in costs, reduction in time or some other desirable change in a relatively simple parameter. However, as noted by Tidd and Bessant (2013), capturing value in terms of learning from the process *per se* is equally critical since it can spur further innovations. Such learning may regard new technologies that can boost the organization's competence, or capabilities and procedures needed for innovation management. These are what some researchers call factors for successful innovation management, which can be divided into organizational-level capabilities and institutional factors, as discussed in the following sections.

### *2.2.1 Organizational capabilities*

Blindenbach-Driessen and van den Ende (2006) proposed three sets of factors related to capabilities of project-based organizations (*Team*, *Senior management commitment* and *Involvement of outside parties*). These factors are considered in the following three sections, using literature on innovation in both traditional manufacturing and project-based industries. The cited authors also identified two other sets of factors related to the process itself (planning of work, and activities undertaken), which have already been discussed in Section 2.2.

- *Team* factors are the individuals, internal collaboration and project management, which jointly form the core knowledge asset of the innovation.
- *Senior management commitment* is often crucial to meet the needs for extensive resources and support throughout the innovation process.
- *Involvement of outside parties* such as suppliers and customers/clients, which is often affected in either the development or diffusion of innovations in project-based industries.

*Team*

The involvement of certain key individuals in the innovation process increases the possibility of success (Rothwell, 1992; Blindenbach-Driessen and van den Ende, 2006). This is because innovation is an essentially human activity, and appropriate individuals must be available to play important roles in the innovation process, such as: idea generator, champion, sponsor, project manager, gatekeeper and problem owner. Fulfilment of each of these roles requires a combination of relevant intellectual or cognitive attributes, behavioural characteristics, and position (responsibility and/or power base) (Boer and During, 2001). The importance of the key individuals varies over time during a project's progress (Robert and Fusfeld, 1981). Idea generation is crucial in initial stages, while commitment and leadership are needed once a project is established to ensure its progress. Thus, the lack of a key individual, or inability to fulfil a key function, at a key time is a serious weakness, regardless of whether the function is fulfilled at an earlier or later, less crucial, time.

One of the key individuals for innovation in project-based organizations, according to several authors, is the project manager. This is hardly surprising as diffusion of innovations in construction is heavily dependent on project management (Murphy et al., 2011). Further, project managers often have both the authority and technical knowledge required to act as facilitators of innovation in the diffusion phase (Nam and Tatum, 1997).

In addition to these key individuals, a dedicated cross-functional project team and effective collaboration among individuals are often seen as necessary for high chances of success in an innovation project (Cooper 1998; Larson and Gobeli 1988; Pellicer, et al., 2014). A cross-functional team is a group of cooperating and collaborating individuals drawn from various functional units (Pinto et al., 1993), which enables boundaries to be bridged (Tidd et al., 2001) and provides higher capacities than solitary individuals for idea generation, learning and improvements.

McDonough (2000) and Santa et al. (2011) claim that use of a cross-functional team has a positive impact on project performance, provided that the team has clear and common goals. However, the term cross-functional is less relevant in organisations operating in project-based industries than in other settings, according to Blindenbach-Driessen and van den Ende (2006), as they seldom include functional units such as R&D, marketing and operations. The cited authors propose that the term multi-disciplinary team is more useful since these organizations are structured in disciplinary rather than functional units.

*Senior management commitment*

Senior management commitment, i.e. the involvement and support of senior managers throughout the entire innovation process, is another important factor (Rodriguez, 2008). Two major dimensions are recognised by Rodriguez (2008): senior management support and attitude toward risk. Senior management support is related to the provision of appropriate funding and resources for the process. However, it is also important for senior managers to encourage teams, help them overcome problems and foster collaboration and communication (Cooper et al., 2004). Certain activities could also benefit from senior management involvement, e.g. selection of projects, since it could lead to appropriate resource allocation during the course of the innovation project (Cooper, 1998; Wheelwright and Clark, 1992).

Senior managers' attitude toward risk reflects their willingness to accept occasional failures as an inevitable part of business (Menon et al., 1997). High managerial risk aversion increases inter-functional conflict, as parties try to avoid responsibility for failures and focus on low-risk tasks rather than more intricate, multi-departmental or multi-disciplinary activities (Rodriguez, 2008). Blayse and Manley (2004) and Rothwell (1992) point out that the commitment of senior management should incorporate open-mindedness to facilitate creation of a learning organization and an innovation-fostering culture.

*Involvement of outside parties*

In many innovation projects internal collaboration is not enough, and external knowledge is needed for a satisfactory outcome, especially for radical innovations, which often require the acquisition and dissemination ("absorption") of new knowledge. External, strategic collaboration has been a cornerstone of manufacturing industry development for decades and is often taken for granted (Gann, 1996). However, external communication and collaboration are still acknowledged as important in both manufacturing and project-based literature for exploiting scientific and technological know-how (Rothwell, 1992; Pellicer et al., 2014; Blayse, Manley, 2004).

Nevertheless, exploiting external knowledge is not easy, thus it is generally accepted that firms need a sufficient absorptive capacity to acquire and successfully exploit external knowledge (Bönte, 2005; Cohen and Levinthal, 1990). The ability to absorb new knowledge and practices is largely determined by firms' prior professional knowledge stock (Cohen and Levinthal, 1990).

However, there is a dilemma in inter-firm cooperation: the flow of knowledge and information between partners is important for success, but there are risks of unintended outflows of core knowledge, which might severely undermine a firm's competitiveness (Jordan and Lowe, 2004; Bosch, 2009). Trust in partners is therefore an essential element for building and sustaining collaborative alliances (Fawcett et al., 2012). Bosch (2009) further found that the strong governmental regulations in construction discourage external relationships to occur outside construction projects.

Involvement of customers/clients in innovation projects is also generally crucial, for identifying their needs and requirements, which is vital for satisfactory outcomes in any industry (Pellicer et al., 2014; Cooper, 1998; Rothwell, 1992). Close connection with potential clients and the market also facilitates the incorporation of knowledge and experience into the projects (Blayse and Manley, 2004). However, close client involvement typically occurs during development in project-based industries (Gann and Salter, 2000), due to their importance and major involvement during the diffusion phase. Thus, organizations often know their clients well and specific investigation of clients' needs is seldom needed (Blindenbach-Driessen and van den Ende, 2006).

### *2.2.2 Institutional factors*

In addition to the organizational level factors described above, some "institutional" factors (Edquist, 1997) rooted in the wider environment may also strongly influence the innovation process (Hueske et al., 2015; Rolfstam et al., 2011). These factors are often national or tied to a specific industry, and considered beyond the control of any individual organization or team involved in an innovation project. They include various formal as well as informal factors that shape practices and activities, such as culture, norms, procedures and regulations (Rolfstam et al., 2011). Such institutions strongly influence the innovative climate by affecting actions and interactions between actors and networks (Malerba, 2002). Regulatory authorities may, for instance, restrict (or trigger) innovation initiatives (Hueske et al., 2015). Studies focusing on project-based industries such as construction often highlight regulations and the early decoupling point of the client as obstacles to the introduction of innovations developed separated from a construction project (Pries and Janszen, 1995; Gosling and Naim, 2009). Kadefors (1995) argues that there is strong institutionalization in construction, much of which can be attributed to the fragmentation of the project organizations and the complexity of the products. Institutions can also be defined as cultural rules, which act as templates for the way we perceive our environment and act (DiMaggio and Powell, 1991).

## 2.3 Industrialized construction

An early contribution to the understanding of industrialized construction was presented by Gann (1996), describing Japanese house-building manufacturers as controlling the entire production system. Gann (1996) found that these companies used systematized technical solutions with production in advanced factories. The production principles used by these house-building manufacturers were described as similar to those used in the Japanese automotive industry, commonly referred to as Lean production (Womack et al., 2007). The ground principles of Lean production are: elimination of waste, continuous improvements, close internal and external collaboration, clear customer focus, and robust, standardized processes (Liker, 2004; Womack et al., 2007).

Lean principles have also been applied in analyses of the construction industry, contributing with an understanding of industrialized construction, characterized by integration and control of technical, process, organizational and production-related solutions and activities (Björnfot and Stehn, 2007). Perhaps most importantly, the focus is on maximizing the efficiency of the whole production system rather than individual construction projects. Similarly, Nadim and Goulding (2011) explored industrialized construction in the European construction industry and found five patterns that have to be integrated to increase uptake: people, technology, business process (e.g. production), product and market.

Various terms have been used to interpret the industrialization approach, e.g. Lean construction, industrialized construction and off-site construction (Alves and Tsao, 2007; Lessing et al., 2015; Kamar et al., 2011; Pan et al., 2012; Gibb, 2001). In this thesis the term industrialized construction is used. Regardless of the term applied, a requirement for industrialized construction is standardization of both products and processes to decrease the

of construction (Bertelsen, 2004). Thus, research perspectives on industrialized construction have shifted from focusing on production methods and prefabrication, towards the more comprehensive views described, for example, by Nadim and Goulding (2011), Brege at al. (2014) and Lessing et al. (2015).

Lessing et al. (2015) interpreted industrialized construction as a process- and product-oriented alternative to traditional project-based construction methods and principles, with strategic differences affecting the whole supply-chain. Due to its comprehensiveness, it needs to be managed strategically rather than on a business project level (Lessing et al., 2015). Brege et al. (2014) constructed a business model including elements of market position, product offering and operational platform based on a multiple case study of five industrialized house builders in Sweden. This strategic development of industrialized construction was further described by Lessing (2015) as involving a process model in which platforms for both technical solutions and processes are (continuously) developed and managed (Figure **2**).

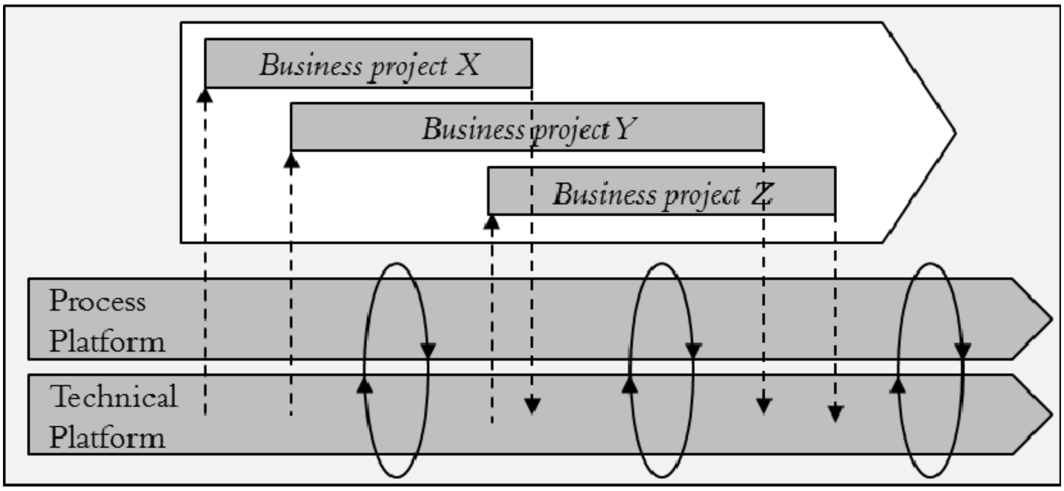


*Figure 2. Process model for continuous development of platforms for delivering both technical and process solutions (adapted from Lessing, 2015)*

Technical and process platforms have emerged as essential elements of industrialized construction during the past decade. The use of platforms, with standardized solutions, can offer tested and robust technologies, for both products and processes (Björnfot and Stehn, 2007). Platforms in construction can be viewed as systems for storing knowledge and pre-defined product architectures, components, modules, related processes, and both the internal and external relationships needed to customize products for clients (Jansson et al., 2014). Standardization and incremental development of platforms (combined with strong commitment and loyalty from the organization) can also reduce uncertainties in the construction process and raise productivity (Thuesen and Hvam, 2011). Furthermore, a process based on standardized sequences facilitates learning and experience feedback, and increases opportunities to improve the constructability of designs (Jansson et al., 2014).

A key element when developing platforms is the decomposition of a complex system/product into more manageable modules: essential and independent functional units with standardized interfaces and interactions that allow composition of products by combination (Baldwin and Clark, 2000). In addition to creating product variety by interchangeability, modularization is used to decrease the difficulty of design tasks. Dividing a product into modules makes it easier to understand and allows independent and parallel design work on different parts of the product (Elgaard and Miller 1998). The modularization of products and processes also opens possibilities to introduce more industrialized methods, i.e., prefabrication. Nevertheless, little attention has been paid to process modularization and configuration, although they are essential steps to raise productivity (the main reason for adopting platforms in construction).

Configurable product and process platforms have been developed in manufacturing industry to increase the flexibility of products offered to customers (e.g. Robertson and Ulrich, 1998). While platforms increase the product and process variety in mass-producing industries, the introduction of platforms in project-based industries such as construction has the opposite effect. The primary motive for developing platforms in construction is to increase productivity by reducing the variety of both products and processes in construction projects (Haug et al., 2009). In addition, mass-production industries mostly operate in a make-to-order or assemble-to-order supply chain, where the product design, production process, and supply chain parameters are at least already largely present for all possible configurations when customer orders arrive (Winch, 2003). In contrast, (industrialized) construction companies mostly operate in an engineer-to-order context, in which most of the product design, production process, and supply chain parameters are still undefined when a client order arrives (Johnsson, 2013; Gosling and Naim, 2009). Thus, optimizing the balance between pre-definitions (standardization) and leaving parts and processes open for customization in specific projects is crucial for construction companies developing platforms (Haug et al., 2009) and industrialized methods.

While industrialized house manufacturers mainly operates in private sectors, the studied infrastructure sector operates in a sector that is dominated by a strong public client, which put additional pressure on customize products and processes in setting where the client manage the diffusion phase. Harryson (2002) suggest that a new process for industrialized products in the infrastructure sector is needed involving increased integration between stakeholders but little attention has been paid to the challenges related to the public client.

# 3 RESEARCH METHODS

*This chapter presents my research journey and the research process, followed by the research strategy. The conducted studies are then described and finally the research is evaluated.*

## 3.1 Research journey and project

I have a professional background as a production manager at a prefabrication supplier producing concrete structures for houses and facilities. This, and my educational background (a MSc. in industrialized production, where continuously increasing productivity and introducing innovations in competitive markets are major routine goals) led me to believe that prefabrication and other industrialized methods were important components of projects in all parts of the construction industry. My research journey started in 2010 (Figure 3) when I became a Ph.D. student and member of Luleå University of Technology's Structural Engineering group.

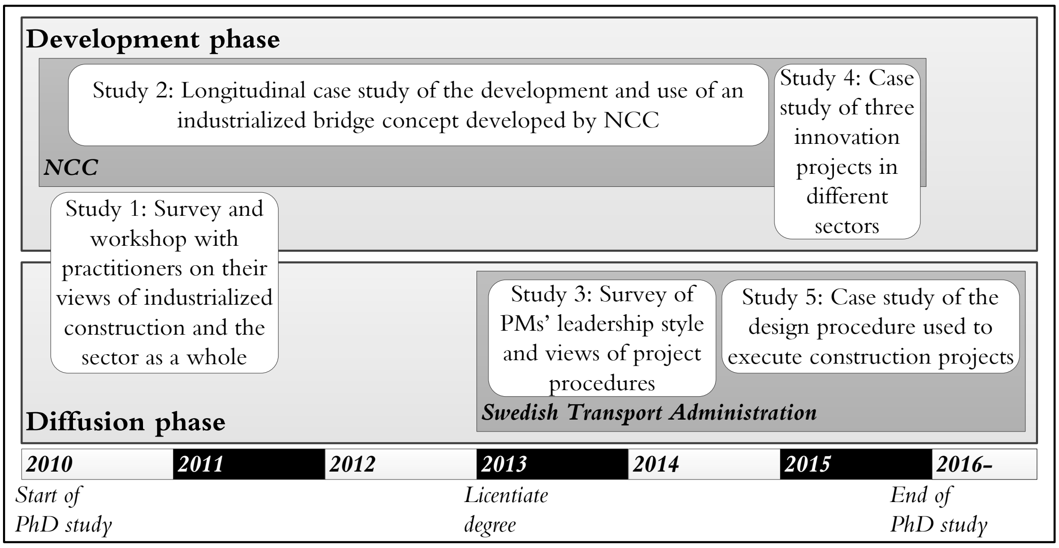


*Figure 3 Studies during my research journey related to development and diffusion phases of the innovation process*

My first research project was a case study of the development of "a new industrialized concrete bridge" involving both prefabrication and modern on-site construction methods. The project was supported by

Svenska Byggbranschens Utvecklingsfond (SBUF, the development fund of the Swedish construction industry) and the case organization was NCC.

However, discussions with contractors and suppliers during the initial stage of my research journey made me realize that my assumption that industrialized construction was common in the construction industry was not valid for the Swedish infrastructure sector. Consequently, a first study (hereafter Study 1) was conducted to explore industry actors' views of industrialized construction and the future of the infrastructure sector. The study involved a survey with a complementary follow-up workshop. It provided a comprehensive view of the innovation process, addressing issues in both the development and diffusion phases, and inspiration for the rest of the research journey.

Furthermore, the findings prompted a shift from the initial purpose of the research project to a more exploratory approach focusing on managerial issues rather than technical barriers for the introduction of industrialized concrete bridges. Industrialized construction has been analysed from an innovation perspective as it is a new and unexplored concept within the infrastructure sector that requires extensive changes throughout the supply-chain. After receiving a licentiate degree in the beginning of 2013, the reorientation of my research prompted me to join the Construction Engineering and Management group at the Luleå University of Technology. With my broad view of the industry in mind, I decided that two major aspects required detailed exploration: the *development* of industrialized construction, and management of its *diffusion*.

Due to the established relationship with NCC, the *development* phase has been explored in a continuation of my initial SBUF project, (Study 2). NCC has been a suitable case organization during my research project since it is a major contractor that is active in industrialized construction within both the infrastructure and housing sectors. The longitudinal data acquired have contributed both rich and comprehensive knowledge about the development phase and the kinds of challenges contractors face when attempting to introduce industrialized construction in the project-based infrastructure sector. The last study addressing the development phase (Study 4) reflects the width of my research approach. In collaboration with staff involved in Luleå University of Technology's research on Product Innovation, the overall purpose was to explore how project-based organizations develop innovations (particularly in this study innovative production). Management of the development of innovative production methods, to increase competitiveness, has been studied and analysed through a multiple case study of innovation projects in three organizations (including NCC) operating in different project-based industries.

The second major aspect addressed in my doctoral research, *diffusion* of radical innovations, has been explored by studying how STA manages construction projects, for two reasons. This was because the client was identified in Study 1 as a main factor hindering increased diffusion of industrialized construction and STA is the largest public client of infrastructure products in Sweden. Thus, a research project (financed by STA) was initiated to explore barriers associated with procedures undertaken during construction projects soon after I became a licentiate. Information obtained from preliminary unstructured interviews with project managers at STA and a systematic literature review on leadership was used to guide a larger survey of project managers' attitudes towards project procedures and their style of leadership in connection to project performance (Study 3). The results of Study 3 revealed that project managers feel that the standardized procedure used by STA is intricate and comprehensive and raises difficulties, especially in small projects.

The findings from Study 3 subsequently provided foundations for a research project (Study 5) financed by BBT, which is part of a long-term research and innovation program initiated by STA to increase industrialization throughout the supply-chain (Trafikverket, 2012). Study 5 is still on-going and the purpose is to explore how the standardized design procedure used by STA in construction projects affects the productivity and the diffusion of innovations such as industrialized construction.

As this brief summary shows, my research journey has been far from linear and the research approach has been broad. The broad approach and the close connection with the industry during my journey have been essential for achieving the overall research goals, but it has to some extent made the result rather scattered.

My supervisors and I share the same broad curiosity, an exploratory approach was deemed appropriate for addressing the phenomena of interest, and the foci have shifted during the course of the research. Thus, the studies have provided indications of numerous facets of innovation and its management in the construction industry. Some of these indications are tentative and require further investigation. However, the research approach has also contributed broader knowledge and a more comprehensive understanding of the system of managing innovations in the project-based infrastructure sector. I have also applied both qualitative and quantitative research methods during my research journey, which has improved my preparation for life as a researcher since I view my Ph.D. study as a beginning rather than an end.

## 3.2 Research strategy and design

Research not only provides insights regarding the field of study, but also offers constant opportunities to hone methodology. Thus, the research strategy applied has emerged throughout my doctoral studies rather than following a pre-set sequence. As noted by Abowitz and Toole (2009), people play vital roles in many aspects of construction, such as leadership, innovation and planning, thus construction research requires proper application of social science research methods. They further note that there is no single ideal research method in social research and that every method has inherent strengths and weaknesses. For these reasons mixed methods, including both qualitative techniques (case studies) and quantitative techniques (surveys), have been applied. This strategy has proved to be highly suitable for the rather broad and exploratory purpose of increasing understanding of the management of radical innovations in the infrastructure sector. Yin (2013) suggests that use of mixed methods permit more complex research questions to be addressed and richer data to be collected than a single method can provide alone. Mixing qualitative and quantitative methods also allows the researcher to combine research strategies with complementary strengths and weaknesses.

Case studies are beneficial in fields that are still in an exploratory stage, since they facilitate analyses of intricate behaviour in natural settings and comprehensive studies of problems (Edmondson and

McManus, 2007). Since general characteristics of innovation processes include uncertainty, complexity, diversity and interdependence (Boer and During, 2001), especially in contexts where radical innovations are rare, case studies have been conducted since they can capture rich data and identify new aspects and phenomena (Eisenhardt, 1989; Yin, 2013). However, case studies' ability to provide deep understanding of a specific research field is also their primary weakness since they do not allow the researcher to extend findings beyond the studied context or draw statistically valid conclusions about wider populations.

In contrast, quantitative techniques such as surveys allow the collection of large amounts of information from a population, but only on topics that can be self-reported (Abowitz and Toole, 2009). While qualitative methods are used to extend general theories (Yin, 2013), a quantitative study enables statistical generalizations and thus can be used to confirm and strengthen suggested relationships between theoretical factors (Hair et al., 2006). Quantitative surveys have been used to test relationships in two of the studies, and rigorous statistical analysis in Study 3 allowed the detection of relevant relationships with high degrees of confidence.

To conclude, as Abowitz and Toole (2009) also note, mixed methods are particularly appropriate in fields of construction research involving relationships among individuals and other social factors. This clearly applies to my research since the management of radical innovations developed separately from construction projects involves numerous individuals, interacting in settings that are unfamiliar for them, within a broader culture where there are strong institutional influences.

The five studies underpinning this research, their contributions to the appended papers and their connections to the research questions (RQ) are summarized in Table 1. Briefly, an initial survey (Study 1) was conducted to explore practitioners' view on industrialized construction and the future of the sector. Two case studies (Studies 2 and 4) were subsequently conducted to explore and describe the development phase of the innovation process. Both involved multiple data collection methods, which to some extent allowed triangulation. In addition, the diffusion phase of the innovation process has been examined in both a quantitative survey (Study 3) and an on-going case study (Study 5) of the design procedure used by STA to support realization of construction projects. The conducted quantitative and qualitative studies are briefly presented in the next sections and more extensively described in the appended paper (Papers I-IV).

*Table 1. Summary of studies and their connections to the appended papers and research questions (RQs)*

| *Study* | *Unit of observation* | *Data collection methods* | *Paper* | *RQ* |
|---|---|---|---|---|
| 1 | Practitioners' views and attitudes regarding industrialized construction and the sector as a whole | Survey<br>Workshop | I | RQ 1<br>RQ 2<br>RQ 3 |
| 2 | Development and use of an industrialized bridge concept | Interviews<br>Observations<br>Workshops<br>Document study | II | RQ 1<br>RQ 2 |
| 3 | Project managers at the STA | Survey | III | RQ 3 |
| 4 | Innovation projects at project-based organizations (development phase) | Interviews<br>Observations<br>Document study | IV | RQ 2 |
| 5 | Design procedure used to execute construction projects (diffusion phase) | Document study<br>Interviews<br>Project meetings | | RQ 3 |

### *3.2.1 Study 1*

The purpose of this study was to explore practitioners' views of and attitudes towards industrialized construction and the future of the infrastructure sector. The concept of industrialized construction has been studied by other authors, e.g. Lessing et al. (2015), in the housing industry. However, since the infrastructure sector provides a unique context the approach was exploratory, involving both an essentially qualitative survey and a complementary workshop with practitioners. Study 1 addresses both the development and diffusion phases of the innovation process as exemplified by industrialized construction.

*Sample and data collection*

The data collected through a questionnaire survey targeted a sample consisting of 159 candidate respondents regarded as suitable after discussion with experienced practitioners active in the Swedish infrastructure sector. The sample included clients, consultants, contractors and material suppliers.

A questionnaire was formulated, inspired by prior literature on industrialized construction and off-site construction (Lessing, 2015; Gibb, 2001). Before distribution, the questionnaire was piloted and discussed with several people, both practitioners and academics, in order to minimize misunderstandings and leading questions. The questionnaire was slightly modified after the pilot study. The final questionnaire included 25 questions covering various subjects and aspects (Appendix A). Responses of open-ended questions are more difficult to compile than those of structured questions, but provide richer material. Thus, both closed and open-ended questions were used in an attempt to acquire a general view of the infrastructure sector. The questionnaire was sent to the candidate respondents by email and 61 completed questionnaires were received, representing a response rate of 42 percent.

A workshop attended by contractors, clients, consultants and material suppliers was subsequently held to discuss interesting findings regarding industrialized construction obtained from responses from the survey. Fourteen participants were invited, based on experience, interest and opportunity to influence the development of the Swedish infrastructure sector. For a summary of the workshop, see Appendix B.

*Analysis*

The analysis applied in this study was relatively simple and has been reported in Paper I, which explored aspects such as the respondents' views of core elements and barriers for industrialized construction. The responses to the open-ended questions in the questionnaire were evaluated by qualitative content analysis to categorize answers and make the data more manageable and meaningful (Gibbs, 2002). Coding into categories is essential in qualitative research since it greatly facilitates interpretation of the acquired data. Answers referring to different categories of barriers, or standardization and prefabrication of various parts, were counted to obtain indications of their importance, as perceived by the respondents. The primary focus of Study 1 was to identify categories and patterns regarding the focal phenomena. These patterns subsequently helped to design a quantitative survey undertaken by the Productivity Committee of the Ministry of Enterprise, Energy and Communications, as reported in SOU (2012) and used to strengthen the results reported in Paper I.

### *3.2.2 Study 2*

The initial purpose of Study 2 was to explore effects of an industrialized bridge concept on the on-site construction process. The concept was studied during a construction project and due to fruitful collaboration, I was further involved in the development of the bridge concept until the end of 2014. Study 2 primarily addresses the development phase of the innovation process run by the contractor, but also contributed knowledge of the interaction required between contractors and clients during the diffusion phase.

#### *Case selection and data collection*

The studied industrialized bridge concept developed by NCC includes parts constructed by traditional on-site construction methods and prefabricated parts, thus (in this respect at least) it is a typical, representative example of a modern infrastructure structure. A more detailed description of the concept is provided in Larsson and Simonsson (2012) and Paper II. Industrialized bridge concepts are rare in Sweden and the possibility to obtain rich data due to the involvement of the contractor in the research project further enhanced the concept's suitability as a study object.

The case study started in 2010 with open-ended interviews with the platform manager and examination of technical documents and drawings of the existing bridge concept to gain an understanding of the focal context before the construction project started. Data about the product and process were then collected during a construction project by observing the construction work, interviewing the project manager at the site, and studying project documents such as drawings, calculations, and schedules. The observations during the construction both increased understanding of the concept and provided valuable construction data (from a time study) used in Paper II, Larsson and Simonsson (2012) and Krantz et al. (2015).

After the study of the construction project I soon started to be involved in further development of the bridge concept, consequently the industrialized bridge concept provided the focus of a longitudinal case study of the development and use of industrialized construction that lasted until the end of 2014. The primary data collection methods used during the longitudinal case study are summarized in Table 2.

*Table 2. Summary of data collection methods used in Study 2*

| ***Data sources*** | ***Quantity*** | ***Individuals involved or material examined*** |
|---|---|---|
| Interviews | 2 | Platform manager |
| | 2 | Project manager |
| Existing documents | - | Drawings, technical documents |
| Construction project | - | Calculations, drawings, schedule, cost estimates |
| Observations | 2 weeks | During prefabrication and reinforcement of superstructure |
| Workshops | 2 | Contractor and supplier representatives, consultants, academics |
| Industry seminars | 3 | Consultant, contractor, client and academic representatives |

*Analysis*

All data collected during the longitudinal case study have been transferred into a database for further analysis. However, no structured analysis has been applied to the extensive data at the time of writing.

Data from Study 2 have been used in several conference and journal articles (including Paper II) prepared during various stages of the research project. The data collected from observations of the construction project have been analyzed through value stream mapping (VSM) (Larsson and Simonsson, 2012). VSM is an effective tool for identifying activities at a construction site and mapping manufacturing flows (Alvarez et al., 2009). Values from the VSM have been used in several process simulations (Paper II; Krantz et al., 2015). In Paper II the data collected through various methods were used to analyze the bridge from a modularization perspective and the bridge was consequently mapped into modules.

### *3.2.3 Study 3*

Study 3 was conducted to obtain an understanding of the attitudes of project managers employed by STA towards the current diffusion phase in typical settings in the sector, their ways of managing construction projects, and the diffusion phase of the radical innovation process. Effects of project managers' leadership styles on the performance of a construction project were explored in Paper III, based on a more quantitative part of the survey.

Findings regarding project managers' attitudes towards the current approach for handling the diffusion phase have not been published, but presented to STA and are used in this thesis to inform the discussion. However, the survey data presented in this thesis mostly concern responses to the questions regarding the project managers' leadership styles.

#### *Sample and data collection*

The data were collected via a questionnaire survey targeting a sample consisting of all 213 project managers employed by STA. A questionnaire was initially formulated based on both previous literature and semi-structured interviews with three STA project managers, then slightly modified following a pilot study with a group of five potential respondents. The final questionnaire is presented in Appendix C.

The questionnaire was sent by email to the 213 project managers, who were given two weeks (in December 2013) to complete it. Two reminders were sent out during this time. Since the response rate (63%) was considered insufficient an additional reminder was sent out in January 2014, which further increased it to a level deemed sufficient (87%). Of the 185 questionnaires that were finally received 23 were removed from the final sample because too much information was missing. Thus, 162 completed questionnaires were finally analyzed, representing a response rate of 76%. Since the expressed reason that several respondents declined to participate was lack of time, most non-responses and late responses were probably due to the same reason. Thus, potential non-response bias was assessed by comparing early and late responses (Armstrong and Overton, 1977). No significant differences were found between responses of early respondents (collected in December) and late respondents (collected in January) regarding effects of the independent leadership factors. This suggests that non-response bias did not substantially affect results of this survey study.

*Measurements*

The empirical data presented in this thesis and appended papers concern project managers' leadership styles. To classify their leadership styles, the respondents were asked to answer how well different statements fitted their view of their project leadership style (Table 2 in Paper III) according to a 5-point Likert scale (from 1 = not at all to 5 = very well). Keywords inspired by the four leadership styles (Producer, Administrator, Entrepreneur/Developer, Integrator) suggested by Adizes (1976) were integrated into the 12 items (three for each style).

Respondents were also asked to provide information about the cost, time, and quality, of their last project; the three most frequently used parameters to measure project performance (Westerveld 2003). More specifically, the respondents were asked to make qualitative judgments about how well three statements regarding each of these parameters (Table 2 in Paper III) fitted their view of the performance of their last project, according to a five-point Likert scale (from 1 = not at all to 5 = very well).

In addition to the Likert questions, items on several variables concerning project characteristics (turnover, duration, and contract form) were included and subsequently used in a split sample approach for multivariate regression analysis. Respondents were also asked to state their views of the complexity of their last project (in terms of the number of stakeholders with different interests involved) according to a five-point Likert scale (from 1 = not at all complex to 5 = highly complex). The measurements are further described in Paper III.

*Analysis*

The data were imported into SPSS version 22 software for statistical analysis. Study 3 has been reported in Paper III, where principal component analysis (PCA) was applied to transform information concerning leadership styles (as described by 12 questionnaire items) and project performance measures (nine items) into smaller sets of latent variables (factors) to explore trends in the dataset (Hair et al., 2006). PCA uses all the variance in a data set (in contrast to common factor analysis, which only uses the common variance). Thus, PCA factor solutions are more robust. Varimax rotation was used to maximize independence of the factors from one another (i.e., minimize the correlation amongst them), which is important when factors are subsequently used in multiple regressions (Hair et al., 2006).

Multiple regression analysis was applied to assess the relative influence of the four leadership styles extracted from the factor analysis on project performance. Multiple regressions allow the prediction of a single dependent variable from several independent variables in the same equation (Hair et al., 2006). Split samples were used to explore potential effects of the considered project characteristics on relationships between leadership styles and project performance. The data analysis techniques are described in more detail in Paper III.

### *3.2.4 Study 4*

The purpose of Study 4 was to explore influences on the capability to manage radical production innovation projects in engineer-to-order settings. Thus, factors that influence the capability to manage innovation projects, as identified for instance by Cooper (1999), were explored. The studied innovation projects were all initiated to improve the production process and can consequently be viewed as process innovations. The unit of observation for this study was the innovation process. The study primarily addresses the development phase, but due to the settings in project-based industries the diffusion phase was also indirectly studied. Findings are presented in Paper IV.

#### *Case selection and data collection*

Because settings are likely to be more uncertain and complex for radical innovations than for incremental innovations (Boer and During, 2001), innovations that have caused substantial changes in firms' production processes were studied. Due to the exploratory approach of this research, the criteria for selecting innovation projects were based on the possibility to acquire in-depth data rather than representativeness and breath. Thus, it focused on just three innovation projects, undertaken by different organizations that were strategically chosen since the researchers had unique access to them through their research. The three firms operate in different engineer-to-order industries: aerospace, house building, and bridge construction. I used my contacts at NCC to acquire information in the bridge construction case study.

Data regarding the selected cases were primarily collected through individual in-depth semi-structured interviews. The selected respondents had various roles in the innovation projects, and thus contributed different perspectives. The conducted interviews were semi-structured to obtain rich content, focusing mainly on respondents' perceptions of the innovation process. An interview guide (Appendix 4) based on the aim of the study was used to maintain coherence during the data collection. However, the questions were opened-ended to allow each respondent to formulate answers from their point of view in relation to the given topics (see Paper IV). Departures from the original questions were permitted, hence the format of the interviews was adapted slightly to pursue interesting and particularly relevant data that arose during interviews (Eisenhardt, 1989).

Observations have also been recorded at all three organizations to gain further knowledge about the firms and their contextual settings. Secondary data were collected from publicly available sources, and in some cases internal documentation. Any clarifications required regarding the secondary data were covered during interviews and observations. The data collection methods used in Study 4 are summarized in Table 3.

*Table 3. Summary of data collection methods used in Study 4*

| ***Methods*** | ***Case A*** | ***Case B*** | ***Case C*** |
|---|---|---|---|
| Interviews (Respondents) | Project manager R&D staff | Factory manager | Department manager R&D staff |
| | Business development & marketing manager | Academic representative | Department manager |
| | Production developer | Production manager | |
| | Process Engineer | | |
| | Chief Engineer | | |
| Observations | Regular observations at firm during 2015 as part of a joint research project | Observations at firm including tours of the factory | Regular observations at firm from 2010 to 2015 as part of a joint research project |
| Secondary data | Website | Website | Website |
| | Annual reports | Annual reports | Annual reports |
| | Technical reports | | Technical reports |
| | Presentations | | |

*Analysis*

The initial analytical steps were to summarize responses in the recorded interviews and transfer them into a database for further analysis. They were then subjected to thematic analysis, where the empirical data regarding each question were addressed and categorized into general themes to increase meaningfulness of the information and facilitate management and interpretation of the data (Gibbs, 2002). For example, the success factors drawn from Cooper (1998) and other sources provided a conceptual schema to cluster the empirical data. Within-case analysis was undertaken to find unique patterns from each innovation project (Eisenhardt, 1989). This was then followed by cross-case analysis to find common differentiating characteristics according to the method proposed by Yin (2013).

Triangulation was applied to some extent by using observations and secondary data collected in the case study in addition to the interview data. This allowed me and the co-author (Lisa Larsson) of Paper IV to complement, interpret and to some degree validate the interview data. During the data analysis, iterations between emerging results, theory, and empirical data from the case study were performed to consolidate the developing conclusions (Eisenhardt, 1989; Yin, 2013).

### *3.2.5 Study 5*

The purpose of Study 5, which is on-going, is to explore how the standardized design procedure used by STA affects the diffusion phase of the innovation process. The standardized procedure strongly influences the innovation climate since it steers the design of specifications for procuring contractors. A desire to modify current procedures and increase their adaptability to suit projects with given characteristics was identified in Study 3. Findings from Study 5 have not yet been reported elsewhere as only preliminary results can be revealed as yet.

#### *Case selection and data collection*

This is primarily a retrospective case study of 10 construction projects with different characteristics such as size, project manager, contract type, project complexity and location (selected because variations in studied cases is important for obtaining general understanding of phenomena). Data are being collected primarily through a comprehensive document study, but complementary information will be obtained from semi-structured interviews with project managers and by attending project meetings. At the time of writing, six projects have been briefly studied by examining relevant documents collected via STA's document portal, which is used by both internal and external actors during the execution of construction projects and compiles diverse relevant documents.

#### *Analysis*

The data from the document study have been transferred into a database for further analysis. As yet only preliminary patterns in terms of involved actors and lead times from the multiple case study have been analyzed.

## 3.3 Evaluation of conducted research

Before evaluating the research, the discussion presented in the thesis is outlined. The research questions and empirical data from the studies have been used to frame the considerations and conclusions presented in the discussion chapter, in conjunction with innovation management theory that has emerged during the research process. The findings indicate that such theory must be broad, as it concerns an intricate process involving diverse human agents acting in an unfamiliar and fragmented setting. Industrialized construction is novel to the infrastructure sector and its introduction requires changes in both knowledge and climate of the context, which is essential for developing and diffusing radical innovation.

Preliminary steps taken during the qualitative discussion included categorizing data from the studies in relation to phases and levels of the innovation process. Key themes found in literature (e.g. teams, customer involvement, collaboration) were subsequently used to further discuss the empirical information and relate it to the research questions. The process has involved iterations between empirical data and theory to consolidate the developing conclusions (Eisenhardt, 1989). The discussion and conclusions presented here were validated through continuous meetings with my supervisors and a seminar with my research group.

Measures based on concepts of reliability and validity are widely used to evaluate the quality of both qualitative and quantitative research (Yin, 2013; Golafshani, 2003). Four tests are commonly used to assess the quality of any empirical social research, such as the analyses in Studies 1-5: *reliability, construct validity, internal validity* and *external validity* (Yin, 2013). Some literature suggests that reliability and validity are more appropriate for quantitative studies and terms like credibility, confirmability, dependability and transferability should be applied when evaluating qualitative studies (Guba and Lincoln, 1994). However, since both qualitative and quantitative methods have been applied in my studies, the concepts of reliability and validity are used here, partly to ensure coherence in the evaluation, and partly to avoid unnecessarily pedantic semantic considerations.

### *3.3.1 Research quality – qualitative studies*

Exploratory case studies such as those underlying this thesis, can be difficult to judge in terms of research quality (Yin, 2013). However, several procedures have been applied in attempts to ensure that the research adequately meets the following quality criteria.

*Reliability* refers to replicability, i.e. the degree to which different researchers studying the same cases with the same purpose would obtain the same results (Yin, 2013). To improve reliability, databases for each of the case studies have been established, containing documents, field notes, reports and information such as guidelines for each set of conducted interviews. A comprehensive case study protocol was also drafted for Study 2, and all activities monitored during observations of the construction project in the study were documented in a log, which has been used in analysis of the construction process in several articles (Paper II; Larsson and Simonsson, 2012; Krantz et al., 2015). This documentation allows me (or other researchers) to perform further analyses of the collected data if desired (Yin, 2013). In addition, all interviews were recorded to enable investigator triangulation (Patton, 2005).

*Construct validity* in a qualitative study, sometimes known as trustworthiness, refers to the degree to which descriptions of phenomena by a researcher reflect the studied phenomena, i.e. how well the findings correspond with reality (Flick, 2009). The protocol and databases established in this research to increase reliability should also have promoted construct validity. Another way to increase construct validity is to employ multiple data sources, thereby allowing findings to be tested and corroborated (or refuted) by data triangulation (Patton, 2005). Hence, multiple data sources (interviews, documents and observations) have been used in the two completed case studies (Studies 2 and 4), and in Study 1, where both a qualitative survey with open-ended questions and a workshop were conducted. In the on-going case study (Study 5) only documents have been studied as yet, but the intention is to complement the documentary evidence with information drawn from interviews with the project managers responsible for the studied construction projects.

Moreover, findings from the conducted case studies have been discussed in several industry presentations, workshops and continuous meetings with both representatives of the studied organizations and researchers in my research group to reduce misinterpretations of the data. Subjectivity and the indications of bias become most important when applying a qualitative research approach (Yin, 2013). However, my position in a workplace where experienced academics and practitioners critically analyze research work and collaborate with researchers with related interests, such as Product innovation, should have helped to reduce such bias. In addition, the research has been validated by publishing findings in peer-reviewed journals and conferences.

*Internal validity* refers to the degree to which identified causal relationships, e.g. how and why event X led to event Y, are valid and is mainly a concern in explanatory case studies. Internal validity is mainly addressed in the analytical phase by pattern matching, i.e. comparing observed patterns with those previously established in other studies (Yin, 2013). Due to the exploratory nature of my research, pattern matching has not been conducted since categories and patterns found needed to be explored rather than explained.

*External validity* refers to the degree to which findings from case studies can be generalized beyond the examined cases (Yin, 2013). No attempt is made to draw statistically significant general conclusions from case studies (unlike analyses in quantitative research), as the samples are too limited. However, all of the case studies presented here have been conducted in similar contextual settings (the infrastructure sector), which is beneficial for external validity since it facilitates detection of patterns and attempts to draw tentatively general conclusions. The multiple case approach used in Study 4, focusing on organizations active in three different engineer-to-order industries, should also have helped strengthen external validity (Eisenhardt, 1989; Yin, 2013). Moreover, both contractor and client perspectives have been addressed in the conducted case studies (and surveys), which could further increase the generalizability of findings regarding the studied phenomenon of radical innovation in the infrastructure sector.

### *3.3.2 Research quality – quantitative studies*

The assessment of *reliability* of the quantitative surveys conducted in Study 3 and (to some extent) Study 1 revealed some flaws related to the fact that the constructs in the questionnaire were, to a large extent, new and untested (Paper III). Reliability here refers to the stability and consistency of results obtained using given measures (in this context, constructs in the questionnaire) (Golafshani, 2003). To increase reliability the questionnaire was formulated using information from both previous literature (e.g. Adizes, 1976; Chang and Ibbs, 2006) and semi-structured interviews with three STA project managers, then slightly modified after a pilot study with a group of five potential respondents. Some of the constructs related to project performance (cost, quality and time) have been previously used (Rönnberg Sjödin et al., 2016). Tests reported in Paper III also showed that Cronbach Alpha values were satisfactory, corroborating the reliability.

The concept of validity in quantitative research refers to the degrees to which it actually measures what it was supposed to measure and the results are truthful (Golafshani, 2003). *Construct validity* refers to how well focal variables have been measured. It may have been initially low in Study 3, due to the use of new constructs, but should have increase following the pre-testing. In addition, the keywords used in new items were all chosen after an extensive literature review conducted before the questionnaire was developed.

*Internal validity* is the extent to which variables really causing the results are measured (Hair et al., 2006). Thus, in addition to the selected independent variables (leadership styles), effects of well-established control variables (experience, age, gender) on the dependent variables (project performance parameters) were also examined in Study 3.

*External validity* refers to the possibility of generalizing results to populations beyond the studied sample, which heavily depends on sample size in relation to the total sampled population and response rate. The survey in Study 3 targeted all 213 project managers employed by STA. The large sample size, together with a rather high rate of usable responses (76 percent), enhances the theoretical validity of extending statistically significant findings to populations beyond the sample. Thus, although there are also many project managers working for independent consultancy firms, the sample should provide adequate representation of the project manager population in the Swedish infrastructure sector.

# 4 SUMMARY OF FINDINGS

*This chapter presents the main findings from each of the five conducted studies relevant to the research purpose.*

## 4.1 Findings from Study 1

This first study included both a survey and a workshop, and provided greater understanding of industrialized construction in the infrastructure sector, which has received little attention. This is deemed a significant contribution as better knowledge of core elements of, and barriers hindering, industrialized construction (as perceived by professional stakeholders) can help foster broader awareness of possible ways to implement industrialized construction. The empirical findings from this study can be divided into two groups: a set concerning drivers for industrialization, and another concerning core elements of and barriers to diffusion of industrialized infrastructure construction.

According to the empirical data, the main drivers for industrialization in the infrastructure sector are the demands for cost and time reductions and increased competition from foreign contractors and suppliers. New norms and rules make it easier for foreign firms to compete for contracts in infrastructure projects in Sweden. According to findings from the workshop this is forcing Swedish contractors and suppliers to adopt both product and process innovations, such as greater industrialization, to survive in a more global and competitive market.

Study 1 revealed that the industrialization strategy is multi-faceted and that the respondents regard standardization of both products and processes as the main elements. Further, findings from Study 1 revealed five other important elements that should be included in the concept of industrialized construction: prefabrication, automation, continuous improvement, integrated design and production, and planning for efficient production (Figure 4).

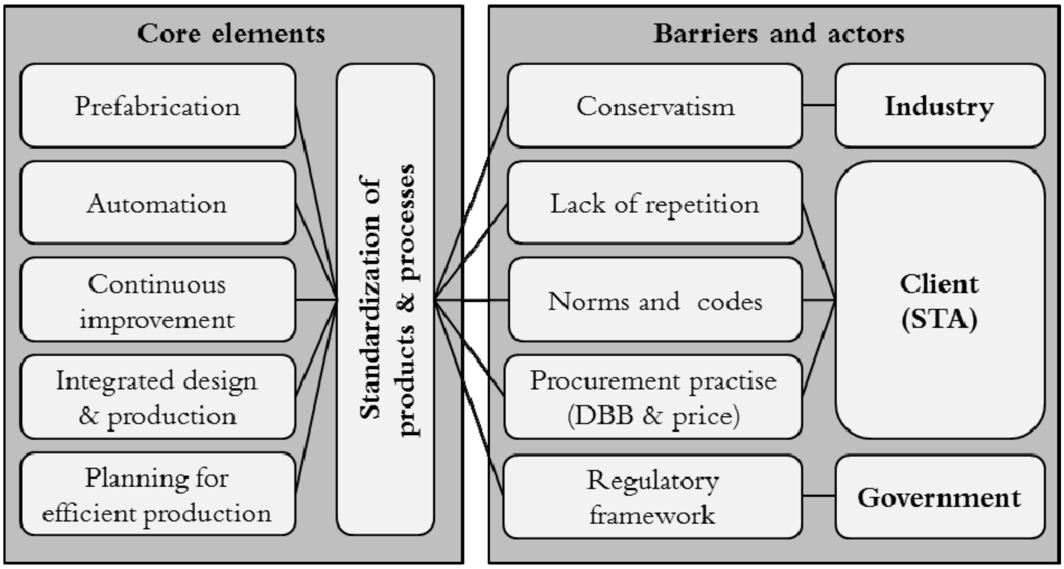


*Figure 4. The main perceived barriers (process and product) hindering increased industrialization of infrastructure construction, their relationships to the core elements, and the actors who could reduce them (from Paper I)*

Three out of five barriers for industrialized construction identified in Study 1 (lack of repetition, norms and rules, and procurement practices) are affected by STA procedures and management, which raised interest in further investigation of their roles within the innovation process. The conservatism of both people and regulations was identified as an important barrier, raising questions regarding the management of change in the sector, and the strength of institutional factors. Further findings about the main perceived barriers impeding increased industrialization, their relationships to the core elements, and stakeholders who strongly influence them, are presented in Paper I.

Study 1 also revealed that small bridges are seen as suitable products for standardization in the infrastructure sector, and components such as beams and the superstructure are suitable for standardization and prefabrication. These conclusions provided vital input for Study 2.

## 4.2 Findings from Study 2

The initial purpose of Study 2 was to explore effects of the industrialization of a product (small concrete bridge) on the on-site construction process (Larsson and Simonsson, 2012). The study started in 2010 as a case study of a construction project, but it has since become a longitudinal study of the development of industrialized bridge concepts, involving workshops, interviews, industry presentations and participation in development meetings. As a participant in meetings I perceived increased knowledge about the challenges of developing innovations in the infrastructure sector. Study 2 primarily addresses the internal development phase managed by the contractor, but also contributed to an increased understanding of the challenges involved in the diffusion (both internal and external) of industrialized products in the infrastructure sector.

During the longitudinal study the focal industrialized bridge concept has also been used for other purposes, such as exploring the modularization concept. The introduction of manufacturing principles and standardization of components and processes has been recognized as important for industrialization of the infrastructure sector. Product and process platforms have been promoted as possible enablers of standardization in the sector, and hence benefits including increased productivity. These platforms are based on reusable modules, with standardized interfaces that allow both interchangeability and customization. The industrialized bridge concept was used in Paper II to test the utility of database-driven discrete-event simulation for evaluating configurations generated using product (*dp*) and process (*pv*) platforms in industrialized infrastructure construction (Figure 5).

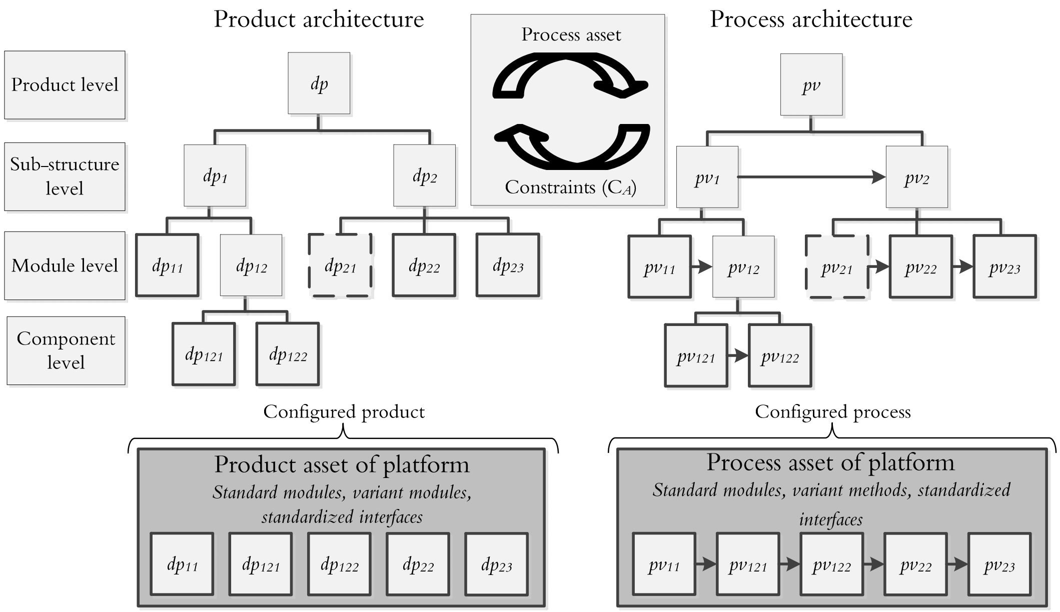


*Figure 5. Performance evaluation of configured product and process platforms (from Paper II)*

During workshops with the contractor and main supplier the product design was decomposed into physical modules and components. The product architecture was subsequently matched with a process architecture composed of activities required for constructing the superstructure. Findings reported in Paper II show that viewing construction as a manufacturing process with a clearly definable process architecture increases opportunities to build simulation models that are configurable, customizable and reusable for multiple scenarios and construction projects. Hence, the platform concept allows the introduction of database-driven DES systems that interpret the dynamic interdependencies and interactions between planned construction tasks in order to evaluate overall performance. The focus on engineering solutions in early design stages contributes to large variations in the construction process, which increases the difficulty of planning tasks and risks of errors due to the specific peculiarities connected to on-site construction. Hence, estimates of the "quality" of a developed schedule are generally based on experience. The proposed approach allows more robust assessments, taking into account variations in the workers' productivity, the supply chain capacities and uncertainties related to the construction site. As shown in Krantz et al. (2015), the same simulation model also has potential utility for assessing embodied energy and greenhouse gas emissions, which is increasingly important during the development and planning of construction projects.

Data from the initial case study conducted in 2010 have been used as input for the simulations described in both Paper II and Krantz et al. (2015). Both papers contribute to the understanding of the utility of database-driven DES for evaluating and developing product and process platforms in the project-based construction industry, thereby helping both managers and researchers to improve systems for planning projects, and reduce the major uncertainties that exacerbate scheduling problems and cost overruns.

To conclude, platforms based on modules can help efforts to develop industrialized bridge construction by simplifying the product and process architecture. Their use enables data-base driven DES evaluation during both the development and diffusion of innovations, and hence the planning of construction projects. Overall, this longitudinal study of the industrialized bridge concept has contributed to increased understanding of the development and to some extent the diffusion of innovations in the infrastructure sector. The concept involves both product and process innovation, thus it is a highly suitable study object for addressing the research questions and meeting the overall research purpose.

## 4.3 Findings from Study 3

The purpose of Study 3 was to explore project managers' attitudes to the current standardized design procedure, effects of their leadership styles on project performance, and the diffusion into construction projects of the radical innovation process. How project managers' leadership styles affect the performance of a construction project was reported in Paper III. The project manager is involved throughout the entire construction project and thus has a comprehensive overview of, and impact on, all stages of the assigned project, from the initial feasibility study and early design through procurement, construction work, and handover of the completed structures to the maintenance department. Hence, characteristics of project managers, particularly their leadership styles, may be critical project success factors, but there are uncertainties regarding how they influence projects' success. Thus, in the study the respondents were classified into groups with four leadership styles (producer, administrator, developer and integrator).

Empirical findings reported in Paper III confirm that leadership style should be regarded as a critical success factor that strongly influences project performance in terms of cost, time, and quality criteria. The results further highlight the importance of an appropriate contingency perspective, in terms of four project characteristics: complexity, burn rate, duration, and type of contract. The results indicate that rapid projects with high time pressures (burn rates) should be managed by project managers who can be characterized as either producers or integrators, whereas complex projects (with numerous involved actors) should be managed by integrators. Moreover, developers perform better in design-build projects than in design-bid-build projects. These findings also indicate that experienced project managers should be appointed to projects with high organizational complexity to increase chances of satisfactory project performance.

Study 3 also investigated respondents' attitudes towards the standardized design procedure that currently controls construction projects in Sweden. The project managers were asked to answer open-ended questions about both positive and negative aspects of the procedure (Appendix C). The findings revealed that their attitudes towards the current standardized procedure were generally negative, and the most frequently mentioned disliked aspects were its intricacy, extensiveness, and greater suitability for large than for small construction projects. These findings were some of the motives for the on-going study of the standardized design procedure (Study 5).

Construction projects involve uncertain sequences of activities, both planned and unplanned, performed to meet objectives that are often (but not always) strictly defined. Thus, the project manager plays crucial roles, often setting the ground rules and fostering a collective approach that strongly influences project performance. The construction industry is highly heterogeneous and project characteristics vary substantially in terms of size, complexity, customization, and time pressure. Thus, understanding effects of different leadership styles on performance in projects with different characteristics is vital.

To conclude, the findings reveal that the project manager strongly affects the outcome of construction projects, and hence the diffusion phase of the innovation process. Further, results regarding the contingency perspective indicate that the project manager may also affect the degree of innovation in construction projects. Innovation processes are often characterized as uncertain and complex, indicating that integrators should be suitable for innovative projects.

### 4.4 Findings from Study 4

The purpose of Study 4 was to explore how innovation projects are handled in different engineer-to-order industries. For this purpose, both the development and diffusion phases of three innovation projects initiated to improve production processes (and thus deliver process innovations) were investigated, and the findings are presented in Paper IV. Findings from Study 4 add knowledge regarding influential factors for managing radical innovation in engineer-to-order industries, and interactive effects on firms' capabilities to be innovative in their production development. Strong and engaged key individuals proved to be essential for enabling the innovations. However, the right people and partners have to be available at the right time in the innovation process. For example, an idea generator is often important in the early development phase, but can be devastating during the diffusion of process innovation, when the project shifts from creative and flexible stages towards stricter more controlled stages in which changes lead to cost and time overruns. This is extremely important in process innovation, where internal acceptance is needed for an innovation to be successful.

Diffusion of innovations that are process related, such as production innovations, can be particularly difficult due to the required adaption of many internal functions. This increases the incentives to involve cross-functional teams during their execution. Involving a cross-functional team has proven to increase the possibility of internal acceptance of innovations, thereby facilitating their diffusion.

A difficulty observed in the studied cases is that the process innovations have also resulted in changes or restricts in the products offered to customers. This is often the case in engineer-to-order industries since they produce one-piece, complex products diffused in project-based arrangements. When a change of a product offer spins from production development rather than product development, the required market and customer involvement might not be present. This can lead to barriers in diffusion into markets that often treat radical innovations cautiously. Early customer involvement is therefore important to enhance market pull by the receiver, even when innovations are primarily intended to improve production processes and diffused internally. Findings from Study 4 indicate that certain aspects of the studied process innovations need specific attention, especially since they entail changes or restrict in the product offer that directly affect the customer in industries where the customer has a strong position.

## 4.5 Findings from Study 5

The purpose of the on-going Study 5 is to investigate the standardized design procedure used by STA, and its effects on the diffusion phase. It is based on retrospective analysis of infrastructure projects, focusing on the early design procedure since this is where most of the limitations for contractors to be innovative are imposed. As already mentioned, the study was prompted by a desire (identified in Study 3) to modify current procedures and increase their adaptability to suit projects with given characteristics. Findings from study 5 have not yet been reported elsewhere because only preliminary results can be revealed as yet. However, the preliminary findings show that the diffusion of innovations in the infrastructure sector is strongly affected by clients' procurement procedures. STA therefore has a unique opportunity to promote increases in productivity and degrees of innovation in the infrastructure sector. STA, in response, has increased the share of design-build contracts it awards, in order to reduce the time spent on early design of technical solutions in-house before procuring contractors and hence increasing possibilities for innovations.

Study 5 has also revealed that more attention to organizing and structuring functional requirements, rather than technical solutions, is needed. However, in addition, the preliminary findings show that the standardized design procedure used by STA hinders innovations since it demands the performance of certain activities before the contractor is procured, even in a design-build contract. The standardized design procedure currently used by STA involves eight major stages, each with a gate between them. Figure 6 illustrates preliminary results from the six projects studied to date, and durations from a design-build project involving a short road section and two small bridges with a turnover of approximately 200 million Swedish Krona (SEK). It also shows the main actors involved in the different stages of a design-build project. Since Study 5 focuses on procedures until construction starts, the construction times are irrelevant and not included. The first stage of the design procedure (analyze project potential) is performed before the investment department enters the project and is thus beyond the scope of Study 5.

| Planning the project | Establish specifications and procure designer | Early design | Establish specifications and procure contractor | Detail design and prepare for construction | Construct | Inspect and approve product | Finish project |
|---|---|---|---|---|---|---|---|
| 2 months | 1 month | 25 months | 15 months | 3 months | | | |
| -Project manager (PM)<br>-Internal specialists | -PM<br>-Purchaser | -PM<br>-Internal specialists<br>-Design consultant<br>-County admin. board | -PM<br>-Purchaser | -PM<br>-Contractor<br>-Design consultant | -PM<br>-Contractor<br>-Design consultant | -PM<br>-Inspector<br>-Contractor | -PM |

*Figure 6. Construction project with schedule times and main actors involved in indicated phases*

The findings show that much of the design work is performed before the contractor enters the construction project. Specifications used when procuring the contractor are often extensive and include demands on technical solutions. Several causes for this have been identified during Study 5. First, the lengthy early design phase in itself imposes limitations since numerous actors are involved, and they often demand the inclusion of specific activities that are important for them. For example, the contractor is never signed before the project has been approved by the relevant county administrative board (Länsstyrelsen). This restricts the contractor since county administrative boards often demand preliminary drawings to enable them to study environmental effects and approve the solution.

Another cause is that technical consultants involved in the design phase usually use proven solutions due to the lack of incentives for change and (perhaps) the strict regulations applied in the infrastructure sector. Functional requirements, often stated to contribute to innovation possibilities, often become technical solutions before the contractor is involved.

The findings also reveal some variations in the activities and documentation leading to the specifications. These variations are often related to the people involved in the process. Preliminary results from Study 5 reveal that project managers often modify the design procedure, for instance, by finding their own ways of undertaking essential activities and documenting progress. This corroborates findings from Study 3 that project managers are key individuals in construction projects.

Preliminary findings from Study 5 increase the justification to develop an adaptable design procedure that eases the workload of project managers and increases opportunities both to enhance diffusion of innovations and raise productivity. They also confirm that the extensive standardized design procedure used by STA restricts possibilities to introduce new solutions in later stages of construction projects.

# 5 DISCUSSION

*This chapter discusses results from the research studies and appended papers in relation to previous theory. It starts by framing the findings in terms of the radical innovation process, and then discusses conclusions regarding the research purpose and posed research questions.*

The overall purpose of the research underlying this thesis has been to increase understanding of the management of radical innovations in the infrastructure sector, as manifested by industrialized construction. To obtain a comprehensive view, both of the core (development and diffusion) phases of the innovation process have been addressed. The five studies (Figure 7) conducted during the course of the research have jointly helped fulfil the research purpose. Study 1 can be viewed to some extent as the point of departure for the rest of the conducted studies, and set the tone for this exploratory research on innovation processes in the infrastructure sector, which have received little previous attention.

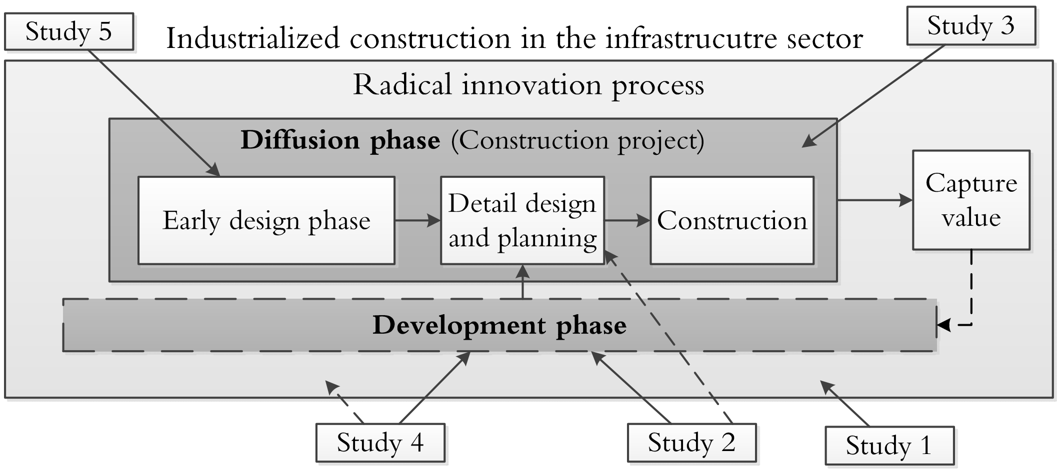


*Figure 7. Schematic illustration of the radical innovation process in the infrastructure sector*

## 5.1 Industrialized construction in the infrastructure sector

The cumulative result from the studies support the comprehensive and multi-faceted view of industrialized construction, proposed for instance by Lessing et al. (2015). Many of the elements/constructs identified in

Study 1 (e.g. standardization, continuous improvement and prefabrication) are also in line with previous literature. The comprehensiveness of industrialized construction is rather high, which complicates its development and diffusion since multiple stakeholders throughout the supply-chain have to collaborate. This research further indicates that in a mature sector such as infrastructure construction, where typical features include conservatism, a lack of incentives to change and a strong public client, introducing industrialized construction could be especially difficult.

However, the facts that STA has expressed the will and taken action to increase innovations such as industrialized construction in the infrastructure sector should increase incentives for collaboration between stakeholders, e.g., contractors, suppliers and consultants, in order to move towards a more standardized production strategy (Thuesen and Hvam, 2011). Several studies underpinning this thesis indicates that collaboration is needed for integrating design and production, which has been promoted as an important step to enhance knowledge flow and transfer in industrialized construction (Lessing et al., 2015). However, challenge found for contractors in the infrastructure sector is that they cannot control the whole process because public clients often manage the diffusion phase. This is a significant difference from the house building sector, where manufacturers often control the entire process (Lessing et al., 2015), which facilitates creation of an innovative climate involving openness and collaboration.

Nonetheless, some authors, e.g. Larsson et al. (2012) and Simonsson (2011), have found that introducing industrialized production methods in the infrastructure sector strongly increases productivity of the on-site construction process. It can also transform difficult on-site activities (often requiring extensive knowledge) into standardized assembly tasks. The importance of simplifying on-site construction as a driver for introducing industrialized construction also correlates well with findings from Study 1 where practitioners' belief that complex and time-consuming structures such as bridges' superstructures are most suitable for standardization and prefabrication.

To meet ever-increasing demands for product customization in manufacturing industries, configurable product and process platforms have been developed to increase the flexibility of products offered to customers, as described for example by Robertson and Ulrich (1998). Platforms have also gained increasing interest in industrialized house building, mostly focused on product modularity and configuration (Haug et al., 2009; Jensen et al., 2012). However, the main motive for implementing industrialized construction is to increase productivity by reducing the variety of both products and processes in construction projects, so the construction process must also be considered. The introduction of standardization in terms of platforms and modularization is explored in Paper II. Paper II shows that implementation of module-based platforms not only facilitates for increased productivity, but also customization to meet project-specific requirements. Thus, Study 2 shows that modularization simplifies provision of the balance between standardization and flexibility, which is vital for platforms in the construction industry (Haug et al., 2009; Jensen et al., 2015).

Rigorous testing and evaluation are routine steps in the development of new technologies and products in manufacturing industries (Rothwell, 1992), but results from conducted studies shows that empirical testing is difficult in the infrastructure sector because the structures are large, complex, expensive and embedded in project-based arrangements. However, Study 2 shows that the introduction of manufacturing principles, such as standardization, also facilitates use of process simulation in construction. The use of database-driven discrete event simulation for evaluating construction processes during both the development phase and planning of the diffusion phase is a possibility explored in Paper II and Krantz et al. (2015). This type of process evaluation could assist to reduce clients' uncertainties, which are often claimed to hamper uptake of innovations in the construction industry (e.g. Pries and Janzen, 1995).

Nonetheless, findings from Study 1 reveal that the infrastructure sector is highly conservative, so any shift from a short-term project focus to a long-term process focus (which is required for increasing industrialized construction) will take time. Furthermore, due to the multi-faceted, comprehensive nature of industrialized construction, changes throughout the supply-chain are needed. Thus, it must be regarded and treated as a radical innovation and strategically developed.

## 5.2 Radical innovation in the infrastructure sector

This research, and statements from the STA, indicates that increasing the rate of industrialized construction could be an appropriate strategy to address the problem of low productivity in the infrastructure sector. However, Study 2 and 4 shows that managing the development and diffusion of radical innovations, such as industrialized construction, is challenging, and rather different from managing the more historically common incremental innovations that typically occur within construction projects (Slaughter, 1998; Nam and Tatum, 1997; Blayse and Manley, 2004). The entire innovation process involved in incremental innovations is often managed by the same stakeholder, which simplifies the frequently intricate diffusion phase. In the infrastructure sector, this stakeholder is often STA, as the major public client in Sweden.

The cumulative findings from studies (e.g. 1, 3 and 5) however reveal that one of the main reasons that the radical innovation process substantially differs from the incremental innovation process is that there is a clear separation between the development and diffusion phases (Figure 8).

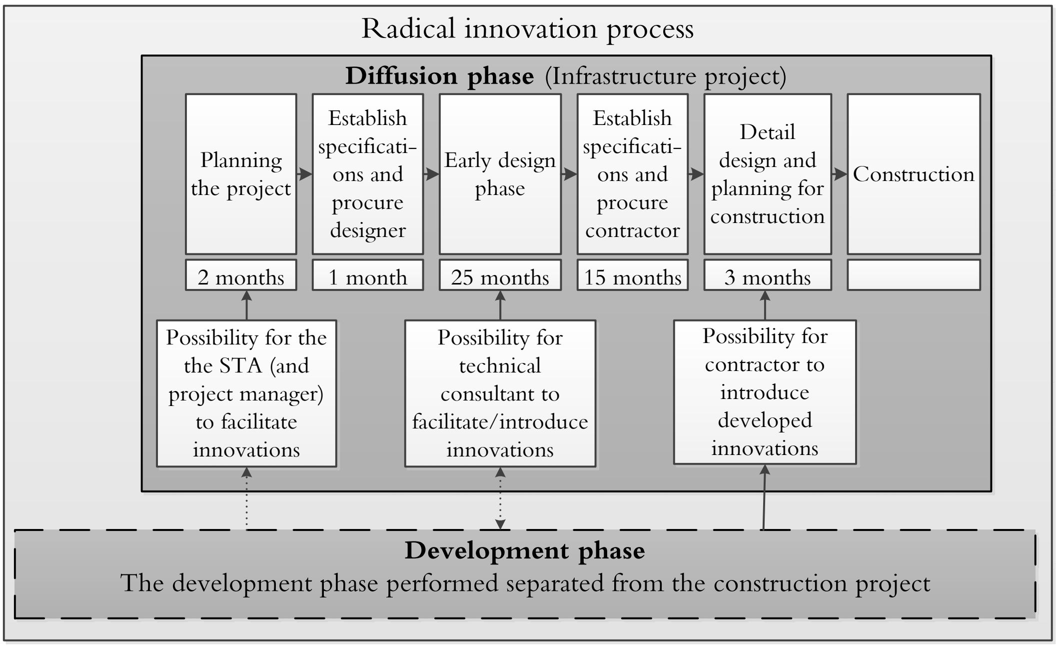


*Figure 8. Construction process in relation to possibilities to introduce innovations*

Study 4 indicates that this separation between the two phases is a distinctive feature of project-based industries with heavy reliance on public clients. Major stakeholders, e.g. contractors, undertake the development phase in innovation projects separated from construction projects. The diffusion phase in the studied radical innovation process has been initiated by the (public) client and Study 4 indicates that it is managed as a rather strict linear process where the contractor enters late. Studies underpinning this research however reveal that these two separated phases are largely intertwined and affects each other in numerous ways.

The client is an important promoter of construction innovation generally, according to previous literature (e.g. Winch, 1998; Blayse and Manley, 2004), and in the Swedish infrastructure sector according to findings of the research presented here. Considering the radical innovation process in the Swedish infrastructure sector as a whole (Figure 8), as the main public client STA must be regarded as the often required problem owner due to its strong position and government-assigned task of creating conditions to improve productivity and innovation in the infrastructure sector. Furthermore, Study 1 shows that STA controls identified barriers (e.g. regulations and procurement practices) making the diffusion of industrialized construction more difficult.

Consequently, the situation in the infrastructure sector where the client manages a strict linear process during the diffusion phase from initiation to completion poses challenges for diffusion of innovations. Study 5 reveals that the diffusion phase could be regarded as an innovation process by itself, since it starts with planning (*pre-development*), followed by a design sub-phase in which a unique product is often *developed* and subsequently *diffused* in construction projects to *capture value*. This structure of the diffusion phase creates conditions that hamper diffusion of more radical innovations, developed by the contractor.

Because these construction projects become highly formalized at early stages and are strictly regulated by linear project management principles they do not provide a context that promotes innovation. The diffusion phase has been shown in Study 5 to be strictly controlled by a standardized design procedure, including a stage-gate process that imposes a rather formalized process from the start. High formalization and linear project management in early stages of an innovation process have been identified as two aspects hampering the openness needed for generating ideas and realizing innovations (Boer and During, 2001; Keegan and Turner, 2002).

Furthermore, the same standardized design procedure, with the same gates, is applied for all type of infrastructure projects (diffusion phase) to ensure that essential activities are conducted and essential documents are produced. Hence, the early design phase in infrastructure project tends to be extensive and involves multiple stakeholders, such as technical consultants, internal specialists and the county administrative board (Figure 8). Study 5 indicates that due to the extensiveness of the design procedure, project managers often modify mandatory activities and documents, as they adjust the process to maintain the required workflow in relatively small, routine projects. The adjustments made by the project managers increase challenges for contractors since the specifications that are the outcome of the early design phase, and used during procurement of contractors, vary depending on the project manager.

The contractor often enters the diffusion phase when functional requirements have already been transferred into technical solutions, even in design-build contracts. Viewing the innovation process from a knowledge perspective (Figure 8), the required design knowledge is available early in the diffusion phase while process knowledge, often possessed by the contractor, is absent. This indicates that the need for the right knowledge at the right time, which is required to obtain satisfactory outcomes from innovations according to Boer and During (2001) is not met, hindering the productivity improvements desired by STA. This lack of production knowledge during the early design phase could also at least partly explain the present focus on incremental product innovations in the infrastructure sector.

The product focus and lack of production knowledge in the early design phase could also hamper the diffusion of industrialized construction since it involves process-based increases in productivity, and hence requires extended process knowledge (Lessing et al., 2015). Thus, creating suitable conditions for fruitful interaction between the client and the contractor is a key challenge to address in order to facilitate diffusion of industrialized construction. This conclusion supports claims by Pries and Janszen (1995) that in a mature industry characterized as conservative (like the infrastructure construction industry; Study 1), changes in both organizational capabilities and the industry climate are often necessary for diffusion of radical innovations. Several factors facilitating or hampering the management of radical innovations have been identified in this research. These factors strongly affect the outcome of the innovation process and can be divided into two main sets, described below: *capabilities for innovation management* and *institutional factors*.

### *5.2.1 Capabilities for innovation management*

Three categories of capabilities for successful innovation management discussed in previous literature have been explored in this research: *teams, senior management commitment,* and *involvement of outside parties* (Blindenbach-Driessen and van den Ende, 2006). These capabilities have been frequently identified in industries where the development and diffusion phases are managed by the same stakeholder, which is not the case in the infrastructure sector. With this in mind, the research reveals that from a systems perspective some capabilities have not been adequately addressed either in the development or diffusion phase.

The *teams* in both phases of the innovation process were identified (Study 2, 4 and 5) as having a product-oriented approach in early stages. Required design knowledge was present in both the development team and the team involved in diffusion during early stages, but a lack of representation of production staff (and hence production knowledge) was identified. The lack of production knowledge hinders the introduction of process-related innovations such as industrialized construction that are intended to raise productivity.

Study 4 suggests that this lack of production knowledge during development varies between different engineer-to-order industries. Organisations operating in industries such as industrialized house building and aerospace are more used to performing development projects since they are vital for survival in a highly competitive market. Study 2 and 4 indicates that development projects in the infrastructure sector are performed in close relation, and with the same knowledge as construction projects which is in line with what Gann and Salter (2000) found in their study. Study 4 shows that especially the case within aerospace developed their process innovation in a distinct R&D department with specific allocated resources. An explanation for the lack of suitable knowledge in the infrastructure sector could be that construction companies that are active in mature sectors such as infrastructure are not traditionally used to performing development projects and most resources are invested in realizing construction projects. Gann and Salter (2000) even suggest that the right knowledge could be missing internally, and appropriate networks may not be formed since there are major differences in performing these two types of projects (development projects and construction projects), and hence different kinds of knowledge are required. This could also be an possible explanation to why some required knowledge (such as production) was not present in either early development phase, or during the planning of the diffusion phase (construction projects) in the conducted studies (Study 2 and 4) of the infrastructure setor.

Study 3 and 5 identified a lack of production knowledge also in the project team responsible for early design stages of the diffusion phase at STA, leads to a focus on the product rather than its realization at site. Hence, it could be suggested that productivity is not the primary focus for measuring project success at STA. A properly assembled project team with representatives from a wide range of functions is often seen as important not only from a knowledge perspective but also for acquiring the internal acceptance required for successful diffusion of process innovations (Tidd and Bessant, 2014).

*Senior management commitment* is important for the creation of a suitable team (Tatum, 1987), as senior managers are needed to release suitable personnel from their day to day activities. Study 4 indicates that senior management influences the outcome of projects through resource allocation, but there are more important factors that often compensate for lack of senior management commitment. The lack (to some extent) of senior management commitment found in Study 4 could be due to the focus on business projects and the fact that investment in development requires an appropriate strategy, which has been identified as an important aspect for successful innovations (Blayse and Manley, 2004; Cooper, 1998).

Several of the conducted studies have highlighted the fact that innovation is essentially a human activity (Boer and During, 2001) and key individuals within the team have been needed in difficult times. In the development phase of the innovation process, a strong project manager has been apparent in all cases considered in Study 4. In two of the cases, the presence of a strong and devoted project manager has helped overcome weaknesses in other influential factors.

However, the right people and partners have to be available at the right time in the innovation process (Robert and Fusfeld, 1981). Study 4 indicates, for instance, that an idea generator is important in early stages, but devastating during the internal implementation and external diffusion phases of innovation. In the diffusion phase, the project shifts from a creative and flexible stage towards a more formally structured stage, in which new ideas beyond the specified scope will cause changes to the established process, and hence both cost and time overruns.

Consideration of the overall innovation process in the infrastructure sector (Figure 8) reveals that two key actors have major abilities to facilitate or even introduce innovations into the process before the contractor enters: the *project manager* assigned to the project and the *technical consultant* responsible for the early design.

The *project manager* employed by STA enters at the beginning of the process and can facilitate innovations during the planning of the project. Findings from several of the conducted studies highlight the importance of the project manager during the innovation process. Study 3 reveals that the project managers assigned to execute construction projects have large possibilities to influence the diffusion efficiency. This further highlights the dependency of innovations on people (Boer and During, 2001) and the importance of suitable project management by the project manager for the adoption of innovations in construction (Murphy et al., 2011). Empirical findings from Study 3 further reveal that a contingency perspective has to be implemented since different styles of leadership are suitable for projects with different characteristics. Due to his/her pivotal importance, the project manager must be treated as the champion from an innovation perspective. This further emphasizes the need to choose a suitable project manager to promote the diffusion of innovations.

The *technical consultant* procured to run the early design phase has the ability to facilitate and even introduce innovations into the process. Study 5 indicates that most of the conditions facilitating innovation are composed during the extensive early design phase and the focus during this phase should be on creating functional requirements rather than, as currently, technical solutions.

*Involving outside parties* in the development phase of innovations performed separately from construction projects is crucial due to the structure of the innovation process. Approaching the client in the early development phase is essential to increase the awareness and market pull required to introduce innovations. In all studied cases (in both Studies 2 and 4) the development phase has been triggered by a possibility to increase productivity of the production process, i.e. process innovation. However, the developer (contractor in the construction industry) seems unaware that the process innovation often, but not always (Tatum, 1987), becomes a product innovation for the client. An innovation that is triggered by the possibility to improve the construction process is the introduction of prefabricated solutions. Prefabricated solutions are a major component in industrialized construction (e.g. Study 1, Lessing, 2015) but have been difficult to diffuse in the infrastructure sector. In such cases, because the intended process innovation leads to changes or even restrictions in the possible product offered to customers the developer must enable both internal and external diffusion.

The external diffusion phase is often simplified by early client involvement in development, but the client has not been appropriately addressed in any of the studied cases from the infrastructure sector. Boer and During (2001) found that this is often the case in industries where there is little experience of product innovation. This explanation together with the fact that, as a public client, STA has to follow the public procurement act (LOU) could to some extent hamper the involvement of customers during the development phase. Nevertheless, findings from Studies 2 and 4 indicate that there have been difficulties in convincing the client of the superiority of the developed innovations and to create the market pull required to increase incentives for development.

The consultant responsible for the early design also has the ability to facilitate and introduce innovations (Study 5 and Figure 8). This implies that the contractor could increase the chance of introducing innovations by collaborating with external designers (and other stakeholders) during the development phase. However, external collaboration is a two-edged sword: it is often needed to supply the increased and/or new knowledge needed to develop radical innovations, but it raises risks of unintended outflows of knowledge, which could severely impair contractors' ability to compete. Thus, trust is essential when establishing collaborations (Bosch, 2009). Nevertheless, the lack of a stable external network based on trust was indicated in Study 4, and further findings indicated that collaboration is mostly internal in the studied engineer-to-order industries during the development phase.

### *5.2.2 Institutional factors affecting innovation management*

As the largest public infrastructure client in Sweden, STA has unique potential to influence the Swedish infrastructure sector, not only by setting norms and regulations, but also through its choices of contract forms and project requirements. Study 1 confirmed that institutional factors such as procurement practices and regulations strongly influence the innovative climate in the infrastructure sector, as noted by (for instance) Kadefors (1995) and Pries and Janzen (1995). Pries and Janszen (1995) even argue that the role of technical regulations in construction is so dominant that contractors must produce not to satisfy their clients, but to meet the strict regulations. This is also shown in Study 1 and combined with the strong position of the client, largely uniformed demands arises, hampering major innovation initiatives. These factors tempt contractors to focus more on internal processes for competitive advantage than on satisfying the client since the competition becomes mainly cost-based (Tatum, 1987; Pries and Janzen, 1995).

The organizational structure of STA also contributes to the short-term and cost-based focus within the infrastructure sector. Study 5 reveals that STA separates its investment department from its operation and maintenance department. The separation of their budgets increases the focus on initial costs and hampers diffusion of innovations that are based on long-term life-cycle cost considerations. This contributes to the focus on initial costs that occurs within large parts of the construction industry, according to (for example) Pries and Janzen (1995), and respondents in Study 1.

## 5.3 Fulfilment of the research purpose

The purpose of the research this thesis is based upon has been to increase understanding of managing radical innovations in the infrastructure sector as manifested by industrialized construction. Three research questions were posed to guide the rather broad and exploratory investigations undertaken to fulfil the research purpose. The main findings from the research and their relations to the research questions are summarized in Table 4.

*Table 4. Summary of findings in relation to the posed research questions (RQ)*

| |
|---|
| ***RQ 1: How is industrialized construction, as a radical innovation, received?*** |
| - It is a multi-faceted and comprehensive concept that involves and affects multiple stakeholders in the supply-chain and needs to be strategically managed |
| - Industrialized construction, as a radical innovation, put preassure on changed industry climate since it currently are percieved as consevative and involves a strong public client that strictly manage the diffusion phase |
| - Integration of design and production is important from a supply-chain perspective but difficult to achieve due to the separation between development (in development projects) and diffusion (in construction projects) |
| - While focus is on increased productivity by standardization (process innovations), it also causes changes, or even resricts, in the product offered to clients and therefore includes both an internal and an external acceptance |
| ***RQ 2: How could the development phase be managed to facilitate diffusion?*** |
| - Increased external collaboration is needed to increase the knowledge base |
| - Client involvement in development is needed to increase awareness and market-pull of innovations developed separated from construction projects |
| - Internal collaboration is needed to increase the required internal acceptance |
| ***RQ 3: How is the diffusion phase managed and what challenges can be identified?*** |
| - The process is controlled and formalized from the start, which restricts chances to introduce radical innovations that needs openness and collaboration |
| - Actors such as project managers and technical consultants have an important role to facilitate innovativeness and performance in projects |
| - An early focus on technical solutions hamper process innovations that could facilitate the needed increase in productivity |
| - The standardized design procedure is comprehensive and hampers the essential project flow in day-to-day projects |

# 6 CONCLUSIONS

*This chapter presents theoretical and practical research contributions, followed by limitations of the research and suggestions for further investigations.*

Instead of a project perspective, the kinds of radical innovation studied in the research underpinning this thesis demand a more comprehensive approach to realize effectively and a general perspective to analyse. Considering industrialized construction as a radical innovation reveals that the innovation process in the infrastructure sector involves a clear separation between a development phase and a diffusion phase.

Industrialized construction requires changes throughout the supply-chain since it involves both product and process changes, and this research confirms previous suggestions, e.g. by Lessing (2015) and Gann (1996), that it provides a possible way to improve the low productivity in construction. The research further offers an important contribution to the literature on industrialized construction in the infrastructure sector by highlighting the comprehensiveness of the multi-faceted concept of industrialized construction. Both core elements and barriers to diffusion are identified. Radical innovations, in which the two main phases of the innovation process are separated, are often needed to trigger change in mature industries such as the infrastructure sector.

A contractor perspective was initially adopted in the research, focusing primarily on the development of industrialized construction methods for the infrastructure sector. However, findings from my early studies revealed major client-related challenges during the diffusion phase. This highlighted the need for suitable connections between the development and diffusion phases for innovations to succeed. Thus, it has been essential to address both main phases of the innovation process since they are separated but highly intertwined. This research provides greater understanding of the management of radical innovations in the infrastructure sector and the following two sections highlight the theoretical contributions and managerial implications.

## 6.1 Theoretical contributions

The main theoretical contribution of this thesis is the extension of construction innovation analysis beyond the level of individual construction projects. Most innovations in construction have previously been incremental and project-level (Pries and Janzen, 1995; Winch, 1998), while radical innovations involving multiple stakeholders throughout the supply-chain have been scarce. This research increases understanding of the clear separation between the development and diffusion phases of more radical innovations, such as industrialized construction, and the challenges they raise. This separation is especially evident in sectors where public clients manage the diffusion phase, such as construction projects in the infrastructure sector.

Ways to manage innovation processes have been extensively studied in traditional manufacturing industries (Tidd and Bessant, 2013), where the same organisation often manages the whole process, but they have received relatively little attention within construction. In construction, and other project-based industries, the interaction between the developer (e.g. contractor) and client is more intense throughout the process and an understanding of each other's perspectives is needed. Management of these innovation processes in the public-based infrastructure sector also differs from that in (for instance) house building, where industrialized house manufacturers often control and manage both the development and diffusion phases.

Ways to successfully manage innovation processes have been previously considered in various contexts, for example, by Cooper (1998), Pellicer et al. (2014) and Rothwell (1992), but sparsely explored in project-based industries. Thus, another contribution of this research is the identification of certain capabilities that appear to be important for successful innovations in these industries. Two aspects that are especially evident are the exceptionally strong position of the public client and the engineer-to-order structure of the process. The ways contractors manage the development process and clients manage the diffusion phase (in construction projects) have major consequences for chances of introducing innovations such as industrialized construction. Thus, this research both contributes to general construction management literature and highlights some distinctive aspects of the infrastructure sector.

Due to the project-based setting, construction management literature has focused on ways to execute individual construction projects successfully, and hence short-term efficiency. Factors influencing success have been frequently considered, e.g. by Chua et al. (1999), Songer and Molenaar (1997) and Ibbs et al. (2003). However, success factors that have not been previously considered are characteristics of the project manager, particularly his/her leadership style. This research suggests that leadership style should be added to the list of known success factors since the quantitative survey of project managers', employed at STA, shows that it has major effects on project performance parameters (and prospects for introducing innovation).

## 6.2 Managerial implications

This research presents various aspects of the radical innovation process and emphasizes the challenges of diffusing innovations in the current industry climate. A more comprehensive understanding of the system should increase the ability of stakeholders to make correct long-term decisions. STA, as the major public client, has already taken some initiatives to facilitate the diffusion of innovations such as industrialized construction, both by initiating a long-term research and innovation program and by increasing the rate of design-build contracts.

From a client perspective it is important to understand that unique project-specific products often result in low productivity and if the purpose is to increase the rate of innovation such as industrialized construction the way clients manage the diffusion phase must change. The client has a strong position in the radical innovation process, and hence must act as the problem owner (enabler) and create incentives for the contractor to develop innovations such as industrialized construction. More active engagement by the client would increase the required market-pull and facilitate increases in the rate of innovation.

This research further reveals that regardless of the type of contract used in construction projects, changes in the standardized project procedure are needed to promote increases in the diffusion of innovation. The standardized design procedure that governs construction projects often contributes to the formulation of strict procurement documents that restrict possibilities for contractors to introduce innovations. Further, due to the variety in projects configurable design processes are required to meet specific requirements of projects. Introducing a system that can be readily adapted to fit projects with different characteristics could both ease the workload of project managers and promote creation of a more innovative climate.

Two actors (project manager and consultant) have been identified as having major opportunities to affect the diffusion of innovations. The project manager is the most important individual due to his/her involvement and strong position during the whole diffusion phase. The consultant responsible for the early design process enters early in the diffusion phase, when there are major possibilities to affect the project. Hence they are important individuals in terms of the ability to create opportunities for innovation, and their roles must be addressed by the contractor (or other innovation developer) as early as possible in the development phase to promote and increase understanding of innovations.

Further managerial implications related to the development phase are that industrialization involves more than prefabrication. The multi-faceted analysis shows that a change throughout the supply-chain is needed to facilitate for increased rate of industrialized construction. However, introducing elements of industrialized construction, such as modularization, has proven to be challenging since the client is used to procuring unique products tailored to fit project-specific needs. Two important aspects for successful innovation management are the availability of key individuals and suitably engaging the client in the development phase.

This research indicates that the development phase is highly dependent on key individuals and availability of the right individuals at the right time of the process. Strong individuals, such as project managers acting as champions, are vital for driving the development of innovations. This could be partly because of the lack of familiarity with the development of innovations outside construction projects in the sector, and thus the need for individuals capable of driving their development in difficult periods.

The contractor has to understand that intended process innovations, such as prefabrication, often restrict, or at least change, the products that can be offered to clients. Thus, including the client in the development phase is often crucial since the client has to understand that benefits of industrialized construction are more related to processes, i.e. increasing productivity, than products. This is a change in focus since the project-based infrastructure sector has previously focused on achieving product improvements within individual construction projects.

## 6.3 Limitations and suggestions for further research

A Ph.D. project is inevitably limited in time and scope, which affects both the research methods that can be applied and findings. The broad purpose of increasing understanding of managing radical innovation in the Swedish infrastructure sector inevitably imposed limitations in the depth of the research. However, due to the scarcity of relevant previous research an exploratory approach seemed appropriate. In this final section of the thesis, limitations and suggestions for further research are discussed.

The first identified limitation of the research is that some barriers noted in Study 1 have not been studied in depth. These are related to previously identified institutional factors (Kadefors, 1995; Pries and Janzen, 1995). For example, effects of the strict regulations in the infrastructure sector on the diffusion of radical innovations have not been adequately addressed. I assume that these often technical regulations have to be addressed in the development phase and, if properly addressed then, they should have less importance during the diffusion phase. The technical norms and regulations are currently under revision and further studies should assess their effects on the innovation process as a whole when the revision is finished. Another institutional factor that has not been adequately addressed is STA's procurement strategy. A major research effort is required to analyze its effects on the rate of innovations in the infrastructure sector, and could provide highly illuminating insights.

The research has also paid limited attention to organizational structure, which strongly influences relevant organizational capabilities of both the innovation developer and the client. Preliminary findings indicate that STA's organizational structure promotes a focus on price in the sector, by dividing investment and maintenance into two departments with separate budgets. However, further research is needed to identify optimal organizational structures for both the innovation developer and client.

Further knowledge of the identified limitations is needed to fully address all aspects of the innovation system present in the infrastructure sector and create a model for successful innovation management. Such a model would help the sector to boost its current low productivity and innovation rate. Due to the purpose of increase understanding, an exploratory approach has been applied in this research, so the creation and validation of a model would require more quantitative, explanatory studies and consideration of the roles of more actors, such as suppliers and technical consultants responsible for the important early design.

Findings from this research could serve as input for addressing innovation in various other sectors, especially those where public clients are involved since there are often distinctive interactions between clients and producers in such cases. Finally, there is an increasing trend towards customization and findings from this research could also provide inspiration for further research into industries that move towards project-based settings where clients enter early in the design process (Gann and Salter, 2000).

## REFERENCES

Abowitz, D. A., and Toole, T. M. (2009). Mixed method research: Fundamental issues of design, validity, and reliability in construction research. *Journal of Construction Engineering and Management*, 136(1), 108-116.

Adizes, I. (1976). Mismanagement styles. *California Management Review*, 19(2), 5–20.

Alashwal, A. M., Rahman, H. A., and Beksin, A. M. (2011). Knowledge sharing in a fragmented construction industry: On the hindsight. *Scientific Research and Essays*, 6(7), 1530-1536.

Álvarez, R., Calvo, R., Peña, M. M., and Domingo, R. (2009). Redesigning an assembly line through lean manufacturing tools. *The International Journal of Advanced Manufacturing Technology*, 43(9-10), 949-958.

da CL Alves, T., and Tsao, C. C. (2007). Lean construction - 2000 to 2006. *Lean Construction Journal*, 46.

Armstrong, J. S., and Overton, T. S. (1977). Estimating nonresponse bias in mail surveys. *Journal of Marketing Research*, 396-402.

Atkin, B. (2014). Industrialized building. *Construction Management and Economics*, 32(1-2), 1-6.

Baldwin, C. Y., and Clark, K. B. (2000). *Design rules: The power of modularity*, MIT Press, Cambridge.

Bertelsen, S. (2004). Lean Construction: Where are we and how to Proceed. *Lean Construction Journal*, 1(1), 46-69.

Björnfot, A., and Stehn, L. (2007). Value delivery through product offers: A lean leap in multi-storey timber housing construction. *Lean Construction Journal*, 3(1), 33-45.

Blayse, A. M., and Manley, K. (2004). Key influences on construction innovation. *Construction Innovation*, 4(3), 143-154.

Blindenbach-Driessen, F., and Van Den Ende, J. (2006). Innovation in project-based firms: The context dependency of success factors. *Research Policy*, 35(4), 545-561.

Boer, H., and During, W. E. (2001). Innovation, what innovation? A comparison between product, process and organisational innovation. *International Journal of Technology Management*, 22(1-3), 83-107.

Bosch-Sijtsema, P. M., & Postma, T. J. (2009). Cooperative Innovation Projects: Capabilities and Governance Mechanisms*. *Journal of Product Innovation Management*, 26(1), 58-70.

Brege, S., Stehn, L., and Nord, T. (2014). Business models in industrialized building of multi-storey houses. *Construction Management and Economics*, 32(1-2), 208-226.

Brown, S. L., and Eisenhardt, K. M. (1995). Product development: Past research, present findings, and future directions. *Academy of Management Review*, 20(2), 343-378.

Bönte, W., and Keilbach, M. (2005). Concubinage or marriage? Informal and formal cooperations for innovation. *International Journal of Industrial Organization*, 23(3), 279-302.

Caerteling, J. S., Di Benedetto, C. A., Dorée, A. G., Halman, J. I., and Song, M. (2011). RETRACTED: Technology development projects in road infrastructure: The relevance of government championing behavior. *Technovation*, 31(5-6), 270-283.

Cantarelli, C. C., Molin, E. J., Van Wee, B., and Flyvbjerg, B. (2012). Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases. *Transport Policy*, 22, 49-56.

Chang, A. S., and Ibbs, W. (2006). System model for analyzing design productivity. *Journal of Management in Engineering*, 22(1), 27-34.

Chua, D. K. H., Kog, Y. C., and Loh, P. K. (1999). Critical success factors for different project objectives. *Journal of Construction Engineering and Management*, 125(3), 142-150.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 128-152.

Cooper, R. G. (1994). New products: the factors that drive success. *International Marketing Review*, 11(1), 60-76.

Cooper, R. G. (1998). Benchmarking new product performance: results of the best practices study. *European Management Journal*, 16(1), 1-17.

Cooper, R. G. (1999). The invisible success factors in product innovation. *Journal of Product Innovation Management*, 16(2), 115-133.

Cooper, R. G., Edgett, S. J., and Kleinschmidt, E. J. (2004). Benchmarking best NPD practices-II. *Research Technology Management*, 47(3), 50.

Daft, R. L. (1978). A dual-core model of organizational innovation. *Academy of Management Journal*, 21(2), 193-210.

Dave, B., and Koskela, L. (2009). Collaborative knowledge management—A construction case study. *Automation in Construction*, 18(7), 894-902.

DiMaggio, P. J., and Powell, W. (1991). *The new institutionalism in organizational analysis*, University of Chicago Press, Chicago.

Dubois, A., and Gadde, L. E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction Management and Economics*, 20(7), 621-631.

Edmondson, A. C., and McManus, S. E. (2007). Methodological fit in management field research. *Academy of Management Review*, 32(4), 1246-1264.

Edquist, C. (1997). *Systems of innovation: technologies, institutions, and organizations*, Cassell Academics, London.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, 14(4), 532-550.

Eriksson, P.E., Szentes, H., Olofsson, T., and Lagerqvist, O. (2011). *Slutrapport – Hinder och Drivkrafter för Industriellt Anläggningbyggande*, (In Swedish). Luleå University of Technology, Luleå, Sweden.

Egan, J. (1998). *Rethinking Construction (the Egan Report)*, Department of the Environment, Transport and the Regions, HMSO, London.

Elgaard, P., and Miller, T. D. (1998). Designing product families. In Design for integration in manufacturing. *Proceedings of the 13th IPS Research Seminar*, Fuglsoe, Denmark.

Fairclough, J. (2002). *Rethinking Construction Innovation and Research: A Review of Government R&D Policies and Practices,* Department for Transport and Local Government Regions (DTLR), London.

Fawcett, S. E., Jones, S. L., and Fawcett, A. M. (2012). Supply chain trust: the catalyst for collaborative innovation. *Business Horizons*, 55(2), 163-178.

Flick, U. (2009). *An introduction to qualitative research*, Sage Publication Ltd.

Flyvbjerg, B., Skamris Holm, M. K., and Buhl, S. L. (2004). What causes cost overrun in transport infrastructure projects?. *Transport Reviews*, 24(1), 3-18.

Gann, D. M. (1996). Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics*, 14(5), 437-450.

Gann, D. M., and Salter, A. J. (2000). Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy*, 29(7), 955-972.

Gibb, A. G. (2001). Standardization and pre-assembly-distinguishing myth from reality using case study research. *Construction Management and Economics*, 19(3), 307-315.

Gibbs, G.R. (2002) *Qualitative Data Analysis*, Open University Press, Milton Keynes.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*, 8(4), 597-606.

Gosling, J., and Naim, M. M. (2009). Engineer-to-order supply chain management: A literature review and research agenda. *International Journal of Production Economics*, 122(2), 741-754.

Guba, E., and Lincoln, Y. (1994). *Competeing Paradigms in Qualitative Research- Handbook of qualitative research*, Sage Publications, Newbury Park, CA, USA.

Hair, J. F., Black, B., Babin, B., Anderson, R. E., and Tatham, R. L. (2006). *Multivariate data analysis,* Prentice–Hall, London, UK.

Harryson, P. (2002). *Industrial Bridge Construction: Merging Development of Process, Productivity and Products with Technical Solutions*, Licentiate thesis. Department of Structural Engineering, Chalmers University of Technology, Göteborg, Sweden.

Hart, S.L. (1997). Beyond greening: strategies for a sustainable world. *Harvard Business Review*, 75(1) 66-77.

Haug, A., Ladeby, K., and Edwards, K. (2009). From engineer-to-order to mass customization. *Management Research News*, 32(7), 633-644.

Hueske, A. K., Endrikat, J., and Guenther, E. (2015). External environment, the innovating organization, and its individuals: A multilevel model for identifying innovation barriers accounting for social uncertainties. *Journal of Engineering and Technology Management*, 35, 45-70.

Höök, M. and Stehn, L. (2008). Applicability of Lean Principles and Practices in Industrialized Housing Production. *Construction management and Economics*, 26(10), 1091-1100.

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). Project delivery systems and project change: Quantitative analysis. *Journal of Construction Engineering and Management*, 129(4), 382-387.

Jansson, G., Johnsson, H., & Engström, D. (2014). Platform use in systems building. *Construction Management and Economics*, 32(1-2), 70-82.

Jantunen, A. (2005). Knowledge-processing capabilities and innovative performance: an empirical study. *European Journal of Innovation Management*, 8(3), 336-349.

Jensen, P., Olofsson, T., and Johnsson, H. (2012). Configuration through the Parameterization of Building Components, *Automation in Construction*, 23, 1-8.

Jiao, J. R., Simpson, T. W., and Siddique, Z. (2007). Product family design and platform-based product development: a state-of-the-art review. *Journal of Intelligent Manufacturing*, 18(1), 5-29.

Johnsson, H. (2013). Production strategies for pre-engineering in house-building: exploring product development platforms. *Construction Management and Economics*, 31(9), 941-958.

Jonsson, H., and Rudberg, M. (2014). Classification of production systems for industrialized building: a production strategy perspective. *Construction Management and Economics*, 32(1-2), 53-69.

Jordan, J., and Lowe, J. (2004). Protecting strategic knowledge: insights from collaborative agreements in the aerospace sector. *Technology Analysis & Strategic Management*, 16(2), 241-259.

Kadefors, A. (1995). Institutions in building projects: implications for flexibility and change. *Scandinavian Journal of Management*, 11(4), 395-408.

Kamar, A. M., Hamid, Z. A., Azman, N. A., and Ahamad, M. S. S. (2011). Industrialized Building System(IBS): Revisiting Issues of Definition and Classification. *International Journal of Emerging Sciences*, 1(2), 120-132.

Keegan, A., and Turner, J. R. (2002). The management of innovation in project-based firms. *Long Range Planning*, 35(4), 367-388.

Krantz, J., Larsson, J., Lu, W., and Olofsson, T. (2015). Assessing Embodied Energy and Greenhouse Gas Emissions in Infrastructure Projects. *Buildings*, 5(4), 1156-1170.

Larson, E. W., and Gobeli, D. H. (1988). Organizing for product development projects. *Journal of Product Innovation Management*, 5(3), 180-190.

Larsson, J., and Simonsson, P. (2012). Decreasing complexity of the on-site construction process using prefabrication: a case study. *Proceedings of the 20th International Group for Lean Construction,* San Diego, USA.

Latham, M. (1994). *Constructing the Team-Final Reports of the Government Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry,* controller of Her Majesty's stationary Office, London, UK.

Lessing, J. (2015). *Industrialised House-Building - Conceptual orientation and strategic perspectives*, Doctoral thesis. Department of Construction Sciences, Lund University, Lund, Sweden.

Lessing, J., Stehn, L., and Ekholm, A. (2015). Industrialised house-building–development and conceptual orientation of the field. *Construction Innovation*, 15(3), 378-399.

Li, Z., Shen, G. Q., and Xue, X. (2014). Critical review of the research on the management of prefabricated construction. *Habitat International*, 43, 240-249.

Liker, J. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill Professional.

Loosemore, M. (2015). Construction Innovation: Fifth Generation Perspective. *Journal of Management in Engineering*, 31(6).

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy*, 31(2), 247-264.

McDermott, C. M., and O'Connor, G. C. (2002). Managing radical innovation: an overview of emergent strategy issues. *Journal of Product Innovation Management*, 19(6), 424-438.

McDonough, E. F. (2000). Investigation of factors contributing to the success of cross-functional teams. *Journal of Product Innovation Management*, 17(3), 221-235.

Menon, A., Jaworski, B. J., and Kohl, A. K. (1997). Product quality: Impact of interdepartmental interactions. *Journal of the Academy of Marketing Science*, 25(3), 187-200.

Murphy, M., Heaney, G., and Perera, S. (2011). A methodology for evaluating construction innovation constraints through project stakeholder competencies and FMEA. *Construction Innovation*, 11(4), 416-440.

Nadim, W., and Goulding, J. S. (2011). Offsite production: a model for building down barriers: A European construction industry perspective. Engineering, *Construction and Architectural Management*, 18(1), 82-101.

Nam, C. H., & Tatum, C. B. (1997). Leaders and champions for construction innovation. *Construction Management and Economics,* 15(3), 259-270.

Olhager, J. (2003). Strategic positioning of the order penetration point. *International Journal of Production Economics*, 85(3), 319-329.

Pan, W., Gibb, A. G., and Dainty, A. R. (2012). Strategies for integrating the use of off-site production technologies in house building. *Journal of Construction Engineering and Management*, 138(11), 1331-1340.

Panuwatwanich, K., Stewart, R. A., and Mohamed, S. (2009). Validation of an empirical model for innovation diffusion in Australian design firms. *Construction Innovation*, 9(4), 449-467.

Patton, M. Q. (2005). *Qualitative research*. John Wiley & Sons.

Pellicer, E., Yepes, V., Correa, C. L., and Alarcón, L. F. (2014). Model for systematic innovation in construction companies. *Journal of Construction Engineering and Management*, 140(4).

Peres, R., Muller, E., and Mahajan, V. (2010). Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing*, 27(2), 91-106.

Pinto, M. B., Pinto, J. K., and Prescott, J. E. (1993). Antecedents and consequences of project team cross-functional cooperation. *Management Science*, 39(10), 1281-1297.

Pries, F., and Janszen, F. (1995). Innovation in the construction industry: the dominant role of the environment. *Construction Management and Economics*, 13(1), 43-51.

Roberts, E. B., and Fusfeld, A. R. (1981). Staffing the innovative technology-based organization. *Sloan Management Review*, 22(3), 19-34.

Robertson, D., & Ulrich, K. (1998). Planning for product platforms. *Sloan Management Review*, 39(4).

Rodríguez, N. G., Pérez, M. J. S., and Gutiérrez, J. A. T. (2008). Can a good organizational climate compensate for a lack of top management commitment to new product development?. *Journal of Business Research*, 61(2), 118-131.

Rolfstam, M., Phillips, W., and Bakker, E. (2011). Public procurement of innovations, diffusion and endogenous institutions. *International Journal of Public Sector Management,* 24(5), 452-468.

Rothwell, R. (1992). Successful industrial innovation: critical factors for the 1990s. *R&D Management*, 22(3), 221-240.

Rothwell, R. (1994). Towards the fifth-generation innovation process. *International Marketing Review*, 11(1), 7-31.

Rönnberg Sjödin, D., Frishammar, J., and Eriksson, P.E. (2016) Managing Uncertainty and Equivocality in Joint Process Development Projects, *Journal of Engineering and Technology Management*, (In Press).

Santa, R., Bretherton, P., Ferrer, M., Soosay, C., and Hyland, P. (2011). The role of cross-functional teams on the alignment between technology innovation effectiveness and operational effectiveness. *International Journal of Technology Management*, 55(1/2), 122-137.

Segerstedt, A., and Olofsson, T. (2010). Supply chains in the construction industry. *Supply Chain Management: An International Journal*, 15(5), 347-353.

Simonsson, P. (2011). *Buildability of Concrete Structures: Processes, Methods and Material, Doctoral thesis*. Department of Civil, Environment and Natural Resources, Luleå University of Technology, Luleå, Sweden.

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, 124(3), 226-231.

Songer, A. D., and Molenaar, K. R. (1997). Project characteristics for successful public-sector design-build. *Journal of Construction Engineering and Management*, 123(1), 34-40.

SOU (2002). *Skärpning Gubbar! Om Kunkurrensen, Kvaliteten, Kostnaderna och Kompetensen i Byggsektorn*, (In Swedish). SOU 2002:115. Byggkommissionen, Stockholm, Sweden.

SOU. (2009). *Återkrav inom Välfärdssystemen - Förslag till Lagstiftning*, (In Swedish). SOU 2009:6, Finansdepartementet, Stockholm, Sweden.

SOU. (2010). *Effektivare planering av vägar och järnvägar*, (In Swedish). SOU 2010:57, Näringsdepartementet, Stockholm, Sweden.

SOU. (2012). *Vägar till Förbättrad Produktivitet och Innovationsgrad i Anläggningsbranschen*, (In Swedish). SOU 2012:39, Produktivitetskommittén, Stockholm, Sweden.

Styhre, A. (2010). The Culture of Complaint in Construction: Affirmative Reflections on its Role and Function. *Construction Management and Economics*, 28(7), 797-803.

Tatum, C. B. (1987). Process of innovation in construction firm. *Journal of Construction Engineering and Management*, 113(4), 648-663.

Taylor, J., and Levitt, R. (2004). Understanding and managing systemic innovation in project-based industries. *Innovations: Project Management Research*, 83-99.

Teicholz, P., Goodrum, P. M., and Haas, C. T. (2001). US construction labor productivity trends, 1970-1998. *Journal of Construction Engineering and Management*, 127(5), 427-429.

Thuesen, C., and Hvam, L. (2011). Efficient on-site construction: learning points from a German platform for housing. *Construction Innovation*, 11(3), 338-355.

Tidd, J., and Bessant, J. (2013). *Managing innovation: integrating technological, managerial organizational change*, John Wiley & Sons, New York, USA.

Trafikverket. (2012). *Trafikverkets Inriktning för Forskning och Innovation 2013-2015*, (In Swedish). Borlänge, Sweden.

Tushman, M., & Nadler, D. (1986). Organizing for innovation. *California Management Review*, 28(3), 74-92.

Westerveld, E. (2003). The Project Excellence Model®: linking success criteria and critical success factors. *International Journal of Project Management*, 21(6), 411-418.

Wheelwright, S. C., and K. Clark. (1992). Creating project plans to focus product development. *Harvard Business Review*, 70(2) 70-82.

Widén, K., Olander, S., and Atkin, B. (2013). Links between successful innovation diffusion and stakeholder engagement. *Journal of Management in Engineering.*

Winch, G.M. (1998). Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, 26(5), 268-279.

Winch, G.M. (2003). Models of Manufacturing and the Construction Process: The Genesis of Re-engineering Construction. *Building Research & Information*, 31(2), 107-118.

Womack, J. P., Jones, D. T., and Roos, D. (2007). *The Machine that Changed the World: The Story of Lean Production*, Free Press, New York, USA.

Yin, R.K. (2013). *Case Study Research: Design and Methods*, Sage, Thousand Oaks, USA.

# Appendices 1-4

**Appendix A: Study 1 – Questionnaire (In Swedish)**

**Appendix B: Study 1 – Workshop questions and summary of results (In Swedish)**

**Appendix C: Study 3 – Questionnaire (In Swedish)**

**Appendix D: Study 4 – Interview guideline (In Swedish)**

I denna enkätundersökning kommer ni som respondenter att svara på frågor som berör brobyggandet i Sverige. Enkäten kommer enbart att användas i forskningssyfte och alla respondenter har möjlighet att svara anonymt. Då ni svarat på enkäten samt sparat era svar sänder ni tillbaka enkäten till samma e-post (johan.ojanen@ltu.se) som ni fick den ifrån. Tack för din medverkan och bidrag till en utveckling mot en hälsosammare och effektivare bro bransch.

| | |
|---|---|
| Namn (frivilligt) | |
| Företag (frivilligt) | |
| Kön (frivilligt) | Kvinna |
| Jobbtitel/arbetsuppgift | |
| Antal år i byggbranschen | >10 år |
| Erfarenhet av platsbyggt | >10 år |
| Erfarenhet av prefab | >10 år |

1. När blir ni delaktiga i ett broprojekt?
   Förstudie

2. Kan du i din yrkesroll påverka och förändra utformningen av ett broprojekt (koncept, konstruktion, tidsaspekt m.m.)?
   Instämmer helt

3. Skulle du vilja kunna påverka mer i utformningen av ett broprojekt, om ja så motivera ditt svar?
   Ja

4. Hur bör en projektering vara utformad för en gynnsam utveckling mot en mer effektiv anläggningsbransch?

5. Vilken har störst ansvar för en snabbare utveckling av brobyggarbranschen, motivera?
   Trafikverket

6. Vilken entreprenadform är vanligast vid ett broprojekt?
   Funktionsentreprenad

7. Har situationen förändrats något under de senaste åren med avseende på entreprenadformen, motivera?
   Instämmer helt

8. Vilken entreprenadform anser du vara mest gynnsam för utvecklingen av anläggningsbranschen, motivera?
   Funktionsentreprenad

9. Vilka brodelar utgör största svårigheterna vid konstruktion av en bro?
   ☐ Ingen uppfattning

10. Vilka brodelar kräver mest arbetsresurser vid byggandet av en bro?
   ☐ Ingen uppfattning

11. Hur tror du att framtidens bro kommer att se ut?
   Platsbyggd

12. Finns det någon/några speciella delar av en bro som du tror passar bättre att prefabricera än andra, motivera?

13. Vilka är de största fördelarna med platsbyggda broar, välj högst tre alternativ?

- ☐ Arbetsmiljö
- ☐ Estetik
- ☐ Kostnad
- ☐ Kvalitet
- ☐ Annat, i så fall vad
- ☐ Logistik
- ☐ Miljöpåver
- ☐ Tidsaspekt

14. Vilka är de största fördelarna med prefabricerade broar, välj högst tre alternativ?

- ☐ Arbetsmiljö
- ☐ Estetik
- ☐ Kostnad
- ☐ Kvalitet
- ☐ Annat, i så fall vad
- ☐ Logistik
- ☐ Miljöpåver
- ☐ Tidsaspekt

15. Vilka är de största nackdelarna med platsbyggda broar, välj högst tre alternativ?

- ☐ Arbetsmiljö
- ☐ Estetik
- ☐ Kostnad
- ☐ Kvalitet
- ☐ Annat, i så fall vad
- ☐ Logistik
- ☐ Miljöpåver
- ☐ Tidsaspekt

16. Vilka är de största nackdelarna med prefabricerade broar, välj högst tre alternativ?

- ☐ Arbetsmiljö
- ☐ Estetik
- ☐ Kostnad
- ☐ Kvalitet
- ☐ Annat, i så fall vad
- ☐ Logistik
- ☐ Miljöpåver
- ☐ Tidsaspekt

17. Vad är de största skillnaderna mellan prefabricerat och platsbyggt?

18. Tror du det är möjligt att standardisera broar eller i alla fall vissa delar, i så fall vilka?

Ja

19. Har anläggningsbranschen förändrats mot ett mer industriellt byggande under de senaste åren, motivera?

Instämmer helt

20. Tror du att anläggningsbranschen kommer att bli mer industrialiserad i framtiden, motivera?

    Instämmer helt

21. Vad anser du är de viktigaste faktorerna vid brobyggande, välj högst tre alternativ samt motivera?

    - ☐ Arbetsmiljö
    - ☐ Estetik
    - ☐ Kostnad
    - ☐ Kvalitet
    - ☐ Logistik
    - ☐ Miljöpåverkan
    - ☐ Tidsaspekt

22. Tycker du att brobyggandet behöver bli mer effektivt?

    Instämmer helt

23. Hur mycket diskuteras filosofier som Lean, Lean Construction, slöseritänkande, ständiga förbättringar inom denna bransch?

    Väldigt mycket

24. Man pratar mycket om att anläggningsbranschen inte har följt effektiviseringen som ägt rum i andra industrier, vad tror du är de största anledningarna till det?

25. Vad behöver förändras för att denna bransch ska bli mer effektiv?

## 1) Vilka komponenter ingår i industriellt tänkande?

Grupp 1

- Upprepning
- Standardisering
- Process (tänka i dessa)
- Planering (effektiv)
- Prefabricering (alla former)
- Partnering
- Logistik
- Effektiva metoder (metodval)
- Ett sätt att tänka
- Tänka hela kedjan

Grupp 2

- Standardiserat arbetssätt
- Många standard arbetssätt ger standardprodukter
- Spårbarhet avseende på tid, plats och person
- Ständiga förbättringar bygger på spårbar
- Modularisering & prefabricering
- Standardisering
- Återanvändning av ex. form

Grupp 3

- Minimera icke värdeskapande arbetstid
- Minska antalet fel
- Minska slöseriet på arbetsplatsen
- Upprepning (projekt till projekt)
- Förbättra processen
- En process med ständiga förbättringar
- Effektivare inköpsprocess
- Produktivitetsutveckling
- Produktutveckling
- Prefabricera komponenter på annan plats

Sammanställning

- Processer är något som förknippas med industriellt tänkande. Att tänka hela kedjan och arbeta med ständiga förbättringar är viktiga aspekter.
- Standardisering av arbetssätt och produkter för att kunna ta del av upprepningseffekter och erfarenhetsåterkoppling är viktigt.
- Att förlägga delar av produktionen till annan plats och arbeta med prefabricering modularisering är även ett viktigt inslag.
- Att kuna spåra produkter för att kunna jobba med att minimera slöserier och fel
- Samarbeta för att uppnå dessa komponenter

## 2a) Vad är kundnöjdhet?

Grupp 1

- Infria förväntan
- Kommunikation (varför & vad)
- Rätt kvalitet
- Spara tid & stress för kunden
- Tillfredställa ett behov

Grupp 2

- Rätt kvalitet
- Rätt tid
- Rätt plats och pris
- Öppna väg tidigt
- Minimera störningar
- Information (för kunden)
- Tillgänglighet av väg (lite underhåll)
- Att minimera störningar

Grupp 3

- Att uppfylla kundens förväntningar
- Minska trafikstörningar under byggtiden
- Korta ner byggtiden
- Införa/öka projekt med ett grönt alt.
- Få ätor kan vara ett incitament på kundnöjdhet
- Funktionell funktion med liten störning

Sammanställning

- Att tillfredställa ett behov hos trafikanten i form av rätt kvalitet, tid, pris och produkt är att infria förväntningarna.
- Om trafikanten dessutom får tillträde till vägen tidigare (förkortad byggtid) och att information (varför & vad) angående störningar finns ökar kundnöjdheten.
- Minimering av störning under byggandet är viktigt för trafikanten.

## 2b) Hur ökar vi den?

Sammanställning

- Dialog (mot kund & mellan aktörer)
- Partnering
- Tydlig kravspecifikation
- Skiljer mellan kund & kund
- Känna kundens kund
- Information
- Samarbete mellan kund och utförare
- Ta med mjuka parametrar ex. trafikstörning vid byggandet i upphandlingen

## 3) Hur skapar vi samarbete tidigare i projekt?

Grupp 1

- Upphandla entreprenör tidigare
- Fler med tidigt men också senare
- Gemensam utveckling
- Alla parter måste få igång samarbete tidigt i projekten
- Prata med varandra
- Bättre geoteknisk utredning i förprojekteringen

Grupp 2

- Att inblandade aktörer lär sig varandras processer
- Sker genom ökad samverkan och tätare möten
- Utveckla moderna entreprenadformer
- Användning av moderna dataverktyg typ BIM, 3D
- Konsulter med längre i processen
- Tätare möten
- Intresserade & involverade parter

Grupp 3

- Vara tydlig i tidigt skede
- Vilken entreprenadform som väljs alternativt ingår i förutsättningarna
- Bra kompetens på båda sidor så att ett bra diskussionsklimat kan etableras
- Förståelse för att utförare och beställare har olika mål men skapa en win-win situation
- Införa "samverkans workshop" i ett tidigt skede i projektet samt uppföljningar kontinuerligt

Sammanställning

- Samarbete bygger på involvering och detta måste etableras tidigt i projektet men även att flera aktörer är med längre i projektet för att lära sig, ex. konsult med i byggskede.
- Möten och workshopar i början på stora projekt för ökad involvering samt uppföljningar kontinuerligt, ex. stage-gate process.
- Att välja en entreprenadform som ger möjlighet för detta är en förutsättning.
- Att förstå varandra och dess process och mål för att skapa en win-win situation.

## 4a) Vilka likheter finns mellan broprojekt och har potential att erfarenhetsåterföras och standardiseras?

Grupp 1

- Allt är jämförbart
- Vägdragning

Grupp 2

- Det mesta utom geoteknik
- Ökad standardisering avseende mått, lättare att använda prefabricering och att återanvända temporära material
- Process
- Servicematerial

Grupp 3

- Standardisera dimensionerna av komponenter i ett projekt med flera likartade broar
- Standardiserad basprocess som kan modifieras med enkla medel
- Brodelar

Sammanställning

- Allt är lika verkar vara ett svar som kan tolkas både på allvar och skoj. Att processen är lika mellan projekt verkar alla vara övertygade om iaf.
- Det som skiljer är mest geoteknik

## 4b) Åtgärder för att bättre kunna utnyttja likheterna

Grupp 1

- För mycket gestaltningskrav, måste tänka igenom krav innan
- Gestaltarna skapar unikhet då de är tidigt med i projekt
- Ta med byggare tidigt tillsammans med gestaltarna
- Tradition

Grupp 2

- Skapa effektivitetsmått så man kan jämföra varandra, utmanar kollegorna i branschen

Grupp 3

- I ett tidigt stadie "förprojektering" sträva efter att broarna blir mer lika
- Specialiserad kompetens för processen så att erfarenheten kan föras vidare i nya projekt

Sammanställning

- För att kunna dra nytta av alla likheter måste gestaltarna få mindre inflyttande och fler aktörer måste bli involverade tidigare.
- Som det är idag är det svårt att jämföra olika alternativ så att skapa ett effektivitetsmått där man väger in alla viktiga aspekter vore idé.
- Processkompetens för ökar erfarenhetsåterföring möjlighet.

## 5) Hur ökar vi förändringsbenägenheten i branschen?

Grupp 1

- Mer tillgänglig tid
- Handla upp på systemhandling
- Planering & samordning
- Tillåt sidoförslag och alt. lösningar
- Kontinuitet för att förstå vinsten
- Serieupphandlingar
- Värdera tid & förslag, inte bara huvudanbud i form av kostnad
- Involvering

Grupp 2

- Kunskap om varandras behov och förutsättningar
- Ökad nåbarhet
- Öppna upp för alternativa lösningar
- TrV sitta närmare projekten
- Det nya måste vara så mycket bättre
- Ska man ändra något i projektet tar det för lång tid (granskning)
- Är dålig på processen
- Standardiserad process inom organisationen vilket underlättar erfarenhetsåterkoppling
- Samarbetsvilja från TrV
- Ökad mängd totalentreprenader

Grupp 3

- En uthållighet och långsiktighet hos beställaren så satsning på utveckling hos entreprenörerna kan ge lönsamhet på sikt
- En högre grad total- & funktionsentreprenader
- Mer positiv inställning hos beställaren att värdera sidoanbud/förslag
- För liten marknad för utveckling
- Andra krav i form av tid & störning från beställare

Sammanställning

- Att förstå att detta inte går snabbt att förändra och att man ser vinning på långsikt är viktigt.
- Hur upphandling och entreprenadformerna är utformade verkar alla vara övertygade om är viktigt. Att inte bara ta priset i beaktning utan värdera ex. tid och störning mer.
- Att ha större förståelse för processen, inte bara sin egen utan hela kedjan. Att få mer tillgänglig tid tidigt för att kunna utforma den bästa lösningen medan låsningarna är få.
- En ökad förståelse och respekt för varandra samt att beställarna är positiva och involverade i projektet ökar dialogen och gör processen smidigare.

## Trafikverket Byggnadsverk Investering

**Enkäten är en del av ett utvecklingsarbete som syftar till att kartlägga och analysera dagens arbetsprocess inom broinvesteringar. Syftet är att identifiera problem och möjligheter som kan finnas i de tidiga skedena inom brobyggandet. Genom att belysa dem är tanken att kunna förenkla och tydliggöra det stöd som NI som projektledare kan behöva under ett projekt och samtidigt öka effektiviteten för genomförandet av nyinvesteringar.**

**Enkäten består av tre delar:**
**Del I. Allmäna frågor kring dig och dagens process inom bro och byggnadsverk**
**Del II. Frågor som specifikt gäller ditt senaste utförda projekt**
**Del III. Åsikter kring Ledningssystemets stöd för Bro och Byggnadsverk**

**Ni som projektledare sitter på en drivande position och har en stor del i hur framgångsrika våra projekt blir, enkäten riktar sig därför enbart till er. Enkäten tar ca 30 minuter att svara på och dina åsikter är väldigt värdefulla för utvecklingen. Dina svar behandlas självklart anonymt.**

### 1. Allmäna frågor kring erfarenhet (år)

**Hur länge har du arbetet inom anläggningsbranschen?**

**Hur länge har du varit projektledare på Trafikverket? (fd. Väg- eller Banverket)**

**Hur gammal är du?**

### 2. Är du man eller kvinna?

### 3. Vilket distrikt tillhör du?

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## Trafikverket Byggnadsverk Investering

### Del I. Allmäna frågor kring dig och dagens process inom bro och b...

**4. Hur väl stämmer nedan påståenden in på arbetssättet inom Trafikverket?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Vi fokuserar på att optimera utnyttjandet av tillgängliga materiella/personella resurser | ○ | ○ | ○ | ○ | ○ |
| 2 Vi jobbar med att bryta ner arbetsuppgifter i mindre enheter för att lättare kunna fördela ut dessa på personer/funktioner | ○ | ○ | ○ | ○ | ○ |
| 3 Vi arbetar med att ständigt effektivisera vårt planerande av materiella/personella resurser | ○ | ○ | ○ | ○ | ○ |
| 4 Vi fokuserar på att förkorta projektets genomloppstid | ○ | ○ | ○ | ○ | ○ |
| 5 Vi arbetar aktivt med att eliminera problem och flaskhalsar i dagens investeringsprocess | ○ | ○ | ○ | ○ | ○ |
| 6 Vi arbetar med att ständigt förbättra våra arbetssätt | ○ | ○ | ○ | ○ | ○ |

Trafikverket Byggnadsverk Investering

**5. Hur väl stämmer nedanstående formuleringar med din projektledarstil?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Jag styr mot konkreta mål och låter medarbetarna själva bestämma hur de ska utföra uppgiften | ○ | ○ | ○ | ○ | ○ |
| 2 Det är viktigare att uppnå snabba resultat än att fundera på hur vi ska uppnå dem | ○ | ○ | ○ | ○ | ○ |
| 3 Jag gillar att ha mycket att göra och fokuserar hellre på nuet än på framtiden | ○ | ○ | ○ | ○ | ○ |
| 4 Jag fokuserar mer på hur mina medarbetare utför en uppgift än resultatet av uppgiften | ○ | ○ | ○ | ○ | ○ |
| 5 Det är viktigt att mina medarbetare har tydliga och strukturerade arbetsuppgifter | ○ | ○ | ○ | ○ | ○ |
| 6 Jag vill ha tydliga system att följa så att projekt flyter på med minsta möjliga störning | ○ | ○ | ○ | ○ | ○ |
| 7 Jag uppmuntrar mina medarbetare till att vara nytänkande och fokusera bortom kortsiktiga mål | ○ | ○ | ○ | ○ | ○ |
| 8 Det är viktigt för mig att ständigt söka nya utmaningar | ○ | ○ | ○ | ○ | ○ |
| 9 Jag vill hellre fokusera på framtida större mål än på verksamhetens löpande krav | ○ | ○ | ○ | ○ | ○ |
| 10 Jag hjälper mina medarbetare att fokusera mot gemensamt uppsatta mål | ○ | ○ | ○ | ○ | ○ |
| 11 Det är viktigt för mig att se till allas olika intressen för att förvandla oss till ett team | ○ | ○ | ○ | ○ | ○ |
| 12 Jag lyssnar på medarbetarnas åsikter och behov för att skapa god arbetsmiljö | ○ | ○ | ○ | ○ | ○ |

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## Trafikverket Byggnadsverk Investering

**6. Hur väl stämmer nedanstående påståenden in på dagens process inom bro och byggnadsverk?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Vi producerar dokumentation som inte efterfrågas eller används | ○ | ○ | ○ | ○ | ○ |
| 2 Ändringar av prioriteringar gör att påbörjade projekt skjuts på framtiden | ○ | ○ | ○ | ○ | ○ |
| 3 Väntan på viktiga projektbeslut är lång | ○ | ○ | ○ | ○ | ○ |
| 4 Intern granskning av handlingar tar lång tid | ○ | ○ | ○ | ○ | ○ |
| 5 Projektledarna har för många projekt samtidigt | ○ | ○ | ○ | ○ | ○ |
| 6 Det är brist på lämpliga interna resurser | ○ | ○ | ○ | ○ | ○ |
| 7 Det är brist på lämpliga externa resurser | ○ | ○ | ○ | ○ | ○ |
| 8 Grundläggande förutsättningar ändras i många projekt | ○ | ○ | ○ | ○ | ○ |
| 9 Interna beställningen från samhälle/underhåll är bristfällig/otydlig | ○ | ○ | ○ | ○ | ○ |
| 10 Otydliga krav som TRV ställer på leverantörer (konsult/entreprenör) leder till konflikter | ○ | ○ | ○ | ○ | ○ |
| 11 Kommunikationsvägar i projekt är otydliga | ○ | ○ | ○ | ○ | ○ |
| 12 Projektledarna har för många övriga arbetsuppgifter | ○ | ○ | ○ | ○ | ○ |
| 13 Nyckelpersoner byts ut under pågående projekt | ○ | ○ | ○ | ○ | ○ |
| 14 Tidplanerna är för optimistiska | ○ | ○ | ○ | ○ | ○ |
| 15 TRV detaljstyr hur leverantören utför sina uppdrag | ○ | ○ | ○ | ○ | ○ |
| 16 Det är svårt att samordna alla resurser inom ett projekt | ○ | ○ | ○ | ○ | ○ |
| 17 Fel entreprenadform väljs i många projekt | ○ | ○ | ○ | ○ | ○ |
| 18 Nytänkande och kreativa alternativ implementeras inte | ○ | ○ | ○ | ○ | ○ |

**7. I vilken utsträckning har du fått utbildning i Ledningssystemet och dess användning?**

| 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Kommentera utbildningens omfattning och kvalitet**

## Trafikverket Byggnadsverk Investering

**8. I vilken utsträckning får du information om Ledningssystemet genom nedanstående kontaktvägar?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|---|
| Ansvarig för Ledningssystemet | ○ | ○ | ○ | ○ | ○ |
| APT | ○ | ○ | ○ | ○ | ○ |
| Chefer | ○ | ○ | ○ | ○ | ○ |
| Intranätet/PPI | ○ | ○ | ○ | ○ | ○ |
| Kollegor | ○ | ○ | ○ | ○ | ○ |

**9. I vilken utsträckning har du enligt din uppfattning möjlighet att förändra Ledningssystemet?**

| 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**10. I vilken utsträckning använder du dig av följande kommunikationsvägar för att föreslå förändringar i Ledningssystemet?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|---|
| Ansvarig för Ledningsystemet | ○ | ○ | ○ | ○ | ○ |
| Chef | ○ | ○ | ○ | ○ | ○ |
| Internt slutmöte för projekt | ○ | ○ | ○ | ○ | ○ |
| Intranätet/PPI | ○ | ○ | ○ | ○ | ○ |

**11. Har du någon gång utnyttjat din möjlighet att ge förslag till förändringar av Ledningssystemet?**

○ Ja

○ Nej

**12. I vilken utsträckning känner du till vilka krav och dokument som gäller för olika Tollgates?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|---|
| TG0 (Mottagen beställning) | ○ | ○ | ○ | ○ | ○ |
| TG1 (Beslut om start av projektplanering) | ○ | ○ | ○ | ○ | ○ |
| TG2 (Fastställd projektspecifikation) | ○ | ○ | ○ | ○ | ○ |
| TG3 (Avtal tecknat) | ○ | ○ | ○ | ○ | ○ |
| TG4 (Godkänd produkt) | ○ | ○ | ○ | ○ | ○ |
| TG5 (Produkt överlämnande) | ○ | ○ | ○ | ○ | ○ |

## Trafikverket Byggnadsverk Investering

**Del II. Frågor som specifikt gäller ditt senaste utförda pro...**

**13. Ungefär hur stor var total kostnaden (planering, projektering och bygg) för detta projekt? (Mkr)**

**14. Vilken entreprenadform användes för projektet?**

**15. Vad innefattade ditt senaste projekt?**

**16. Ungefär hur lång tid varade projektet i sin helhet från intern beställning till avslutat projekt? (Månader)**

**17. Uppskatta hur lång tid i månader de olika faserna tog i ditt senaste projekt? (Utfördes ej faserna så lämna blankt)**

| | 0-1 | 1-2 | 2-4 | 4-6 | 6-8 | 8-12 | 12-24 | >24 |
|---|---|---|---|---|---|---|---|---|
| Upprätta projektspecifikation | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Förbereda och genomföra upphandling (projektering) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Projektera | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Fastställande plan | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Miljöprövning vattenverksamhet, länsstyrelsen | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Tillståndsprövning Mark och Miljödomstol | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Förbereda och genomgöra upphandling (entreprenad) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Bygga (Projektering och bygga vid totalentreprenad) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Utvärdera och överlämna produkt | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Utvärdera projekt och upprätta slutrapport | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**18. Hur väl var Ledningssytemet utformat för ditt senast projekt?**

| 1 Inte alls väl | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**19. Hur väl följde du Ledningssystemet i ditt senaste projekt?**

| 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

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## Trafikverket Byggnadsverk Investering

**20. I hur stor utsträckning användes olika Tollgates i ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket stor |
|---|---|---|---|---|---|
| TG0 (Mottagen beställning) | ○ | ○ | ○ | ○ | ○ |
| TG1 (Beslut om start av projektplanering) | ○ | ○ | ○ | ○ | ○ |
| TG2 (Fastställd projektspecifikation) | ○ | ○ | ○ | ○ | ○ |
| TG3 (Avtal tecknat) | ○ | ○ | ○ | ○ | ○ |
| TG4 (Godkänd produkt) | ○ | ○ | ○ | ○ | ○ |
| TG5 (Produkt överlämnande) | ○ | ○ | ○ | ○ | ○ |

**21. Hur väl stämmer följande påståenden om komplexiteten för ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 I detta projekt fanns det ett stort antal intressenter med olika intressen | ○ | ○ | ○ | ○ | ○ |
| 2 I detta projekt fanns det ett stort antal ömsesidigt beroende aktörer och aktiviteter som måste koordineras | ○ | ○ | ○ | ○ | ○ |
| 3 Detta projekt hade flera mål som var sammankopplade och beroende av varandra | ○ | ○ | ○ | ○ | ○ |

**22. Hur väl stämmer följande påståenden om hur information och samarbete hanterades i ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Vi inom Trafikverket informerade våra leverantörer om förändrade behov och förutsättningar | ○ | ○ | ○ | ○ | ○ |
| 2 I detta projekt förväntades det att information skulle tillhandahållas av beställaren om den kunde hjälpa andra parter | ○ | ○ | ○ | ○ | ○ |
| 3 Parterna informerade varandra om händelser eller förändringar som kunde påverka den andra parten | ○ | ○ | ○ | ○ | ○ |
| 4 Parterna planerade gemensamt hur detta projekt skulle genomföras | ○ | ○ | ○ | ○ | ○ |
| 5 Parterna beslutade gemensamt om justeringar av projektspecifika överenskommelser | ○ | ○ | ○ | ○ | ○ |
| 6 Problem som dök upp under projektets gång behandlades av parterna som gemensamma snarare än som någon enskild parts | ○ | ○ | ○ | ○ | ○ |

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## Trafikverket Byggnadsverk Investering

**23. Hur väl stämmer följande påståenden om tekniska lösningar, kunskaper och arbetsprocesser i ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Inom projektet genomfördes arbetsprocesserna på de sätt vi brukar göra | ○ | ○ | ○ | ○ | ○ |
| 2 Inom projektet använde vi traditionella och beprövade tekniska lösningar | ○ | ○ | ○ | ○ | ○ |
| 3 Inom projektet var våra arbetsprocesser och tekniska lösningar baserade på projektdeltagarnas ackumulerade erfarenheter | ○ | ○ | ○ | ○ | ○ |
| 4 Inom projektet användes arbetsprocesser som kunde utföras genom att använda våra befintliga kunskaper och erfarenheter | ○ | ○ | ○ | ○ | ○ |
| 5 Inom projektet fokuserade vi på att vidareutveckla våra befintliga teknologier och kompetenser | ○ | ○ | ○ | ○ | ○ |
| 6 Inom projektet fokuserade vi på att förbättra och minska ineffektiviteter i våra befintliga arbetsprocesser | ○ | ○ | ○ | ○ | ○ |
| 7 Inom projektet finslipade vi arbetsprocesser och tekniska lösningar så att de blev bättre | ○ | ○ | ○ | ○ | ○ |
| 8 Inom projektet krävdes det inlärning av nya kunskaper och färdigheter för att utföra våra arbetsprocesser | ○ | ○ | ○ | ○ | ○ |
| 9 Inom projektet sökte vi aktivt efter nya tekniska lösningar | ○ | ○ | ○ | ○ | ○ |
| 10 Inom projektet utvärderade vi många olika alternativa tekniska lösningar | ○ | ○ | ○ | ○ | ○ |
| 11 Inom projektet sökte vi kontinuerligt efter nya möjligheter att förbättra våra arbetsprocesser | ○ | ○ | ○ | ○ | ○ |

## Trafikverket Byggnadsverk Investering

**24. Hur väl stämmer nedanstående påståenden om projektresultatet avseende tid, kostnad och kvalitet i ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Projektet genomfördes på ett tidseffektivt sätt | ○ | ○ | ○ | ○ | ○ |
| 2 Projektet färdigställdes på kortare tid i jämförelse med liknande projekt | ○ | ○ | ○ | ○ | ○ |
| 3 Projektets genomförandetid var lika med eller kortare än beräknat | ○ | ○ | ○ | ○ | ○ |
| 4 Projektet genomfördes på ett kostnadseffektivt sätt | ○ | ○ | ○ | ○ | ○ |
| 5 Projektet blev så kostsamt som förväntat eller billigare | ○ | ○ | ○ | ○ | ○ |
| 6 Projektets verkliga kostnader var lika med eller lägre än de internt budgeterade kostnaderna | ○ | ○ | ○ | ○ | ○ |
| 7 Projektets slutprodukt/leverans överrensstämde med våra specificerade prestandakrav | ○ | ○ | ○ | ○ | ○ |
| 8 Prestandan hos projektets slutprodukt mötte samhällets behov | ○ | ○ | ○ | ○ | ○ |
| 9 Slutprodukt/leverans uppnådde den kvalitetsnivå som vi förväntade oss | ○ | ○ | ○ | ○ | ○ |

**25. Hur väl stämmer nedanstående påståenden in på resultatet för ditt senaste projekt?**

| | 1 Inte alls | 2 | 3 | 4 | 5 Mycket väl |
|---|---|---|---|---|---|
| 1 Vår interna projektorganisation lärde sig eller tog till sig ny och viktig information/kunskap från våra leverantörer | ○ | ○ | ○ | ○ | ○ |
| 2 Vår interna projektorganisation lärde sig eller tog till sig viktiga förmågor eller färdigheter från våra leverantörer | ○ | ○ | ○ | ○ | ○ |
| 3 Den kunskap och erfarenhet som våra projektdeltagare erhållit kommer att bli värdefull i framtida projekt | ○ | ○ | ○ | ○ | ○ |
| 4 Inom projektet har vi framgångsrikt kunnat hantera förändringar i projektets innehåll och omfattning | ○ | ○ | ○ | ○ | ○ |
| 5 Inom projektet har vi framgångsrikt kunnat lösa oväntade problem | ○ | ○ | ○ | ○ | ○ |
| 6 Inom projektet har vi framgångsrikt kunnat leverera en slutprodukt/lösning som tillfredställer nya förändrade krav | ○ | ○ | ○ | ○ | ○ |

## Trafikverket Byggnadsverk Investering

**Del III. Åsikter kring Ledningssystemets stöd för Bro och By...**

**26. Vad anser du är positivt med dagens Ledningssystem?**

**27. Vad anser du är negativ med dagens Ledningssystem?**

**28. Vilka åtgärder anser du skulle kunna utföras för att förbättra Ledningsystemet?**

**Stort tack för din medverkan och för att du besvarade alla frågor i denna enkät utan att hoppa över eller lämna vissa frågor obesvarade. Om du är osäker på något i enkäten får du gärna kontakta Peter.Simonsson@Trafikverket.se för mer information. När enkäten är sammanställd kommer resultatet att återkopplas till er.**

**Inledande frågor**

1. Personlig information
    a. Namn?
    b. Roll (i caset)?
    c. Vad har du för bakgrund? Utbildning?

2. Produkt och Produktionsutvecklingsprocessen förenklad (separata bilder)
    a. Var placerar du dig själv i ”case x”?
    b. Var/Vad kan du påverka i ”case x”?
    c. Vad påverkar dig i ”case x”?

3. (Företaget och dess historia? Finns det någon avvikande info i sekundär data-kontrollfrågor)

**Allmänna frågor för fallet**

4. Hur har ni arbetat med att utveckla ”case x”?
    a. Har den producerats förut?
    b. Vad är nytt?
    c. Hur ser produktionen ut? Antal? Serie/Styckes?
    d. Egenskaper för produkten, användning, återvinning/återtillverkning etc.

5. Hur har ni arbetat med att utveckla **produktionslösningen** för ”case x”?

6. Till vilken grad har följande drivkrafter funnits för samarbete i utvecklingen av produktionslösningen?

*0 = inte alls, 6 = mycket hög grad*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | vet ej (vem kan svara) |
|---|---|---|---|---|---|---|---|---|
| Kunskapsbas | | | | | | | | |
| Avancerad teknologi | | | | | | | | |
| Projektledning | | | | | | | | |
| Minska/dela risk och kostnad | | | | | | | | |
| Stimulera kreativitet | | | | | | | | |
| Krav/behov från kund | | | | | | | | |
| Krav/behov från leverantör | | | | | | | | |
| Andra? | | | | | | | | |

7. Vem/vilka beslutade om projektstart?

8. Vilka beslutspunkter fanns under processen?
    a. Vad fanns för beslutsunderlag?

9. Hur dokumenterades utvecklingen?

10. Hur såg tidslinjen ut för detta projekt?

11. Vad var förändringen från tidigare sätt att producera?

**Idé/Behov av förändring**

12. Vad var det som gjorde att idén/behovet av förändring uppstod?
    a. Problem
    b. Möjlighet
    c. Annat

13. När initierades idén/behovet av förändring?

14. Var i organisationen, eller utanför, och av vem initierades idén/behovet av förändring?

15. I vilken utsträckning har ditt företag samarbetat med någon av följande intressenter i idéfasen för detta fall? Hur?

*0 = inte alls, 6 = mycket hög grad*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | vet ej (vem kan svara) |
|---|---|---|---|---|---|---|---|---|
| Universitet eller forskningscentra | | | | | | | | |
| Innovationsförmedlare, t ex konsulter | | | | | | | | |
| Myndigheter | | | | | | | | |
| Kunder/Beställare | | | | | | | | |
| Leverantörer | | | | | | | | |
| Konsumenter/Slutkunder | | | | | | | | |
| Konkurrenter | | | | | | | | |
| Företag verksamma i andra branscher | | | | | | | | |
| Internt | | | | | | | | |

**Utveckling**

16. När började man arbeta med produktionslösningen?

17. Vad var invärde till produktionen?

18. Hur utvecklades produktionslösningen?

19. Vilka hinder har ni stött på under utvecklingen?

20. Hur förbereddes och planerades produktionen och vem deltog?

21. I vilken utsträckning har ditt företag samarbetat med någon av följande intressenter i utvecklingen av produktionslösningen för detta fall? Hur?

*0 = inte alls, 6 = mycket hög grad*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | vet ej (vem kan svara) |
|---|---|---|---|---|---|---|---|---|
| Universitet eller forskningscentra | | | | | | | | |
| Innovationsförmedlare, t ex konsulter | | | | | | | | |
| Myndigheter | | | | | | | | |
| Kunder/Beställare | | | | | | | | |
| Leverantörer | | | | | | | | |
| Konsumenter/Slutkunder | | | | | | | | |
| Konkurrenter | | | | | | | | |
| Företag verksamma i andra branscher | | | | | | | | |
| Internt | | | | | | | | |

22. Skedde några tester av produktionen? I så fall hur?

**Implementering och installation (genomförande)**

23. Hur genomfördes förändringen av produktionslösningen/den nya produktionslösningen?

    Alternativ? Stegvis/på en gång? Annat?

24. Vilka hinder har ni stött på under implementeringen?

25. I vilken utsträckning har ditt företag samarbetat med någon av följande intressenter i implementeringsfasen för detta fall? Hur?

*0 = inte alls, 6 = mycket hög grad*

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | vet ej (vem kan svara) |
|---|---|---|---|---|---|---|---|---|
| Universitet eller forskningscentra | | | | | | | | |
| Innovationsförmedlare, t ex konsulter | | | | | | | | |
| Myndigheter | | | | | | | | |
| Kunder/Beställare | | | | | | | | |
| Leverantörer | | | | | | | | |
| Konsumenter/Slutkunder | | | | | | | | |
| Konkurrenter | | | | | | | | |
| Företag verksamma i andra branscher | | | | | | | | |
| Internt | | | | | | | | |

26. Hur sker överlämningen av ansvaret för produktionslösningen från de som implementerat till de som ska sköta löpande produktionen?
    d. Returer tillbaka till produktionsutvecklare?

**Resultat/värde**

27. Vem/vilka påverkades av förändringen och på vilket sätt?

28. Vilket värde medför förändringen och för vem? (Värdeformuläret)

29. När tillförs värdet? (Värdeformuläret)

30. Hur sker uppföljning av resultat/värde?

**Allmänna frågor**

31. Vad innebär innovation för dig?

32. Vad skulle produktionsinnovation kunna innebära för dig?

33. Vilka värden ser du som störst vid produktionsinnovation?

# PAPER I

## Industrialized construction in the Swedish infrastructure sector: core elements and barriers

Johan Larsson, Per Erik Eriksson, Thomas Olofsson, Peter Simonsson

Published in

*Construction Management and Economics, (2014), 32(1-2), 83-96.*
*(Special issue on Industrialized Building)*

*Construction Management and Economics*, 2014
Vol. 32, Nos. 1–2, 83–96, http://dx.doi.org/10.1080/01446193.2013.833666



# Industrialized construction in the Swedish infrastructure sector: core elements and barriers

JOHAN LARSSON[1]*, PER ERIK ERIKSSON[2], THOMAS OLOFSSON[1] and PETER SIMONSSON[3]

[1]*Department of Civil, Environmental and Natural Resources Engineering,* [2]*Department of Business Administration, Technology and Social Sciences, Luleå University of Technology, Luleå, Sweden*
[3]*Swedish Transport Administration, Luleå, Sweden*

Received 6 November 2012; accepted 6 August 2013



Improving productivity and innovation is a central challenge in all industries, but particularly in construction where improvements have been slow. To meet this challenge, a recent investigation into the actions of Swedish government clients has recognized needs to improve planning during project procurement phases, increase numbers of turnkey contracts and raise industrialization of the sector. In response, the Swedish Transportation Administration has launched a research and innovation programme to foster an industrial approach and identify ways to increase the standardization of products and processes. However, increasing industrialization has been difficult to achieve in the project-based construction industry except in the process-based housing sector. Further, there has been little research on the concept of industrialized infrastructure construction and barriers to its implementation. Opinions and attitudes of clients, consultants and contractors in the infrastructure sector were investigated in relation to the core elements of industrialized construction, and the barriers hindering its development. Opportunities and obstacles related to both product and process standardization for continuous improvements and the relationships between clients and contractors are revealed. Hence, the implementation of industrialized construction requires tightly focused governance at the outset of projects and profound changes to established attitudes, norms and regulations.

*Keywords:* Barriers, industrialization, infrastructure, prefabrication, standardization.

## Introduction

A problem highlighted in numerous studies from many countries, including the UK and the US (Egan, 1998; Teicholz, 2001; Huang *et al.*, 2009), is that productivity increases slowly in the construction industry. In Sweden, recognition of an urgent need to improve productivity and client satisfaction in the industry has prompted a number of government investigations (Building Commission, 2002; Ministry of Finance, 2009; Productivity Committee, 2012). Several productivity studies (e.g. Horman and Kenley, 2005; Josephson and Saukkoriipi, 2005; Mossman, 2009) have also shown that large amounts of material, time and other resources are wasted in traditional onsite construction projects. Such waste is clearly detrimental to productivity. In other industries, waste is reduced and productivity improved by gradual, continuous improvements of industrialized processes (Winch, 2003). Accordingly, researchers and practitioners argue that the construction industry could improve productivity by adopting procedures applied in manufacturing industries, such as the automobile industry (Gann, 1996), to increase the industrialization of design and production processes.

Koskela (2000) identified three distinctive features of construction projects (one-of-a-kind production, site production, and temporary teams) that may explain the inefficiency and complexity that are often discussed in construction management literature. However, the construction industry is far from homogeneous in this respect. In the housing sector, production companies have used industrialized processes and offsite manufacturing for decades, resulting in continuous productivity improvements (Höök and Stehn, 2008; Segerstedt and Olofsson,

*Author for correspondence. E-mail: johan.p.larsson@ltu.se

2010). In contrast, increased industrialization has been difficult to achieve in other construction sectors, such as infrastructure and complex industrial and commercial buildings (Winch, 2003).

Previous research has found that efficiency and productivity are key challenges in the infrastructure sector and that many infrastructure projects suffer from cost and schedule overruns (Flyvbjerg *et al.*, 2004; Minchin *et al.*, 2011; Cantarelli *et al.*, 2012). The Swedish Transport Administration (STA), the major public procurer of infrastructure in Sweden, has been assigned by the government the task of creating conditions to improve productivity in the infrastructure sector. The STA is responsible for creating local norms and regulations for designing and constructing infrastructure in Sweden, apart from the Euro code. These norms are subsequently used by all other infrastructure clients, e.g. municipalities. The exceptional market position of the STA provides a unique opportunity for the STA to influence the infrastructure sector, both by creating an innovative environment and by setting rules and norms.

The client often initiates an infrastructure project by procuring a designer at an early stage in order to specify the product, while the contractor is procured late in the project, to construct the product on site, often based on detailed specifications in design-bid-build contracts. This approach has several negative consequences. Notably, customer-led location-specific design results in little or no repetition, and thus little (if any) post-order design certainty (Fox *et al.*, 2002). It also complicates the link between contractor productivity and client productivity since the client often procures work based on detailed specifications (Bröchner and Olofsson, 2012). Thus, the product design is often excluded from production control (Winch, 2003). In addition, this use of design-bid-build contracts, with late involvement of contractors, reduces opportunities for innovative approaches during construction. Furthermore, the STA hinders the implementation of innovations by failing to consider alternative solutions or allowing contractors to propose potentially better solutions (technically or financially) for a specific product in a specific location.

The Productivity Committee, which is supported by the Swedish Ministry of Enterprise, Energy, and Communications, has recently examined how the STA is handling the assigned task. The Committee concluded that the STA should increase the degree of industrialization, procure more projects based on design-build contracts, and improve its long-term planning during project initiation and procurement phases in order to increase innovation and productivity in infrastructure projects (Productivity Committee, 2012). In response, the STA has launched a long-term research and innovation programme to increase industrialization throughout the value chain and standardization of products. The STA is also reconsidering its tendering specification procedures and criteria. In the future, the organization will strive to avoid specifying more details than the minimum required for a specific project to increase the freedom for contractors to formulate solutions.

Measures to increase the productivity of infrastructure projects are particularly important from a societal perspective since public money is spent on investments that are crucial for national development and economic growth (Caerteling *et al.*, 2011). However, although the largest infrastructure client in Sweden (the STA) is keen to increase industrialization, this approach to improve productivity in the infrastructure sector is not widely used in practice as yet and has been poorly researched.

In order to enhance theoretical understanding of industrialized construction in the infrastructure sector and its practical implications, investigations of the key features of the concept and barriers to its implementation are needed. Thus, the knowledge of, and attitudes to, industrialized construction among practitioners operating in the sector were investigated. The primary focus is on the core elements of the concept (what industrial construction means in this particular context) and perceived barriers to its implementation (the factors hindering increased industrialization in it). The empirical data were acquired from two surveys and a workshop; the second of the surveys was undertaken as part of research commissioned by the Swedish Ministry of Enterprise, Energy, and Communications and reported by the Productivity Committee (2012). However, the paper starts by presenting two relevant industrialization strategies used in construction. Results of the empirical study are then presented and discussed in relation to these strategies, to increase understanding of the complexities in this previously neglected sector. The final section presents conclusions and recommendations for future research.

## Industrialization strategies

Models for industrialization taken from the manufacturing industry are often seen as solutions to the lack of productivity improvements in construction (Winch, 2003). For example, the Swedish and Japanese housing industries show significant similarities to manufacturing processes (Gann, 1996; Höök and Stehn, 2008). Perhaps most importantly, the focus is on maximizing the efficiency of the whole production system rather than individual projects. Industrialized construction normally involves two strategies to decrease the complexity of construction: standardization of products and standardization of processes, both underpinned by continuous improvements (Bertelsen, 2004). The former involves producing many required components in a factory for assembly at the construction site (Höök and Stehn, 2008), while the latter involves developing processes to address unique aspects of specific products in specific locations. However, standardization of both kinds has proved difficult to achieve in the project-oriented infrastructure sector (Winch, 2003), where clients manage projects from initiation to completion and very rarely exploit contractors' knowledge, experience or innovative ideas during early design phases, when most decisions affecting the outcome are taken. Hence, organizational and cultural aspects are also discussed in this section.

## Product innovation

Standardization of products is not a new concept, despite its slow implementation. It has long been recognized as essential for maximizing predictability and efficiency in construction projects (Gibb, 2001). Applying a multi-method approach (interviews, workshops and case studies) as part of the CIRIA (Construction Industry Research and Information Association) project the cited author identified four suitable categories of construction activities and products for industrialization: (1) component manufacture and pre-assembly; (2) non-volumetric pre-assembly; (3) volumetric pre-assembly; and (4) modular building. Infrastructure (e.g. bridges) is categorized among non-volumetric pre-assembly products. The reported findings show that allocating time during planning is essential for efficient industrialized production, especially in infrastructure. Further, both Gibb (2001) and Blismas *et al.* (2006) found that only financial costs are considered in traditional evaluations, while value is neglected, leading to low uptake of innovative products that primarily provide time and quality benefits rather than initial cost savings. These barriers were also confirmed by Blismas *et al.* (2005) during multiple workshops in which 22 constraints identified in previous research were discussed. The discussions highlighted three major categories of constraints for industrialized production: (1) processes related to early design decisions; (2) prioritization of lowest bid prices rather than best value; and (3) supply chain issues including long lead times and scarcity of suppliers.

Various researchers have attempted to identify and discuss the major drivers of industrialized products in the construction industry. In a large interview-based survey of clients' views of the benefits of standardized and pre-assembled products, Gibb and Isack (2003) found that the main advantages are improvements in quality and reductions in time, cost and the complexity of onsite construction, since fewer people are engaged and the onsite activities become more straightforward. Blismas and Wakefield (2009) reported similar findings in a qualitative survey of drivers and constraints for off-site manufacturing in Australia. They also found an additional driver: an increasing shortage of skilled workers, which is also a problem in the Swedish construction industry. However, although benefits and constraints are well documented by researchers, standardized and pre-assembled products and their benefits are poorly understood by many practitioners, leading to a widespread reluctance to use them (Pasquire and Gibb, 2002).

In a study of Japanese housing construction, Gann (1996) found that standardization and prefabrication are the main industrialization principles, but balancing standardization and flexibility is believed to be a key for success. One way of optimizing the balance is through modularization, defined by Gibb (2001) as decomposition of a product into modules with specific interfaces, each fulfilling a specific function in the end product. Development of standardized interfaces between modules is also essential, to ensure interchangeability of module variants.

Various kinds of product specification processes can also be identified, which are closely related to the modularity of the product, the design entry point for the client and the contractual relationships between the client, principal designer and main contractor (Winch, 2003; Hvam *et al.*, 2008). The trade-off between predefined specifications and specifications created in the project depends on the upstream point where the client enters the design process. Hvam *et al.* (2008) define several kinds of product specification processes, depending on how much of the product is standardized. In traditional engineer-to-order design processes, like in infrastructure, component-level standardization can be utilized, but more predefined subsystem-level specifications are used in modify-to-order and configure-to-order design processes. In product-level standardization the client can only select variants. However, in a study of the design process of a modularized multi-storey building, Jensen *et al.* (2012) found that closer integration between design and construction requires complementation of the downstream flow of design information to production with an upstream flow of constraints from production to design.

## Process innovation

Standardization is important not only in product innovation but also in both innovative design and production processes, where attention focuses on technical solutions and planning/execution, respectively. Production information refers to the specification of processes, operations, operational sequences and related resources (Ballard, 2000). Thus, it is only in the production stage that actual product costs, lead times and quality can be determined (Jiao and Tseng, 2004).

It should be noted that product modularization has some negative effects on production, particularly an increased number of process variants. However, the customized components and product structure introduce similarity in the associated production processes (Simpson *et al.*, 2005). Concepts like process platforms have been explored, for example by Jiao *et al.* (2003), that can facilitate coordination of product and process variety management, thus forming a coherent framework for both product and process structure. While most concepts discussed in literature about innovative processes are derived from manufacturing, they are now starting to gain some acceptance in construction literature. For instance, Gibb (2001) noted that construction companies have always struggled to solve the conflict between uniformity and variation. However, according to Sawney (1998) it is possible to manage the conflict between high volume and high flexibility by allocating products to appropriate process platforms and reduce development risks by exploiting similarities between processes to use proven elements in multiple projects. These industrialization concepts have been proposed by several authors, e.g. Vrijhoef and Koskela (2005) and Voordijk *et al.* (2006), as possible solutions to the problems connected to the previously mentioned distinctive features (one-of-a-kind production, site production, and temporary teams) associated with construction.

While product and process design can be standardized for standard products, Ballard and Howell (1998) argued that for non-standard products it is necessary to standardize procedures for planning and managing the design and installation of unique facilities. Hence, another approach to process innovation is the TVF (transformation, flow and value) theory developed by Koskela (2000), which provided foundations for the lean production strategy adapted to the project-based construction industry. Approaches such as the Last Planner system, which focuses on reducing variability (Ballard and Howell, 1998) and value stream mapping of work flows (Simonsson, 2011) are examples of lean tools that have been applied to improve the efficiency of onsite construction processes.

Infrastructure projects, especially in Sweden, are often carried out merely by traditional onsite production methods, with very little prefabrication. According to an STA database (BaTMan), only about 1300 out of over 21 000 bridges administrated by the STA include prefabrication in some way. However, in full-scale tests and case studies, Simonsson (2011) showed there is huge potential for applying more innovative processes and products in Swedish bridge construction. During the studies, the contractors were involved early in the projects to increase the buildability of the product by sharing knowledge about innovative construction methods for all of the building components. Further, the US Federal Highway Administration has recently promoted, and developed a manual for, use of a concept called accelerated bridge construction (ABC), which incorporates innovative solutions for design, planning, materials and construction methods to reduce onsite construction time through prefabrication. ABC also emphasizes the importance of early cooperation between participants, focusing on innovative solutions (Culmo, 2011).

## Organizational and cultural aspects

When addressing industrialization (e.g. product and process innovations) in construction, another issue has to be considered. After studying procedures used by Toyota for over two decades, Liker (2008) concluded that industrialization involves not only the implementation of product and process innovations, but also cultural and attitudinal changes. Similar conclusions have been reached in construction research, e.g. Courtney and Winch (2003) found that some constraints are more strongly related to organizational and behavioural obstacles than to technological obstacles. Survey and workshop findings they presented also show that the construction industries in many countries face the same major challenges and advocate cross-border cooperation in order to increase productivity.

The way business is organized can also hamper industrialization. Because of the focus on site production and one-off production, construction is often undertaken by temporary teams formed to execute a specific project. This does not support long-term thinking and knowledge transfer from an improvement perspective. Further, Kadefors (1995) found that the construction industry is subject to strong institutionalization owing to the need for coordination and communication in complex project organizations, explaining why innovations in individual projects seldom bring about long-term changes. Institutional here refers to the cultural rules that provide foundations for the way people act and think about the world.

Build-operate/own-transfer contracts including responsibilities to meet end users' performance requirements dominate in the single-house market, while design-bid-build contracts between the contractor(s) involved in the project and the client are common in infrastructural projects. This strongly affects the scope for introducing innovations in the market. In the single-house market the manufacturer is at the focal point of the supply/demand chain, whereas in design-bid-build projects, such as typical infrastructure projects, the client acts as a systems integrator in the supply chain (Segerstedt and Olofsson, 2010). A systems integrator is an organization that brings together component subsystems into a whole and ensures that those subsystems function together.

## Research design

A mixed method design was applied in the presented study, including both qualitative and quantitative approaches to increase the reliability of the empirical results (Creswell, 2003). Two surveys and a workshop (all involving clients, consultants and contractors) were undertaken, then the responses in the surveys and discussion in the workshop were analysed. Surveys are frequently used to collect rich descriptive data about focal phenomena, for instance Gibb (2001) and Blismas *et al.* (2006) used them to map both advantages and disadvantages of offsite production perceived by practitioners in the UK. Further, Blismas *et al.* (2005) used a survey to quantify the constraints for implementation of offsite production identified in previous literature. These examples show that the chosen approach is suitable both for collecting rich descriptive data regarding phenomena within a construction context and for quantifying their significance. However, the outcome of a survey depends on how the questions are asked; in this case both open-ended (Survey 1) and structured questions (Survey 2) were used. The workshop involved in-depth discussions that further enrich the empirical data.

In Survey 1 a qualitative approach was adopted, the main objective being to gain a deeper understanding of practitioners' attitudes and opinions about the infrastructure sector in general and industrialization in particular. For this purpose, a questionnaire was developed that included both structured and open-ended questions by the authors in cooperation with three experienced contractors. It was discussed and debated with several people, both practitioners and academics, in order to minimize misunderstandings and leading questions, which can greatly influence the answers. It was then distributed, during the autumn of 2010, to a sample of practitioners selected on both corporate and individual levels after discussions with major firms operating in the infrastructure sector. Each major contractor and consultancy firm selected was asked to contribute suitable respondents with experience of infrastructure construction to participate in the survey. In addition, the STA was asked to contribute respondents from various departments of its organization. The questionnaire was sent out by mail to 159 staff of the companies and the STA, and responses were received from 21 STA staff members, 13 designers from six major consultancy firms and 27 contractors from two of the four largest firms working in infrastructure construction (61 in total), giving a response rate of approximately 40%. For a summary of the types of respondents and their work experience, see Table 1.

Four of the questions in the questionnaire (25 in total) were selected for the analysis presented in this paper, namely:

(1) Do you think that the infrastructure sector will become more industrialized in the future, and if so how?
(2) What are the major reasons for the often stated inefficiency in the infrastructure sector?
(3) Are there any specific parts or components of a concrete bridge that are suitable for prefabrication?
(4) Are there any specific parts or components of a concrete bridge that are suitable for standardization?

These open-ended questions were selected because of their relevance to both industrialized construction and the objectives of the study. Standardization and prefabrication have been identified as important elements of industrialized construction in previous surveys (e.g. Gibb, 2001; Blismas *et al.*, 2005), while concrete bridges are complex infrastructure products and were thus selected as illustrative focal objects. Some of the other questions are also relevant to industrialization, but less relevant to the specific objectives of the study.

To complement some of the results from Survey 1, a workshop was organized with five contractors from two large firms, four clients (STA staff), two consultants from different firms and three suppliers of prefabricated components. These 14 participants were selected because they had wide experience, showed high interest in the focal subject and had substantial opportunity to influence the infrastructure sector in Sweden. Five out of the 14 were Survey 1 respondents. The topics discussed were based on interesting

**Table 1** Summary of respondents (questionnaire survey 1)

| Resp. category | Client | | | Consultant | | | Contractor | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | 21 | | | 13 | | | 27 | | |
| Exp. (years) | 0–5 | 5–10 | >10 | 0–5 | 5–10 | >10 | 0–5 | 5–10 | >10 |
| Construction | 0% | 0% | 100% | 0% | 0% | 100% | 0% | 7% | 93% |
| Onsite | 10% | 10% | 80% | 0% | 0% | 100% | 4% | 11% | 85% |
| Offsite | 29% | 23% | 48% | 24% | 38% | 38% | 30% | 27% | 43% |

aspects of industrialization identified in Survey 1. Three groups were formed to discuss five specific aspects for one hour of the workshop, three of which are addressed here: core elements of industrialization, uniqueness of the infrastructure sector, and reluctance to change. Results from the group discussions were subsequently compiled and discussed jointly during the last hour of the workshop.

Responses in the 62 returned questionnaires and transcripts of discussions during the workshop were analysed mostly using a qualitative approach. Open-ended questions typically provide no predetermined alternative answers for the respondents, hence the responses were analysed by content analysis using VISIO software to categorize answers and make the data more manageable and meaningful (Gibbs, 2002). Coding into categories is essential in qualitative research because it greatly facilitates interpretation of the acquired data. Answers referring to different categories of barriers, or standardization and prefabrication of various parts, were counted to obtain indications of their importance, as perceived by the participants. A primary purpose of these first two studies was to identify categories and patterns to facilitate the planning and design of the second survey, which was intended to quantify the importance of core elements of industrialization and barriers hindering its implementation, as expressed by practitioners with explicit interest in, and to some extent experience of, industrialized construction in the infrastructure sector. Fifty-two questionnaires were sent to people who had been invited and/or registered to attend a special seminar about industrialized infrastructure construction on 11 October 2011, hosted by the Productivity Committee of the Ministry of Enterprise, Energy and Communications. The survey was part of a research project about industrialized construction within the infrastructure sector commissioned by the Productivity Committee. Thirty-three responses were received from four clients (STA), 14 consultants and 15 contractors, giving a response rate of 63%. This sample included no respondents to the first questionnaire or workshop participants.

The design of the questionnaire, including the selection of response alternatives, was based on categories identified in the analysis of responses in Survey 1, the workshop discussions and a previous multiple case study of three infrastructure projects undertaken as part of the research project commissioned for the Ministry of Enterprise, Energy, and Communications (Productivity Committee, 2012).

The first question addressed practitioners' attitudes to core elements by asking: How important are the following elements of industrialized infrastructure construction? (1) Repetition and standardization; (2) Automation; (3) Prefabrication; (4) Planning for efficient production; (5) Experience feedback; and (6) Integrated design and construction. Five-point Likert scale options were provided for the responses, where 1 = not important, 2 = quite important, 3 = important, 4 = very important, 5 = extremely important.

The second question addressed barriers by asking: How large are the following barriers to increased industrialization of infrastructure construction? (1) Lack of large-scale and repetition possibilities; (2) Norms and rules of the Swedish Transport Administration (STA); (3) Design-bid-build contracts; (4) Impaired aesthetics and monotonous architecture; (5) Severe environmental impact due to long transportation distances; (6) Conservative industry culture; (7) New solutions and methods increase risks; (8) Strong focus on lowest bid price; and (9) Government rules regarding plans. Again, five-point Likert scale options were provided for the responses, where 1 = not large, 2 = quite large, 3 = large, 4 = very large, 5 = extremely large.

The third question addressed the suitability for standardization and prefabrication (S&P) of building products and components in infrastructure construction. The respondents were asked to answer the following question: How suitable are the following 11 products and components for standardization and prefabrication? (The reply alternatives were identified in the multiple case study undertaken for the Productivity Committee.) (1) Tunnel lining; (2) Steel bridges; (3) Noise barriers; (4) Retaining walls; (5) Barrier walls; (6) Prefabricated reinforcement; (7)

Edge beams of concrete bridges; (8) Cut and cover concrete tunnels; (9) Prefabricated concrete bridges; (10) Foundations for bridges and tunnels; and (11) Permanent concrete casting moulds. Again, five-point Likert scale options were provided for the responses, where 1 = not suitable, 2 = quite suitable, 3 = suitable, 4 = very suitable, 5 = extremely suitable.

Statistical analyses of the quantitative survey data were very simple: mainly mean values and standard deviations of the Likert scores were calculated to map the respondents' opinions. In addition, a comparison of means test (ANOVA) was applied to determine whether there were any significant differences in mean values of the scores for the three groups of respondents (clients, contractors, and consultants).

## Empirical results

The empirical results are divided into four sections: (1) Interest in and drivers for industrialized infrastructure construction; (2) Core elements of industrialized infrastructure construction; (3) Barriers to industrialized infrastructure; and (4) Standardized and prefabricated products and components.

### Interest in and drivers for industrialized infrastructure construction

According to the responses in Survey 1 nearly all (92%) of the respondents (clients, consultants, and contractors) believe that the degree of industrialization will increase in the future. The main drivers of this increase suggested by the responses are increasing demands for cost and time reductions and increased competition from foreign contractors. To date the large contractors in Sweden have been immune to foreign competition, but new rules and legislation have made it easier for foreign firms to compete for large infrastructure projects. The respondents argue that this is forcing the contractors to adopt both product and process innovations (including increased industrialization of the infrastructure sector) in order to survive in the more global market.

### Core elements of industrialized infrastructure construction

In the analysis of transcripts from the workshop the following seven categorical themes (core elements of industrialized infrastructure construction) were identified:

(1) Process
(2) Standardization
(3) Repetitiveness
(4) Cooperation
(5) Prefabrication
(6) Continuous improvement
(7) Experience feedback

A brief summary of discussions from the workshop is presented below to increase the understanding for the reader. According to all the group discussions, striving to achieve *continuous improvements* in long-term *processes* is a key aspect of industrialized infrastructure construction. One contractor stated that, 'We strongly believe in standardization of work tasks, and that when you have enough (standardized tasks) you put them together in products. Then one can continuously improve the processes linked to the standard products'. In fact, it can be argued that such improvements span many of the other elements. *Experience feedback* was frequently mentioned as an important tool for obtaining *continuous improvements*, and *Cooperation* between involved actors and the creation of clear communication channels as necessary for increased industrialization. One consultant summarized the latter by saying, '… the unique problems (characteristics) of projects makes it particularly important for the contractor to enter early in the process. These problems [technical and architectural issues related to the specific location and structure to be constructed in the project] may be eliminated more easily and earlier by better cooperation.'

The workshop participants agreed that *standardization* is a major requirement for industrialization of infrastructure in general, and that standardized processes are required to make and use standardized products efficiently, through recognizing similarities among projects and exploiting the scope they provide for *repetitiveness*. Discussions of comparable aspects of different projects mostly concerned the similarity of the processes, which would benefit from standardization, but some participants claimed that all types of aspects are comparable among projects. One client summarized this by saying 'It is all very similar, the cross-section of the road is the same, the bridge often has a fixed width, depending on the location, and then you have railings and coatings on top of the bridge.' Every infrastructure project might have unique characteristics, but the process of constructing a specific structure, e.g. a concrete bridge, always follows the same stages, which facilitates repetition.

Survey 2 was designed to investigate practitioners' views about six core elements identified from the workshop and the previous multiple case study. Standardization and repetition were identified as core elements in both the workshop and case study, but they are closely associated so they were merged into a single element. Cooperation was also identified (by the clients, consultants and contractors in both the workshop and case study), as a very important but also problematic element, especially during the design stages and thus was re-labelled integration of design and construction. It is crucial because of the importance of actors exchanging knowledge to facilitate the design of better, more buildable products. Prefabrication and experience feedback were also identified as core elements in the workshop, and were not modified in any way. Automation and planning for efficient production were also identified in the case study and included in Survey 2. Planning for efficient production means using available planning tools to create a continuous flow through the whole process in order to minimize wastes associated with (for instance) delays and shortages of materials. The general elements of *process* and *continuous improvement*, identified in the workshop, overlap with many of the other core elements of industrialization and hence were not included in the quantitative study. The final six core elements addressed in Survey 2 were: (1) automation; (2) experience feedback; (3) integrated design and production; (4) planning for efficient production; (5) prefabrication; and (6) repetition and standardization.

The results show that all six identified core elements of industrialized infrastructure are considered very important, with mean Likert scores ranging from 3.8 to 4.5, see below.

(1) Automation (3.9)
(2) Experience feedback (4.2)
(3) Integrated design and production (4.2)
(4) Planning for efficient production (4.5)
(5) Prefabrication (3.8)
(6) Repetition and standardization (4.1)

Planning for efficient production was considered most important (4.5) and prefabrication least important (3.8). However, since 3.8 is very close to 4, which is labelled 'very important', all six can be considered core elements of industrialization. Furthermore, the standard deviations are quite low, ranging between 0.6 and 0.9. Thus, the responses do not vary considerably and the respondents have similar opinions. In addition, the ANOVA results indicate that there are no statistically significant differences in opinions between the three types of respondents (clients, consultants and contractors) about these elements. This supports the conclusion that the respondents agree that all six are core elements of industrialized infrastructure construction.

## Barriers to industrialized infrastructure

Both surveys also addressed the practitioners' opinions about barriers to industrialization. In Survey 1, the respondents' opinions were sought by including an open-ended question, allowing them to suggest more than one barrier, which was answered by 54 of the 61 respondents. The following eight categories of barriers were identified during the analysis of the qualitative data obtained from Survey 1:

(1) Conservative industry culture
(2) Lack of large-scale and repetition possibilities
(3) STA norms and rules
(4) Design-bid-build contracts
(5) Impaired aesthetics and quality
(6) Strong focus on lowest bid price
(7) Lack of competition
(8) Negative STA reviews

Three out of the eight barriers (conservative industry culture; lack of large-scale and repetition possibilities; and STA norms and rules) were mentioned more frequently (10 times or more) than the others. However, the other five (design-bid-build contracts; impaired aesthetics and quality; strong focus on lowest bid price; lack of competition; and negative STA reviews) were mentioned sufficiently often (5 to 10 times) to be recognized as significant, distinct categories of industrialization barriers. One client summarized this by saying 'A market with relatively low competition and perhaps a bit conservative approach in terms of everything from the rules and norms to execution of projects.' One contractor also highlighted the barriers by saying 'Very governed by laws, standards and requirements. Late project involvement of contractors means that the risk (time, cost, and acceptance) becomes too great to step outside the frame.' No relevant differences in answers between respondent types (clients, contractors and consultants) were detected during the analysis.

Six of the eight categories identified in Survey 1 were directly addressed in Survey 2, while the last two (lack of competition and negative STA reviews) were excluded. Lack of competition was excluded because it was assumed to be closely connected to norms and rules set by the STA (which have previously hindered competition from foreign actors for contracts in Sweden). Negative review was excluded because it was assumed to be closely connected to conservatism in the client organization. Both norms and rules and conservatism are included in the response options in Survey 2, hence the two excluded items are indirect components of the other barriers. Based on the results from the case study, three additional barriers (governmental rules regarding plans; new solutions and methods increase risks; and severe environmental impact due to long transport distances) were added to the list from the first survey. Thus, in total nine categories of barriers were addressed in Survey 2.

The empirical results show that the respondents considered the nine identified barriers to be of varying importance:

(1) Conservative industry culture (3.5)
(2) Design-bid-build contracts (3.5)
(3) Governmental rules regarding plans (3.1)
(4) Impaired aesthetics and monotonous architecture (2.2)
(5) Lack of large-scale and repetition possibilities (3.0)
(6) New solutions and methods increase risks (1.5)
(7) Severe environmental impact due to long transportation distances (1.3)
(8) STA norms and rules (3.1)
(9) Strong focus on lowest bid price (3.5)

Mean Likert scores for two barriers (new solutions and methods increase risks; and severe environmental impact due to long transportation distances) are low and have standard deviations below 1.0, indicating that the respondents agree that these barriers are not large. For the other barriers, standard deviations vary between 1.1 and 1.4, indicating that respondents' opinions regarding their importance vary substantially. These differences in opinions are corroborated by the ANOVA, which indicates that opinions regarding two barriers are statistically significant. Design-bid-build contracts are considered to comprise a very large barrier by contractors and clients, while consultants view it to be of less importance (mean Likert scores: 4.1, 3.8 and 2.9, respectively). Contractors also view governmental rules regarding plans to be a very large barrier, while it is considered to be of less importance by consultants and clients (mean Likert scores: 3.9, 2.3 and 3.3, respectively). Non-significant differences in opinions are also evident for the barrier 'strong focus on lowest bid price' (mean Likert scores: 3.8, 3.4 and 2.3, respectively).

## Standardized and prefabricated products and components

In prior construction management literature on industrialized construction, standardization and prefabrication of products and components have often been highlighted as the two most central aspects of industrialization. Therefore, specific parts of the questionnaires used in both surveys focused explicitly on standardization and prefabrication of infrastructure (generally in Survey 2, and in construction of concrete bridges, as examples of complex products, in Survey 1). In Survey 2, only 24 of the respondents expressed opinions about this issue, because nine felt that they did not have sufficient knowledge and experience of these more technological aspects. This supports our notion of a claimed knowledge gap of industrialization among practitioners in infrastructure. Respondents who did express opinions considered almost all of the 11 listed parts and components to be appropriate or even very suitable for standardization and prefabrication, see below:

(1) Tunnel lining (3.8)
(2) Steel bridge (4.2)
(3) Noise barrier (4.4)
(4) Retaining wall (3.4)
(5) Barrier wall (4.7)
(6) Reinforcement (4.2)
(7) Edge beam at concrete bridge (3.3)
(8) Cut and cover concrete tunnel (2.7)
(9) Concrete bridge (3.6)
(10) Foundations in bridge and tunnel (3.3)
(11) Permanent concrete casting mould (3.5)

Cut and cover concrete tunnels were the only listed component that received a mean Likert score below 3.0 (suitable). Three (barrier walls, noise barriers and

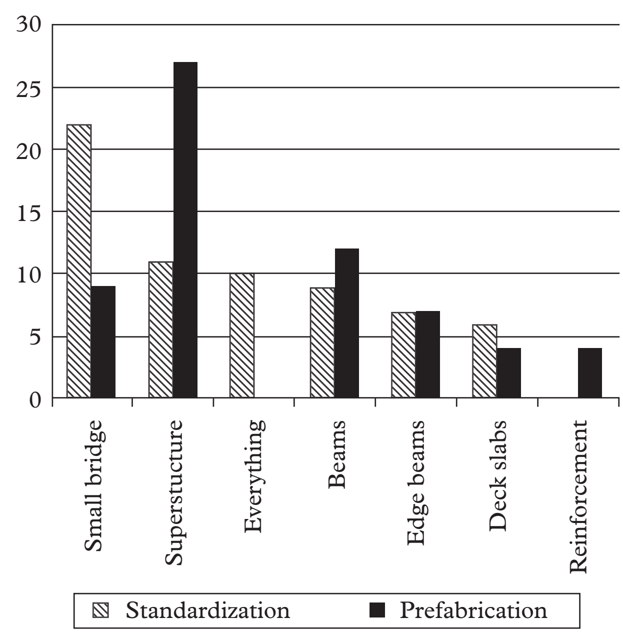



**Figure 1** Numbers of respondents (of 52 who expressed opinions in Survey 1) who felt that the indicated parts of concrete bridges could be standardized and prefabricated

reinforcements) of the four most suitable parts and components for industrialization are considered to be standard products.

In Survey 1, small to medium-sized concrete bridges were chosen to identify subsystems, parts and components of complex products perceived to have the greatest potential for standardization and prefabrication. Nearly all (94%) of the respondents thought that it is possible to standardize concrete bridges, or at least some parts of them. Fifty-two respondents chose to comment on standardized parts, see Figure 1. Further, 42% thought that small bridges should be standardized, and that their superstructure, or parts of it (beams, edge beams and deck slabs), is the most suitable part of medium-sized bridges to standardize. Thus, results from Survey 1 show that similar structures are seen as suitable for both standardization and prefabrication.

## Analysis and discussion

The findings from Survey 1 support prior indications that increasing industrialized construction is an appropriate approach to improve productivity and reduce both costs and time (e.g. Pasquire and Gibb, 2002; Blismas and Wakefield, 2009). Further, respondents in Survey 1 agreed that increased industrialization could be suitable for solving efficiency and productivity issues associated with the infrastructure sector.

An interesting aspect of the empirical results from the surveys and workshop is the multi-faceted views of practitioners and industry experts about industrialized construction in infrastructure projects, a concept that involves much more than merely prefabrication strategies. Many of the identified core elements of industrialization are related to processes (long-term) rather than projects (short-term). The core elements identified from the workshop with selected industry professionals were processes, standardization, repetitiveness, cooperation, prefabrication, continuous improvement and experience feedback. The importance of these elements was subsequently confirmed by the second survey, which added automation, planning for efficient production and integrated design and construction to the list of core elements of industrialized infrastructure construction. Many of these elements are incorporated in industrialization strategies described in the literature regarding the industrialization of products and processes. Standardization is regarded as a major component of an industrialization strategy since it facilitates implementation of many of the other core elements, such as prefabrication, experience feedback and continuous improvement of products and processes. The findings show that it is important to switch the project focus to include processes, as suggested by Höök and Stehn (2008). Both the literature and findings from the workshop highlight the need for flexibility to counter possible causes of reluctance to standardize. One strategy to maintain flexibility within standardization is by modularization, as concluded (for instance) by Gibb (2001). In infrastructure projects, where the client serves as the systems integrator, it is important for the client to permit the development of these innovations, both by allowing early involvement of contractors and by being more open to innovations. As the workshop highlights, many similarities between projects need to be explored in order to see how they can be standardized. Integrating all of the standards into a product or process platform is a possibility highlighted in both the workshop and previous literature (Sawney, 1998). Hence, identifying similarities among projects instead of merely their uniqueness is a first step towards increased industrialization.

Product standardization is one of two strategies for decreasing production complexity proposed by Bertelsen (2004). Possible candidates for standardization and prefabrication (S&P) in infrastructure projects on various product architecture levels, ranging from complete products to subsystems and components, were suggested and are illustrated in Figure 2.

The results from Survey 2 show that three of the four most suitable parts and components for industrialization (barrier walls, noise barriers and reinforcement) are considered to be standard products. The suggestions for parts of concrete bridges that are suitable for both standardization and prefabrication (Figure 1) indicate that the most difficult structures to construct by traditional onsite construction methods should be selected, although this does not imply that they are difficult to construct with innovative methods. For instance, the construction of bridge superstructure, identified as suitable for both prefabrication and standardization, requires complex formwork and reinforcement activities on site. Hence, a clear driver for standardization of parts is complex and time-consuming onsite construction (Blismas *et al.*, 2006). According to Gann (1996), flexibility is important and the superstructure is probably the subsystem least affected by unpredictable geotechnical conditions; hence, it is a suitable subsystem for standardization and possibly prefabrication.

Gibb (2001) noted that concrete bridges are generally non-volumetric products, but their individual components (e.g. deck slabs and beams) can be seen as component sub-assemblies, which increases the scope for standardization. These components are both components within a subsystem (superstructure) and can be easily compared to hollow cores (for example),

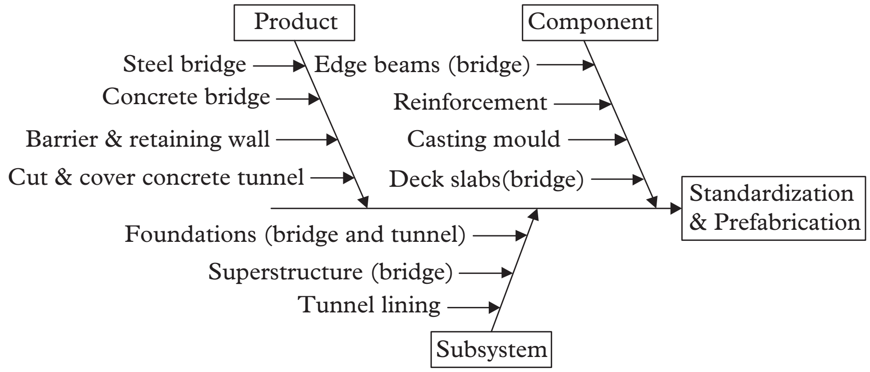



**Figure 2** Products, subsystems and components of infrastructure (e.g. bridges) identified as being suitable for standardization and prefabrication



which are standard components of industrialized housing. The identified subsystems (superstructure and foundation) can also be treated as modules, as they have clear functions and interfaces in bridges. Since every bridge is seen as unique, especially in Sweden, it is important to identify modules and subsequently components of the modules that can be standardized. Hence, the development of standardized products, subsystems and components in the infrastructure sector should exploit recent advances in product platforms, modularization and configuration strategies for building systems (Hvam *et al.*, 2008; Jensen *et al.*, 2012).

However, the scope for innovation depends on how a project is organized (Kadefors, 1995), which is highlighted as a barrier in construction, both by Blismas *et al.* (2005) and here. Since standardization and prefabrication are often characterized by long lead times, the design must be completed early in the project, which is difficult to achieve today as the contractor and supplier are involved late in the project. Two reasons for the reluctance to standardize (industrialize) bridges were frequently mentioned by the respondents. First, architects want to put their unique mark on each bridge, and because they enter early in the project they set constraints on production. Secondly, clients are often conservative, i.e. reluctant to use new product options, as proved solutions decrease risks of failure. These factors are hindering the implementation of more predefined specifications mentioned by, for example, Winch (2003) and Hvam *et al.* (2008), as more time-efficient production methods. However, these specifications could all be incorporated in the design process in infrastructure construction, since the client entered the value chain in the specification phase of the project.

The main perceived barriers to increased industrialization of infrastructure construction, their relationships to the core elements, and the actors who could eliminate them are illustrated in Figure 3. Three out of five barriers (lack of repetition, norms and rules, and procurement strategies) are controlled by the main client in Sweden (the STA).

Removal of all six identified barriers is essential for introduction of the core elements of industrialized construction:

- Design-bid-build contracts split design and production. From an institutional perspective, the clients (STA and principal designer) act as systems integrators, making the contractor a supplier of construction services. In this system standardization of the design (at component, subsystem or product level) can only be implemented by the client. Both Simonsson (2011) and Culmo (2011) highlight the importance of early cooperation for innovation.
- Standardization of production processes can be encouraged by the client by using the same contractor (supply chain integration), but this can be difficult to accomplish using public procurement practices focusing on the lowest price for each new project. This barrier has been highlighted in previous literature, e.g. by Gibb (2001). Solely evaluating solutions in financial terms rather than value is very common in Sweden and is strongly connected to the conservatism barrier.
- Lack of repetition possibilities derived from clients' procurement and contracting practices hinder standardization, continuous improvement and investments in both automation and prefabrication facilities. One way for contractors to handle their late involvement is to explore the process innovation developed by, for instance, Koskela (2000). This approach can help tackle the onsite peculiarities, regardless of whether more industrialized products are implemented. Hence, planning can be improved by exploring process similarities between projects.

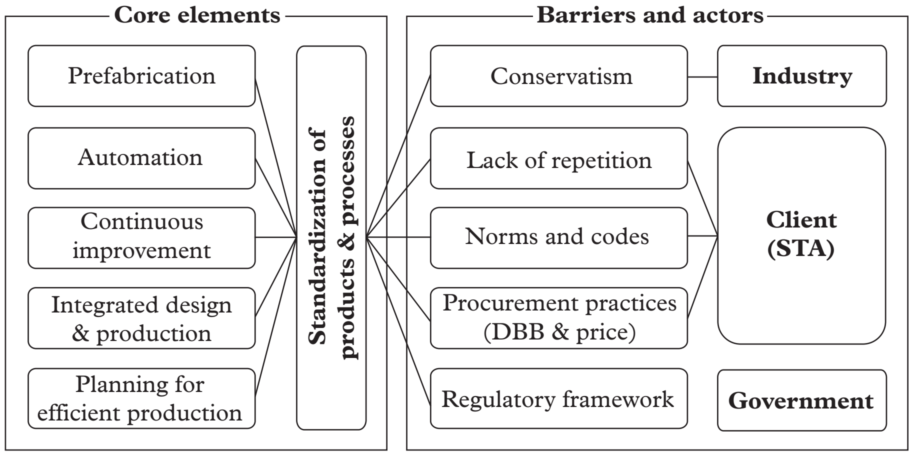



**Figure 3** The main perceived barriers (process and product) to increased industrialization of infrastructure construction, their relationships to the core elements, and the actors who could eliminate them

- Norms and rules of the STA, governmental rules regarding plans and the conservative industry culture also affect the possibilities for standardization, automation and prefabrication. The conservative culture in the construction industry has also been identified as a barrier for innovation in previous literature, e.g. Kadefors (1995). These barriers that are strongly connected to culture are difficult to change and demand more radical counter-measures.

## Conclusions

A better knowledge of core elements of, and barriers to, increasing the standardization of products and processes in a previously neglected context, the infrastructure sector, as perceived by professional clients, can help to foster broader awareness of possible ways to implement industrialized construction in infrastructure projects.

An important contribution to the literature on industrialized construction is the identified core elements of industrialized infrastructure construction. Four are primarily related to the process (planning for efficient production, integrated design and production, continuous improvement and automation) while only one (prefabrication) is primarily related to the product. Five elements contribute to standardization, the single most important element of industrialization, without which it is impossible to evaluate product and process innovations.

Interestingly, three of the five largest perceived barriers could be traced back to the client's role. Thus, the clients (i.e. the STA in Sweden) must address these barriers to increase industrialization. The long-term research and innovation programme launched by the STA to promote increased industrialization throughout the value chain and standardization of products is a first step toward breaking down the barriers and releasing the potential to increase productivity.

The standardization of products is shown to be a possible strategy for reducing the complexity of onsite construction, but it will not become more common as long as the chances for large-scale production and repetitiveness are small. Future research should focus on procurement strategies that support the standardization of products and processes, partly because they are strongly related to the identified core elements and partly because of the importance of shifting the focus from project to process in an industrialized infrastructure context.

Since the empirical results are based on data collected only from Swedish practitioners, international generalizations should be made with caution. Further research on practices in other countries is required to assess international differences and similarities of barriers to industrialized infrastructure construction. In addition, the samples of practitioners are not sufficiently large to draw generalized conclusions, but the main intention was to obtain indications of practitioners' knowledge and attitudes about industrialization in the infrastructure sector, which has been largely neglected in this type of research. In future research larger samples should be surveyed to enable hypotheses to be robustly tested.

## References

Ballard, G. (2000) The Last Planner system of production control, Doctoral thesis, School of Civil Engineering, Faculty of Engineering, The University of Birmingham.

Ballard, G. and Howell, G. (1998) Shielding production: essential step in production control. *Journal of Construction Engineering and Management*, **124**(1), 11–7.

Bertelsen, S. (2004) Lean construction: where are we and how to proceed. *Lean Construction Journal*, **1**(1), 46–69.

Blismas, N.G. and Wakefield, R. (2009) Drivers, constraints and the future of offsite manufacture in Australia. *Construction Innovation: Information, Process, Management*, **9**(1), 72–83.

Blismas, N.G., Pendlebury, M., Gibb, A.G.F. and Pasquire, C. (2005) Constraints to the use of off-site production on construction projects. *Architectural Engineering and Design Management*, **1**(3), 153–62.

Blismas, N.G., Pasquire, C. and Gibb, A.G.F. (2006) Benefits evaluation for off-site production in construction. *Construction Management and Economics*, **24**(2), 121–30.

Bröchner, J. and Olofsson, T. (2012) Construction productivity measures for innovation projects. *Journal of Construction Engineering and Management*, **138**(5), 670–7.

Building Commission (2002) *Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn* [About competition, quality, costs and competence in construction, in Swedish], SOU 2002:115, Stockholm, Sweden.

Caerteling, J., Di Benedetto, A., Dorée, A., Halman, J. and Song, M. (2011) Technology development projects in road infrastructure: the relevance of government championing behavior. *Technovation*, **31**(5–6), 270–83.

Cantarelli, C., van Wee, B., Molin, E.J.E. and Flyvbjerg, B. (2012) Different cost performance: different determinants? The case of cost overruns in Dutch transport infrastructure projects. *Transport Policy*, **22**(July), 88–95.

Courtney, R. and Winch, G. (2003) Re-engineering construction: the role of research and implementation. *Building Research & Information*, **31**(2), 172–8.

Creswell, J. (2003) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 2nd edn, Sage, Thousand Oaks, CA.

Culmo, M.P. (2011) *Accelerated Bridge Construction: Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems*, Federal Highway Administration Report No. FHWA-HIF-12-013, Alexandria, USA.

Egan, J. (1998) *Rethinking Construction*, Construction Task Force Report for Department of the Environment, Transport and the Regions, HMSO, London.

Flyvbjerg, B., Skamris Holm, M.K. and Buhl, S.L. (2004) What causes cost overrun in transport infrastructure projects? *Transport Review: A Transnational Transdisciplinary Journal*, **24**(1), 3–18.

Fox, S., Marsh, L. and Cockerham, G. (2002) How building design imperatives constrain construction productivity and quality. *Engineering Construction and Architectural Management*, **9**(5–6), 378–87.

Gann, D.M. (1996) Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics*, **14**(5), 437–50.

Gibb, A.G.F. (2001) Standardization and pre-assembly: distinguishing myth from reality using case study research. *Construction Management and Economics*, **19**(3), 307–15.

Gibb, A.G.F. and Isack, F. (2003) Re-engineering through pre-assembly: client expectations and drivers. *Building Research & Information*, **31**(2), 146–60.

Gibbs, G.R. (2002) *Qualitative Data Analysis*, Open University Press, Milton Keynes.

Höök, M. and Stehn, L. (2008) Applicability of lean principles and practices in industrialized housing production. *Construction Management and Economics*, **26**(10), 1091–100.

Horman, M.J. and Kenley, R. (2005) Quantifying levels of wasted time in construction with meta-analysis. *Journal of Construction Engineering and Management*, **131**(1), 52–61.

Huang, A.L., Chapman, R.E. and Butry, D.T. (2009) *Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations*, NIST Spec. Publ. 1101, National Institute of Standards and Technology, Gaithersburg, MD.

Hvam, L., Mortensen, N.H. and Riis, J. (2008) *Product Customization*, Springer, Berlin.

Jensen, P., Olofsson, T. and Johnsson, H. (2012) Configuration through the parameterization of building components. *Automation in Construction*, **23**, 1–8.

Jiao, J. and Tseng, M.M. (2004) Customizability analysis in design for mass customization. *Computer-Aided Design*, **36** (8), 745–57.

Jiao, J., Zhang, L. and Pokharel, S. (2003) Process platform planning for mass customization. Paper presented at the 2nd Interdisciplinary World Congress on Mass Customization and Personalization, Munich, Germany, 6-8 October.

Josephson, P.-E. and Saukkoriipi, L. (2005) Slöseri i byggprojekt – behov av förändrat synsätt [Waste in construction projects, in Swedish], FoU-Väst 0507, Göteborg, , Sweden.

Kadefors, A. (1995) Institutions in building projects: implications for flexibility and change. *Scandinavian Journal of Management*, **11**(4), 395–408.

Koskela, L. (2000) An exploration towards a production theory and its application to construction, Doctoral thesis, Helsinki University of Technology.

Liker, J.K. (2008) *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York.

Minchin, E., Lewis, D. and McLeod, L. (2011) Improving productivity on a troubled bridge project. *Journal of Construction Engineering and Management*, **137**(5), 364–71.

Ministry of Finance (2009) *Återkrav inom välfärdssystemen: förslag till lagstiftning* [Repayment in welfare, proposals for legislation, in Swedish], SOU 2009:6, Stockholm, Sweden.

Mossman, A. (2009) Creating value: a sufficient way to eliminate waste in lean design and lean production. *Lean Construction Journal*, **2009**, 13–23.

Pasquire, C. and Gibb, A.G.F. (2002) Considerations of assessing the benefits of standardisation and pre-assembly in construction. *Journal of Financial Management of Property and Construction*, **7**(3), 151–61.

Productivity Committee (2012) *Vägar till förbättrad produktivitet och innovationsgrad i anläggningsbranschen* [Ways to improve productivity and innovation in civil engineering, in Swedish], SOU 2012:39 for the Ministry of Enterprise, Energy, and Communications, Stockholm, Sweden.

Sawney, M.S. (1998) Leveraged high-variety strategies: from portfolio thinking to platform thinking. *Journal of the Academy of Marketing Science*, **26**(1), 54–61.

Segerstedt, A. and Olofsson, T. (2010) Supply chains in the construction industry. *Supply Chain Management*, **15**(5), 347–53.

Simonsson, P. (2011) Buildability of concrete structures: processes, methods and material, Doctoral thesis, Luleå University of Technology.

Simpson, T.W., Siddique, Z. and Jiao, R.J. (2005) *Product Platform and Product Family Design: Methods and Applications*, Springer, New York.

Teicholz, P., Goodrum, P. and Haas, C. (2001) Discussion: US construction labor productivity trends, 1970–1998. *Journal of Construction Engineering and Management*, **127** (5), 427–9. http://dx.doi.org/10.1061/(ASCE)0733-9364(2001)127:5(427)

Voordijk, H., Meijboom, B. and de Han, J. (2006) Modularity in supply chain: a multiple case study in the construction industry. *International Journal of Operations & Production Management*, **26**(6), 600–18.

Vrijhoef, R. and Koskela, L. (2005) Revisiting the three peculiarities of production in construction. Paper presented at the 13th International Group for Lean Construction, Sydney, Australia, 19-21 July.

Winch, G.M. (2003) Models of manufacturing and the construction process: the genesis of re-engineering construction. *Building Research & Information*, **31**(2), 107–18.

# PAPER II

**Discrete event simulation analysis of product and process platforms – a bridge construction case study**

Johan Larsson, Weizhuo Lu, Jan Krantz, Thomas Olofsson

Published in

*Journal of Construction Engineering and Management, (Published online Date 25 November 2015)*

# Discrete Event Simulation Analysis of Product and Process Platforms: A Bridge Construction Case Study

Johan Larsson[1]; Weizhuo Lu[2]; Jan Krantz[3]; and Thomas Olofsson[4]



**Abstract:** Product and process platforms have been promoted as possible enablers of increased productivity in civil engineering. However, such platforms are traditionally applied in mass manufacturing industries where production assets are employed in continuous production of uniform products, which strongly facilitates continuous improvement. The discontinuous nature of project-based production in civil engineering restricts such possibilities. Thus, if platforms are implemented there is a need for methods capable of evaluating the performance of integrated product and production process configurations in specific projects. A possibility, explored in this paper, is to use database-driven simulation. As a case study, a configurable simulation model, based on standardized process patterns and values stored in a platform, has been developed of the production for a bridge concept. The presented results provide evidence that database-driven simulation can support efficient platform evaluation and development by integrating product and process information, even in discontinuous, project-based industrial sectors. The results specifically demonstrate that this approach can be used to evaluate effects of different configurations of construction methods on working time requirements without time-consuming updates of models. **DOI: 10.1061/(ASCE)CO.1943-7862.0001093.** © *2015 American Society of Civil Engineers.*

**Author keywords:** Project planning; Construction management; Process platform; Product platform; Discrete event simulation; Project planning and design.

## Introduction

Construction projects are generally carried out in an uncertain environment in which resources and activities interact in a complex manner. Segerstedt and Olofsson (2010) argued that the supply chain structure in construction causes inherent variations in activity duration, delivery of materials and workforce productivity that impair productivity. Because of the complexities and inherent variation, scheduling construction activities can be extremely challenging, even for the most skilled and experienced planners (Koskela 1992). Thus, the introduction of manufacturing principles and standardisation of components and processes have been promoted by Larsson et al. (2014) as important measures to increase productivity in civil engineering. Similarly, Goodrum et al. (2009) found that changes in installation and modularity of the product, i.e., the prefabrication level, strongly affected the partial factor productivity.

Standardization, repetitiveness, and reusability are key elements of the strategy applied in manufacturing industries to stabilize the production processes. To meet ever-increasing demands for product customization, configurable product and process platforms have been developed to increase the flexibility of products offered to customers, as described for example by Robertson and Ulrich (1998). These platforms are based on reusable parts called modules, with standardized interfaces that allow both interchangeability and customization. Modular platforms provide systems from which a stream of derivative products and associated production processes can be configured, thereby creating variety while retaining the mass production advantages of reusability and economy of scale.

While platforms increase the product and process variety in mass-production companies, the introduction of platforms in construction companies has the opposite effect. The primary motive for developing platforms is to increase productivity by reducing the variety of both products and processes in construction projects (Haug et al. 2009). However, their introduction raises risks of narrowing the market segment because clients are used to ordering building products that are uniquely tailored to their specific needs. Systems building (which involves extensive use of standardized prefabricated components, and was widely adopted in the 1950s and 1960s) increased production efficiency of housing projects, but has been retrospectively criticized for the creation of socially unacceptable residential areas (Gann 1996). Thus, finding the right balance between reusability and customization is essential for construction companies introducing platforms (Bonev et al. 2015; Jensen et al. 2012). A variety of construction alternatives must be maintained to meet project-specific requirements, such as adaptation to the location of the construction site and availability of resources. Consequently, the introduction of platforms in construction requires the ability to evaluate multiple options ex ante in order to select the most appropriate product and process configuration to meet specific projects' requirements.

Previous studies of platforms in construction have mostly focused on product modularity and configuration (Haug et al. 2009; Jensen et al. 2012), although the main motive for implementing platforms is to increase productivity, so the processes must also be considered. More research is needed to identify optimal strategies for integrating parts, modules, and production processes in

[1]Ph.D. Student, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden (corresponding author). E-mail: johan.p.larsson@ltu.se

[2]Senior Lecturer, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: weizhuo.lu@ltu.se

[3]Ph.D. Student, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: jan.krantz@ltu.se

[4]Professor, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: thomas.olofsson@ltu.se

Note. This manuscript was submitted on April 10, 2015; approved on September 29, 2015; published online on November 25, 2015. Discussion period open until April 25, 2016; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

construction projects. Better methods for evaluating possible configurations also are required to meet challenges associated with the complex and uncertain environments of civil engineering projects. Discrete event simulation (DES) models can be highly useful for these purposes, as they allow project managers to simulate the dynamic interactions between resources and activities to evaluate the overall performance of a construction system. They can also improve the reliability of predictions, and take into account effects of inherent uncertainties and unforeseen conditions (Hajjar and AbouRizk 2002).

This paper explores the utility of DES in the configuration and evaluation of platforms to optimize relations between products, modules and processes in construction contexts. It includes a case study focusing on a platform developed for constructing concrete beam bridges with both traditional cast on-site parts and prefabricated components. The bridge concept is scalable with a configurable production process based on process patterns and standardized work packages. The results confirm that DES has high potential to support the evaluation of configurations generated by such platforms with integrated knowledge of the product(s) and processes involved. This can substantially reduce the uncertainties, laboriousness, and complexity of configuring the system and generating schedules. By reducing the uncertainties associated with the inherent variation it can also increase schedules' reliability.

The paper begins with a literature review that highlights possibilities, problems, and knowledge gaps associated with the use of product platforms in construction contexts. DES is then suggested as a means to address a focal identified problem: the optimization and evaluation of integrated configurations of parts, modules, and production processes in construction projects. In the following sections the research design and case study applied to explore potential benefits of the proposed solution are described. The results are then presented and discussed. Finally conclusions are presented and the contribution of the study is summarized.

## Theoretical Framework

### Platforms in the Manufacturing Industry

Platforms are defined by Jiao et al. (2007) as companies' collected predefined standards and solutions that are required to design, customize, and produce the end products for the customer. Fig. 1 illustrates a holistic view of the product fulfillment process through transformations between five domains (customer, functional, design, process, and logistics) supported by platforms throughout the value chain. Customer needs (CN) determined from market analysis are transformed into a product portfolio with a corresponding set of functional requirements (FR) (Meyer and Lehnerd 1997). These requirements are then translated into design parameters (DP), via a process involving definition of a modularized product architecture including physical building blocks, often called modules, that are stored in a product platform (Jiao et al. 2007).

Mapping of the DP into process variables (PV) and logistic variables (LV) involves the identification of connections between the products and production processes. Commonalities across the range of products lead to similarities in operations, processes, and sequences among PVs. As argued by Kusiak (2002), this allows data and knowledge about production activities to be collected and organized in chronologically and logistically appropriate sequences with clearly identified inputs and outputs. Manufacturability and cost commitment are the main concerns in the process domain, thus the process architecture is the actual enabler of the product, according to Jiao et al. (2007). The main concern when transforming a PV into a LV is to align the production configuration and supply chain decisions. Accordingly, the design of the supply chain is determined by mapping the process domain to the logistics domain (Jiao et al. 2007). Increases in customization oblige organizations to adapt their supply chain strategy, focusing more on cooperation and long-term commitment in both internal and external relations (Salvador et al. 2002). The main objective when developing customized platforms is to facilitate provision of customer-oriented variety, while retaining as little variation between products as possible, to sustain production economies of scale (Jiao et al. 2007).

The implementation of standardized and rationalized product architectures enables the provision of customized, flexible solutions (Ulrich and Eppinger 2008). A key element is the decomposition of a complex system into more manageable modules; essential and independent functional units with standardized interfaces and interactions that allow composition of products by combination (Baldwin and Clark 2000). In addition to creating product variety by interchangeability, modularization is used to decrease the complexity of design tasks. Dividing a product into modules makes it easier to understand and allows independent and parallel design work on different parts of the product (Elgaard and Miller 1998). Identifying reusable design elements, or design patterns, among products is vital in all modularization approaches (Elgaard and Miller 1998) as they provide convenient templates for experienced designers to use prior knowledge instead of re-inventing everything from scratch in every project.

### Platforms in the Construction Industry

In traditional construction practices the production process is divided into a parade of trades, while in manufacturing it is divided according to product subassemblies, often produced by independent suppliers (Robertsson and Ulrich 1998), which facilitates modularization and use of platforms. However, modular construction methods and platforms have been implemented in some construction sectors (e.g., industrialized house building) primarily to increase productivity construction and quality. Modular home builders often use large, factory-produced modules to assemble customized homes using a mixture of factory production flows and general construction activities (Nasereddin et al. 2007). According to proposals by Jensen et al. (2015), modularization

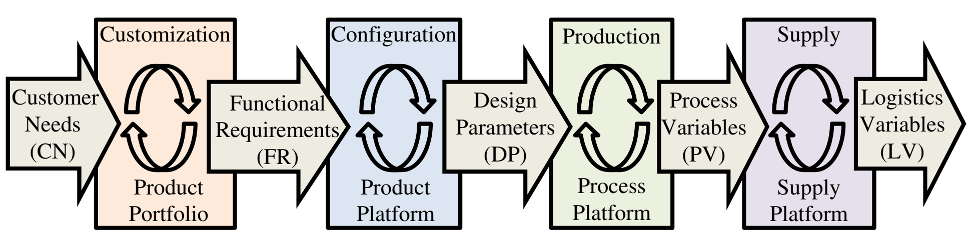



**Fig. 1.** Holistic view of product fulfillment using platforms and supply chain domains (adapted from Jiao et al. 2007)

can be implemented by applying the products-in-products concept, i.e., introducing modular structures (e.g., piles and elevator pits) at various levels of the product architecture. Construction platforms can then be seen as systems for storing knowledge and predefined product architectures, components, modules, related processes, and both internal and external relationships necessary to customize products for clients (Jansson et al. 2014).

A major difference between manufacturing and construction is that customization has prompted mass-production companies to increase product varieties to meet customers' demands and construction companies to decrease their product variety in order to increase productivity (Lampel and Mintzberg 1996; Haug et al. 2009). In addition, mass manufacturing companies mostly operate in a make-to-order or assemble-to-order supply chain, so the engineering design (DP), production process (PV), and supply chain (LV) parameters must already be at least largely preset for all possible configurations when customer orders arrive (Winch 2003). In contrast, industrialized construction companies mostly operate in an engineered-to-order context, in which most of the engineering design, production process, and supply chain parameters are still undefined when a client order arrives (Johnsson 2013; Gosling and Naim 2009).

Therefore, optimizing the balance between predefining parts and leaving parts open for engineering design in specific projects is crucial for construction companies when implementing platforms (Haug et al. 2009; Jensen et al. 2012). Leaving more open for customization places higher demands on the organization because of the associated increase in complexity in development and updates, because producers that offer more customization tend to be less efficient than others (Nahmens and Bindroo 2011). In addition, integrating off-site production and on-site construction activities is important for realizing the potential benefits of off-site production (Pan et al. 2012). Consequently, product and development managers seek opportunities for reuse between customer orders, benefits of scale, focused updating, and rational development and realization (Andreasen et al. 2004). Thus, construction companies introducing platforms must concentrate on optimizing internal processes, e.g., by introducing product configurators (Jensen et al. 2012) and/or standardized tasks and generic process sequences, so-called process patterns (Haug et al. 2009). Fig. 2 shows examples of three process patterns for concrete structures with different degrees of prefabrication. Such process patterns represent a company's knowledge and practices for making concrete structures, which can be stored (for instance) in a relational database representing the process platform.

Standardization of the product should contribute to more efficient building processes and hence reductions in production costs, and shorter delivery times. Standardization and incremental development of platforms (combined with strong commitment and loyalty from the organization) can also reduce uncertainties in the construction process and raise productivity (Thuesen and Hvam 2011). Furthermore, a process based on standardized sequences facilitates learning and experience feedback, and increases opportunities to improve the constructability of designs (Jansson et al. 2015). The modularization of products and processes also opens possibilities to introduce more industrialized methods, i.e., prefabrication. Nevertheless, little attention has been paid to process modularization and configuration, although this is essential to raise productivity (the main reason for adopting platforms in construction).

### Discrete Event Simulation in Construction

Discrete Event Simulation (DES) has been used for analyzing construction projects since the development of CYCLic Operations Network (*CYCLONE*) (Halpin and Riggs 1992). DES has proved to be an effective tool for evaluating and redesigning construction projects to improve performance. Following the release of *CYCLONE* numerous other software packages have been developed, such as State and ResOurce Based Simulation of Construction ProcEsses (*STROBOSCOPE*) (Martinez and Ioannou 1994) and *Simphony.NET* (Hajjar and AbouRizk 2002). These packages provide useful tools for project managers to simulate the dynamic interactions between resources and activities to evaluate the performance of configurations and obtain more reliable predictions of construction schedules, taking into account inherent uncertainties and unforeseen conditions (Kim and Gibson 2003).

Several authors have also proposed that DES could be an effective tool for modelling modular construction projects (Nasereddin et al. 2007; Yu et al. 2009). It has also been applied in the following relevant studies. Using *Simphony.NET*, Alvanchi et al. (2011) modeled the construction processes of a structural steel bridge to evaluate potential plans and optimize the project duration by capturing constraints associated with both the on-site construction process and off-site fabrication shops. Jeong et al. (2006) applied an Arena based supply chain simulation model of manufactured housing to identify bottlenecks and hence improve flows of materials through the chain. In addition, Nasereddin et al. (2007) introduced an approach involving the use of *ProModel* and Visual Basic to automatically develop DES models of modular housing manufacturing processes. The production system parameters (e.g., activity name, average processing time, and activity precedence) are entered into a Microsoft Excel spreadsheet, which is used to automatically generate a DES model, and the approach significantly reduced model development time. However, most previous efforts have focused on simulating production processes rather than modular construction projects.

While the benefits of using DES as a decision support tool have been widely recognized, it has not been widely adopted in practice by the construction industry (AbouRizk 2010), partly because

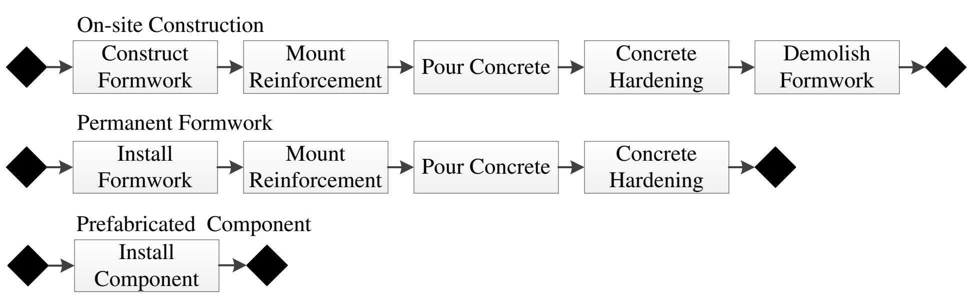



**Fig. 2.** Examples of process patterns for making concrete structures

specifying and updating relations between activities and resources in models can be time-consuming and error-prone (Skoogh and Johansson 2008). For instance, when comparing pouring concrete with crane and skip to pouring concrete with pump, the conventional approach is to build two simulation models to compare them. For pouring concrete with a crane and skip, a *CYCLONE* simulation needs to incorporate crane, concrete mix-truck, materials order, ironworker, carpenter, and concreter cycles, covering the full range of possible states associated with every cycle. All of these simulation elements and their interdependencies must be specified and integrated manually to formalize the simulation model. A separate model has to be developed to include the pump cycle and incorporate the altered logical relationships of the process if pouring concrete with pump is to be evaluated. Such small changes to the input of the simulation model often lead to the need for extensive manual modifications (Konig et al. 2012), which contributes to the low implementation rate in the project-based construction industry.

Database-driven simulation has been proposed to facilitate the building of DES models with a more intelligent and convenient basis. In this approach, as proposed for example by Randell and Bolmsjo (2001), a DES model can be parameterized by data provided through a set of sources such as data forms, tables, and spreadsheets. Jeong et al. (2009) argued that development of a database-driven simulation model is useful for automatically providing sets of parameter values regarding each included product and process for simulations. The required information may be based on the component, action, resources, sequencing (CARS) model as proposed by Fischer et al. (1999). Relational databases based on the CARS model for storing correlated information about products, processes and supply chains when developing a BIM–DES framework for planning and following-up construction activities have also been proposed by Lu and Olofsson (2014). Fig. 3 shows the internal DES mechanism in the proposed framework. Each scheduled activity module in the DES model (which contains an information packet including the required product and process information based on a CARS model) reads the required resources, materials, and preceding activities required for its execution from the linked database. The module broadcasts the resources ($R$; machinery, workforce and materials) required to perform its actions ($A$) and competes with other activities in the schedule for available resources in order to finish associated actions. In this process, materials are also consumed in order to produce components ($C$) required for the subsequent activities. Each resource module receives this broadcast message, checks its status to decide whether it can service the request and (if so) sends confirmation to the activity module. The current activity remains on hold until all required requests are satisfied, including completion of predecessor activities ($S$). When an activity has finished it is pulled from the schedule and marked as completed. If designers don't want to use module in this context, sub-model, package, or algorithm may be other possibilities. Whenever an activity is completed, all activities that have not yet begun are checked to determine whether the prerequisites for starting (status of preceding activities and resource availability) are fulfilled. This is repeated until all the activities in the schedule have been accomplished.

Relational databases facilitate exploration of alternative product configurations, process and supply chain patterns by simply changing the resource and logical relationships in the database. The simulation model reads the updated information from the database, with no need for manual checking and reformalization of the model. Process patterns that include a chain of activities and their preceding interactions facilitate the standardization, storage, and configuration of a construction sequence according to project requirements (Wu et al. 2010). These process patterns define the process platform and are used to generate simulations in which outcomes of alternative product configurations and construction methods can be compared. However, database-driven simulation should not be regarded as a replacement of DES-based construction simulation methods, rather as an approach that is valuable in certain

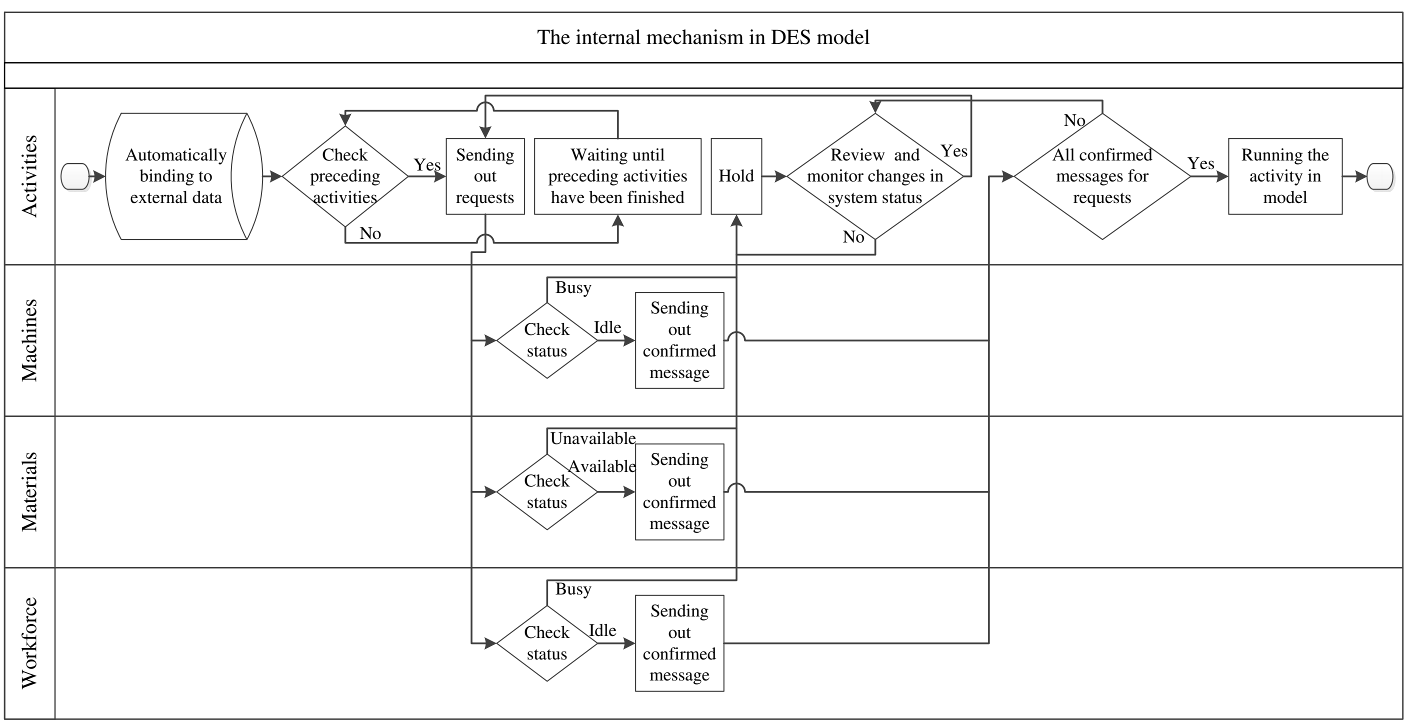



**Fig. 3.** Internal mechanism of the DES model

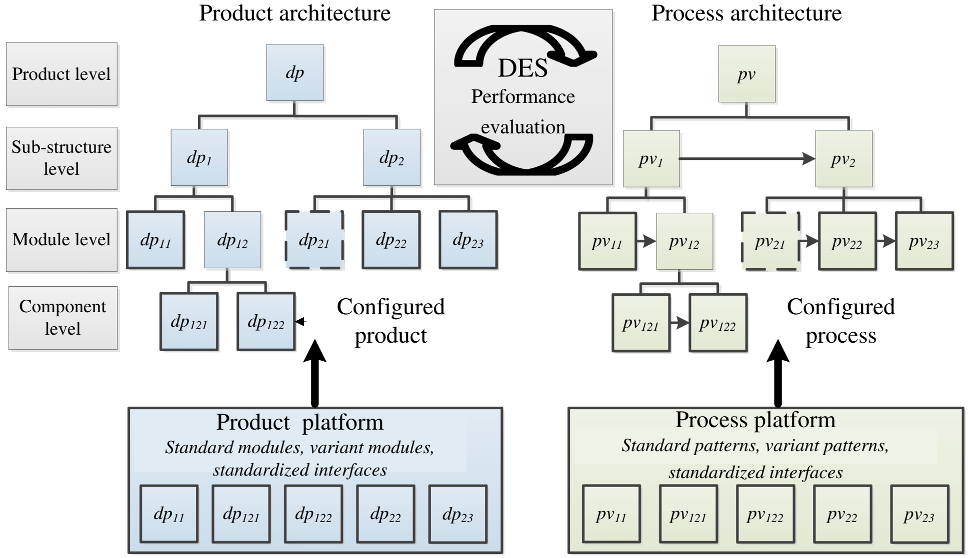



**Fig. 4.** Performance evaluation of configurable product and process platforms

circumstances (Tannock et al. 2007). It is particularly suitable for construction projects where product and process configuration data are stored and maintained in a database, and the main purpose of simulation is to evaluate the resulting configurations.

### *Knowledge Gap and Research Question*

As already mentioned, several studies have considered product modularity and configuration platforms for the construction industry (Haug et al. 2009; Jensen et al. 2012), but not tools capable of explicitly incorporating and configuring product and process data, then evaluating the resulting configurations. A database-driven DES engine as previously described has the potential to incorporate variation in product and process elements in overall performance evaluations (Fig. 4). Therefore, the research question addressed in this study is as follows: Can database-driven DES be applied to evaluate configurations generated from construction product and process platforms (and if so how can it be optimally employed)?

## Research Design

A semi-prefabricated beam bridge concept was selected to test the utility of database-driven DES for supporting the evaluation of configurations generated using product and process platforms in construction contexts. The current version of the focal concept has a span between 8 and 30 m and was developed for fast construction over water and railways by a major contractor in Sweden. It includes parts constructed by traditional on-site construction methods and prefabricated parts, thus (in this respect at least) it is a typical, representative example of a modern civil engineering structure. The bridge concept is also based on cut-to-fit modularity, facilitating assessment of effects of scalability of the product on the process performance.

To gain deeper insights and understanding of the platform design parameters (DP) and process variables (PV) a small construction project was first studied. A case study approach was chosen to collect input data required for the simulations as it is suitable for acquiring deep contextual understanding of both products and production processes (Merriam 1998).

The case study started with open-ended interviews with the platform manager and examination of technical documents and drawings of the existing bridge concept to gain an understanding of the focal context before the construction project started. These documents are usually used for support during the design process. Data about the product and process were then collected during the construction project by observing the construction work, interviewing the project manager at the site, and studying project documents such as drawings, calculations, and schedules. The observations during the construction both increased understanding of the concept and provided valuable construction times (used in the simulations) for assembly of the precast components. This was necessary because the concept is rarely constructed, so the contractor could not provide reliable construction data. Aspects such as numbers of workers, equipment use, and activity variations were discussed during the interviews at site with the project manager. The contractor responsible for the bridge construction used 20% variations in calculations because of the uncertainty often present in construction activities. This level of variation was also used during the test of the database-driven DES model. The data collected from the case study were then used in two workshops to define the product and process platform for the studied bridge concept. Finally the simulation framework developed by Lu and Olofsson (2014) was used to explore effects of different configurations of the beam bridge product and process platform. The methods used for collecting and analyzing data related to the studied bridge concept are summarized in Table 1.

## Results

### *Concept Bridge Product and Process Architecture*

A multidisciplinary team (including representatives of the contractor and supplier of prefabricated parts, consultants, and academics) was appointed to modularize the bridge concept, i.e., identify modules with standardized interfaces (DPs) and process patterns (PVs). Suitable construction methods for each module identified in the bridge concept were then selected after discussion, and selected methods were defined as process patterns (PVs) with corresponding requirements for supply chain resources. These tasks were

**Table 1.** Summary of Methods Used

| Data sources | Number | Units | Description/participants |
|---|---|---|---|
| Interviews | 2 | pcs. | Platform manager |
| | 2 | pcs. | Project manager |
| Existing documents | — | — | Drawings, technical documents |
| Construction project | — | — | Calculations, drawings, schedule |
| Observations | 2 | weeks | During prefabrication and reinforcement of superstructure |
| Workshops | 2 | pcs. | Contractor and supplier representatives, consultants, academics |

undertaken during two workshops. Several process patterns were defined for some of the DPs because the team judged that the optimal choice would depend on the locations and conditions of specific projects.

From a configured product architecture composed of modules (DPs) from the bridge product platform, a complete sequence for a corresponding construction process can be constructed from the set of process patterns (PVs) compiled in the process platform. Fig. 5 illustrates the connections between the configured product and process architectures for the bridge superstructure. The collected data and workshop inputs generated a configurable product and process architecture from which a data-driven simulation model was developed. The model is presented in the next section, followed by the results of applying the proposed methodology to real data from the construction project and workshops.

### *Configuration of the Simulation Model*

A database-driven simulation approach similar to that proposed by Lu and Olofsson (2014) is used to configure the simulation model, in conjunction (in the case study) with data acquired from the sources previously described (Fig. 3). The simulations are carried out using *Simio*, which supports both discrete and agent-based modeling (Sturrock and Pegden 2011). The authors customized *Simio* in accordance with the study's specific requirements. Fig. 6 shows a snapshot of a customized process in *Simio* in which an activity module checks the status of preceding activities.

Because the objective of this study was to assess the utility of DES for integrated evaluations of product and process configurations, only simulations of the bridge superstructure are considered here. The process patterns used facilitate the standardization, storage, and configuration of construction sequences according to project requirements. Thus, they define the process platform and are used in the simulations, which generate predicted outcomes of considered product configurations and construction methods. The required product, process, and supply chain-related information is stored in a relational database in which primary and foreign keys are used to represent the logical links between the CARS tables (Fig. 7). Relational database schemas are very flexible; individual relationships and tables can be added, modified, and removed without disturbing the rest of the schema.

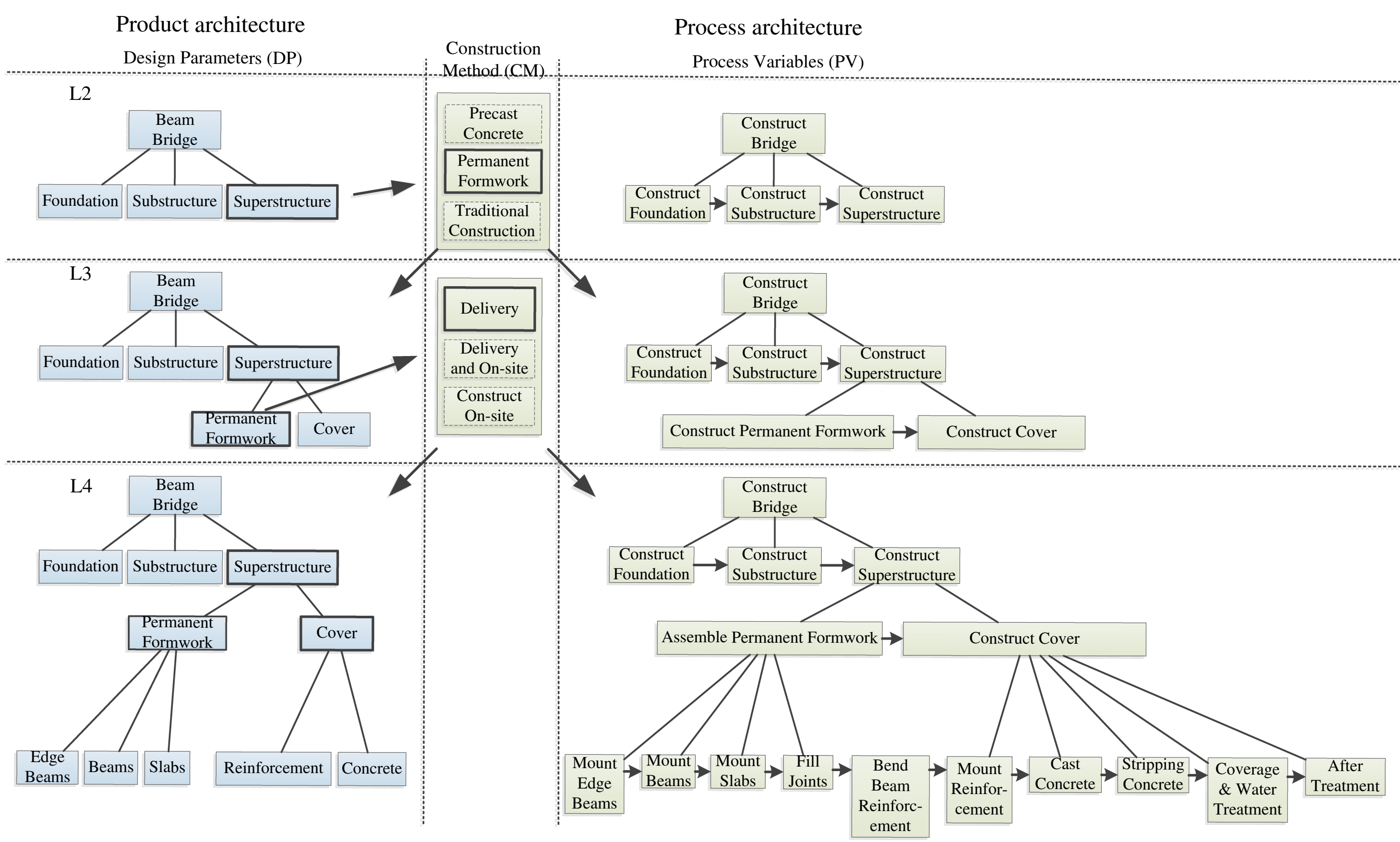



**Fig. 5.** Configured product and process architecture for the superstructure

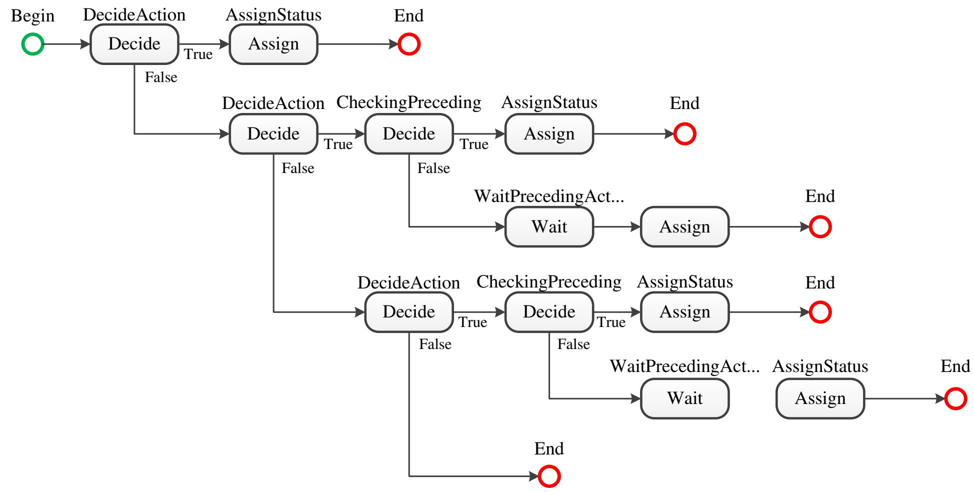



**Fig. 6.** Activity module checks preceding activities

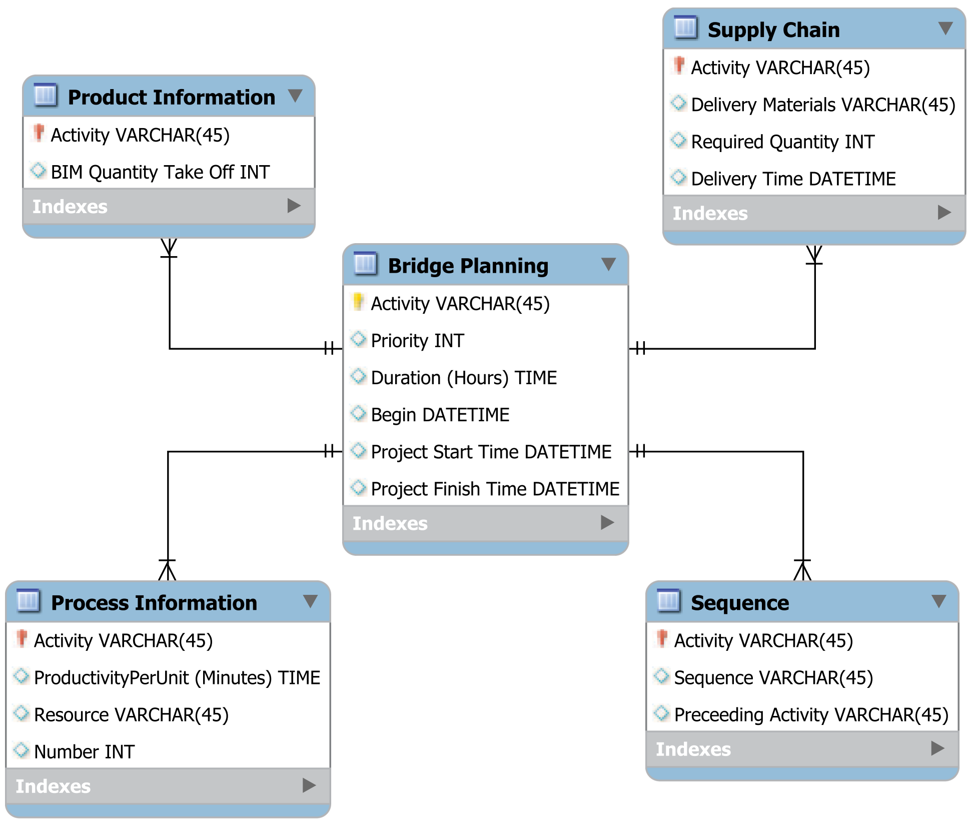



**Fig. 7.** Structure of the relational database

The activity name is the primary key used to retrieve the CARS information from the relational database. The process information table stores the productivity per unit and the required resources for the activity including machinery and workforce requirements. The product information table stores the required take-off quantities of materials for execution of the activity, and the sequence table contains the logical constraints imposed by preceding activities on the current activity. The sequence of activities can be changed if desired, provided the logical constraints set in this table are not violated. Finally, the supply chain table contains material names, arrival times, and delivery quantities. The process architecture is configured in the bridge planning table, which links product, process, and supply chain information to the activities in the construction process.

In the relational database-driven simulation model, alternative product and process scenarios can be evaluated in accordance with project requirements. For example, changes to parameters such as material quantity take-off because of a design modification can be incorporated directly in the simulation model to assess their effects. In addition, different process scenarios can be explored by changing the resource and logical relationships in the database. The main advantage of database-driven simulation is the ability

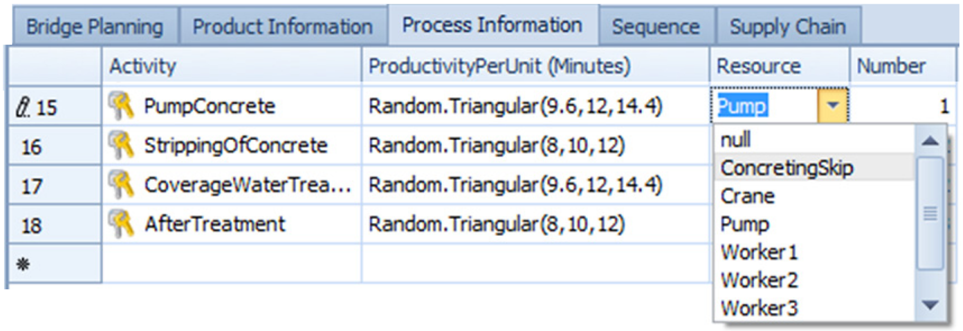



**Fig. 8.** Example of the exploration of alternative construction methods: options for the resource for pouring concrete

to reconfigure the models to assess alternative scenarios by changing inputs to the database, which allows various scenarios to be explored relatively quickly (Franz 1989). Fig. 8 shows how a resource for a specific activity can be changed when comparing alternative concrete pouring scenarios, e.g., by replacing the resource for pouring concrete from a pump to a concreting skip. A triangular (three-point) distribution is used in the presented study, although other distributions could be included as relevant parameters are generally available in practice. Often, for example, a project manager familiar with the operation may be able to make educated guesses of minimum, mode, and maximum values. In addition, triangular distributions are bounded and avoid possibilities of obtaining extreme operation times (Melton et al. 2001).

### Tests of the DES-Based Performance Evaluation

To assess the utility of the DES model for evaluating configurations of the bridge platform, four scenarios were selected and used with differing product and process configurations. These scenarios were selected partly because this is only a first test of the DES model, so it was not deemed necessary to configure and test all possible configurations, and partly because the input data provided by the contractor were limited to these configured scenarios. Different alternative configurations are tested to validate the DES model's ability to evaluate the performance of the bridge platform. A generic process architecture showing the activity sequence for the construction of the superstructure is shown in Fig. 5. The same process architecture and logical dependencies between activities were used in all tested scenarios, but the product and process configurations differed in the scale of the product and construction methods applied at the activity level, as listed in Table 2.

The construction methods compared in the scenarios were:

- Traditional mounting of reinforcement piece by piece versus use of prefabricated rebar carpets (to replace 60% of the required amount of reinforcement); and
- Two alternatives for pouring concrete: concrete pump versus concreting skip.

The construction methods have standardized but different productivity values, which affect the performance of the process. In addition, the bridge to be constructed was larger in Scenarios 3 and 4 than in Scenarios 1 and 2 (Table 2) to assess effects of product scale on the configured process.

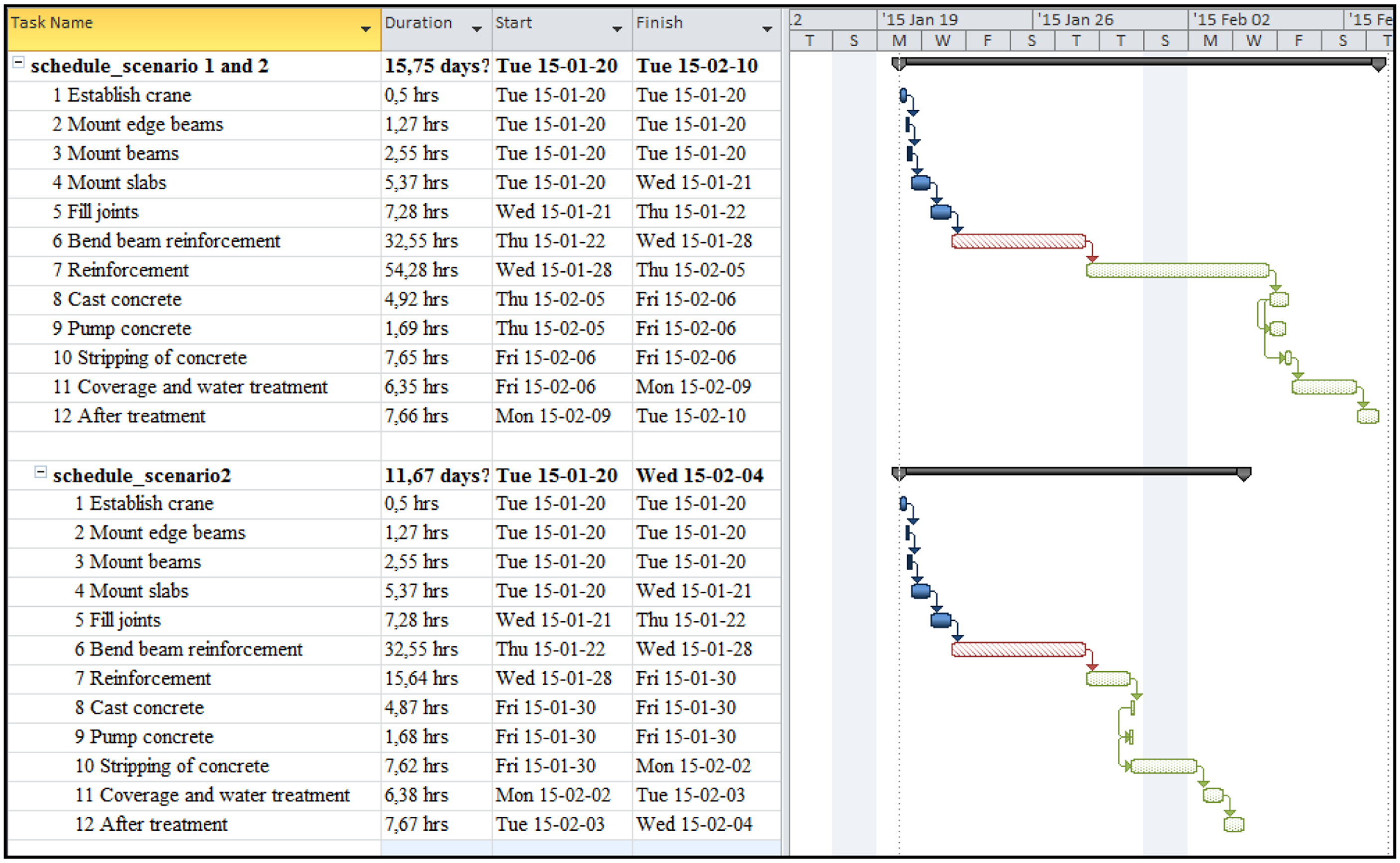
The quantities of required resources (i.e., number of workers, machinery and concrete pumps, etc.) were specified in the DES system. In all scenarios, the number of workers was held constant whereas the alternative construction methods with different productivity values influenced the project performance. According to the project manager, for small bridge projects such as this the number of workers is likely to be the same regardless of the method. For each configured scenario 1,000 simulations were run to get a reasonable estimate of the variation in required working hours (the selected performance criterion). The minimum, maximum, and mean values of the total construction duration for each scenario are summarized in Table 3. The large differences between the minimum and maximum values are attributable to the 20% variation in activities applied by the contractor because of uncertainty. Results of the simulations were discussed with and validated by the project manager for the site. The outcome from scenarios can be subsequently imported into a standard scheduling tool for further evaluation and modifications. In this study the mean outputs were imported into *Microsoft Project*, generating schedules shown in Figs. 9 and 10. The two scenarios for the smaller bridge indicate that the total construction time can be reduced by approximately 25% by using prefabricated rebar carpets (Fig. 9). The two scenarios for the larger bridge show that the total construction time is not affected by the choice of the two concrete pouring alternatives (Fig. 10), thus they do not affect the critical path because the cast concrete activity is more crucial for the total construction time. However, the working hours needed for the two pouring alternatives differ (5 h for concrete pump and 8 h for concreting skip) because of differences in productivity. This shows that a more productive construction

**Table 2.** Input Scenarios for the Assessments

| Scenario | Bridge size (m) | Activity | Productivity |
|---|---|---|---|
| Scenario 1 | $18.0 \times 8.0$ | Traditional reinforcement | 50.0 (kg/h) |
| | | Concrete pump | 21.0 ($m^3$/h) |
| Scenario 2 | $18.0 \times 8.0$ | Rebar carpets (60%) | $1.0 \times 10^3$ (kg/h) |
| | | Concrete pump | 21.0 ($m^3$/h) |
| Scenario 3 | $18.0 \times 20.9$ | Traditional reinforcement | 50.0 (kg/h) |
| | | Concrete pump | 21.0 ($m^3$/h) |
| Scenario 4 | $18.0 \times 20.9$ | Traditional reinforcement | 50.0 (kg/h) |
| | | Concreting skip | 10.0 ($m^3$/h) |

**Table 3.** Total Construction Duration Required for Each of the Tested Scenarios

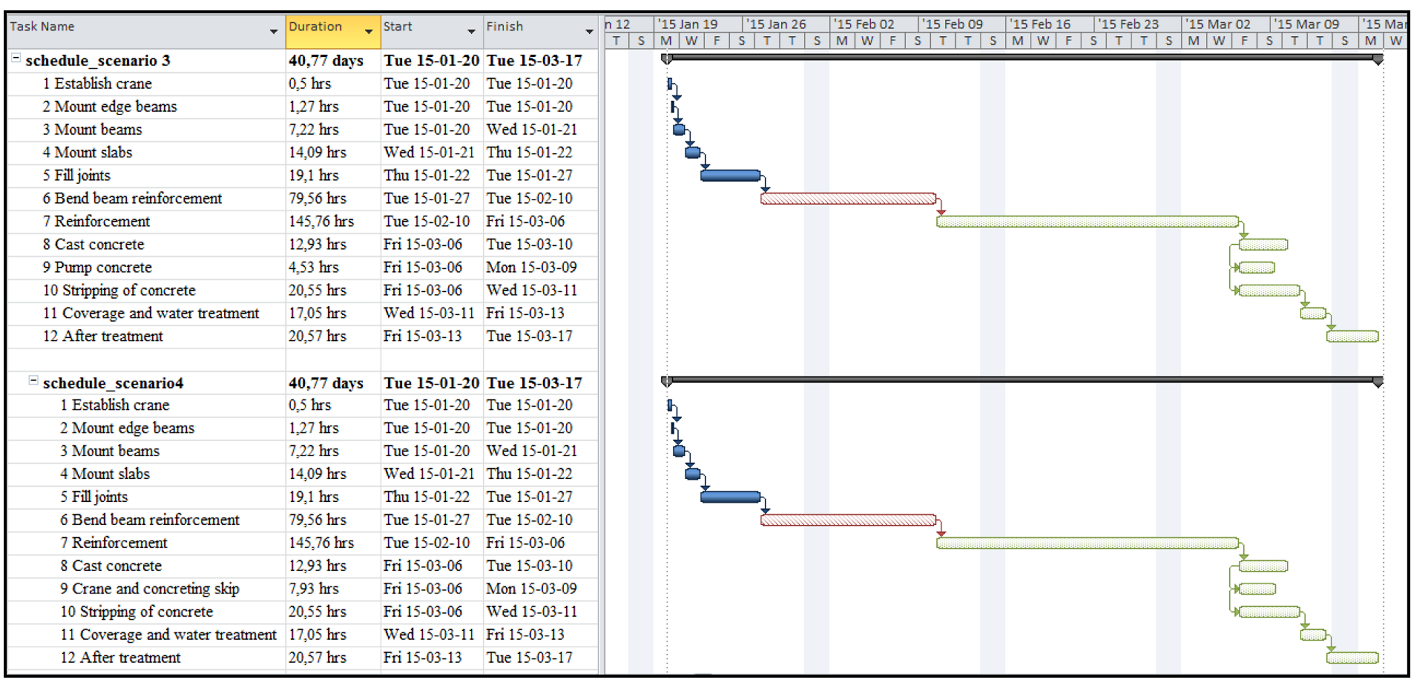
| Tested scenario | Minimum (h) | Maximum (h) | Mean (h) |
|---|---|---|---|
| Scenario 1 | 112 | 144 | 126 |
| Scenario 2 | 80 | 96 | 87 |
| Scenario 3 | 290 | 373 | 326 |
| Scenario 4 | 290 | 373 | 326 |



| Task Name | Duration | Start | Finish |
|---|---|---|---|
| **schedule_scenario 1 and 2** | **15,75 days?** | **Tue 15-01-20** | **Tue 15-02-10** |
| 1 Establish crane | 0,5 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 2 Mount edge beams | 1,27 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 3 Mount beams | 2,55 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 4 Mount slabs | 5,37 hrs | Tue 15-01-20 | Wed 15-01-21 |
| 5 Fill joints | 7,28 hrs | Wed 15-01-21 | Thu 15-01-22 |
| 6 Bend beam reinforcement | 32,55 hrs | Thu 15-01-22 | Wed 15-01-28 |
| 7 Reinforcement | 54,28 hrs | Wed 15-01-28 | Thu 15-02-05 |
| 8 Cast concrete | 4,92 hrs | Thu 15-02-05 | Fri 15-02-06 |
| 9 Pump concrete | 1,69 hrs | Thu 15-02-05 | Fri 15-02-06 |
| 10 Stripping of concrete | 7,65 hrs | Fri 15-02-06 | Fri 15-02-06 |
| 11 Coverage and water treatment | 6,35 hrs | Fri 15-02-06 | Mon 15-02-09 |
| 12 After treatment | 7,66 hrs | Mon 15-02-09 | Tue 15-02-10 |
| | | | |
| **schedule_scenario2** | **11,67 days?** | **Tue 15-01-20** | **Wed 15-02-04** |
| 1 Establish crane | 0,5 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 2 Mount edge beams | 1,27 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 3 Mount beams | 2,55 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 4 Mount slabs | 5,37 hrs | Tue 15-01-20 | Wed 15-01-21 |
| 5 Fill joints | 7,28 hrs | Wed 15-01-21 | Thu 15-01-22 |
| 6 Bend beam reinforcement | 32,55 hrs | Thu 15-01-22 | Wed 15-01-28 |
| 7 Reinforcement | 15,64 hrs | Wed 15-01-28 | Fri 15-01-30 |
| 8 Cast concrete | 4,87 hrs | Fri 15-01-30 | Fri 15-01-30 |
| 9 Pump concrete | 1,68 hrs | Fri 15-01-30 | Fri 15-01-30 |
| 10 Stripping of concrete | 7,62 hrs | Fri 15-01-30 | Mon 15-02-02 |
| 11 Coverage and water treatment | 6,38 hrs | Mon 15-02-02 | Tue 15-02-03 |
| 12 After treatment | 7,67 hrs | Tue 15-02-03 | Wed 15-02-04 |



**Fig. 9.** Possible schedules (mean values) for Scenarios 1 and 2



| Task Name | Duration | Start | Finish |
|---|---|---|---|
| **schedule_scenario 3** | **40,77 days** | **Tue 15-01-20** | **Tue 15-03-17** |
| 1 Establish crane | 0,5 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 2 Mount edge beams | 1,27 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 3 Mount beams | 7,22 hrs | Tue 15-01-20 | Wed 15-01-21 |
| 4 Mount slabs | 14,09 hrs | Wed 15-01-21 | Thu 15-01-22 |
| 5 Fill joints | 19,1 hrs | Thu 15-01-22 | Tue 15-01-27 |
| 6 Bend beam reinforcement | 79,56 hrs | Tue 15-01-27 | Tue 15-02-10 |
| 7 Reinforcement | 145,76 hrs | Tue 15-02-10 | Fri 15-03-06 |
| 8 Cast concrete | 12,93 hrs | Fri 15-03-06 | Tue 15-03-10 |
| 9 Pump concrete | 4,53 hrs | Fri 15-03-06 | Mon 15-03-09 |
| 10 Stripping of concrete | 20,55 hrs | Fri 15-03-06 | Wed 15-03-11 |
| 11 Coverage and water treatment | 17,05 hrs | Wed 15-03-11 | Fri 15-03-13 |
| 12 After treatment | 20,57 hrs | Fri 15-03-13 | Tue 15-03-17 |
| | | | |
| **schedule_scenario4** | **40,77 days** | **Tue 15-01-20** | **Tue 15-03-17** |
| 1 Establish crane | 0,5 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 2 Mount edge beams | 1,27 hrs | Tue 15-01-20 | Tue 15-01-20 |
| 3 Mount beams | 7,22 hrs | Tue 15-01-20 | Wed 15-01-21 |
| 4 Mount slabs | 14,09 hrs | Wed 15-01-21 | Thu 15-01-22 |
| 5 Fill joints | 19,1 hrs | Thu 15-01-22 | Tue 15-01-27 |
| 6 Bend beam reinforcement | 79,56 hrs | Tue 15-01-27 | Tue 15-02-10 |
| 7 Reinforcement | 145,76 hrs | Tue 15-02-10 | Fri 15-03-06 |
| 8 Cast concrete | 12,93 hrs | Fri 15-03-06 | Tue 15-03-10 |
| 9 Crane and concreting skip | 7,93 hrs | Fri 15-03-06 | Mon 15-03-09 |
| 10 Stripping of concrete | 20,55 hrs | Fri 15-03-06 | Wed 15-03-11 |
| 11 Coverage and water treatment | 17,05 hrs | Wed 15-03-11 | Fri 15-03-13 |
| 12 After treatment | 20,57 hrs | Fri 15-03-13 | Tue 15-03-17 |



**Fig. 10.** Possible schedules (mean values) for Scenarios 3 and 4

method is not always the best choice. Other methods that are more suitable according to specific project requirements, i.e., site conditions and available resources, can be as productive in terms of total construction time.

## Discussion

Partly because of the discontinuous nature of project-based engineering and construction processes, especially in civil engineering projects, the focus in early design stages is on specific engineering solutions rather than constructability. This can result in mismatches between the products and processes planned to realize them. Modularization can decrease the complexity of the product architecture and facilitate the development of platforms for storing information about the products, which can assist design processes and experience feedback. Platforms have been introduced in some construction sectors, but mostly in industrialized house building, and mostly for storing knowledge about modularized products (e.g., Jensen et al. 2012; Voordijk et al. 2006). Much less attention has been paid to process modularization and configuration, although this is also essential for raising productivity (the main motive for adopting platforms in construction). Thus, there are needs to extend the implementation of platforms in the construction sector, and to integrate modularized product and process information in them.

Convenient tools for configuring the platforms and assessing the configurations are also required. This study demonstrates the potential utility of database-driven DES for efficient evaluation of different platform configurations. The results show that viewing construction as a manufacturing process with a clearly definable process architecture increases opportunities to build simulation models that are configurable, customizable, and reusable for multiple scenarios and projects. The platform concept allows the introduction of data-driven DES systems that interpret the dynamic interdependencies and interactions between planned construction tasks in order to evaluate overall performance. There are two major benefits of using DES for evaluations. First, different configurations can be evaluated to identify which is the most suitable to meet a project's requirements (allowing flexible customization while retaining standard process patterns). A schedule can then be generated based on the information from the evaluation. Second, the evaluation of the process architecture can be used to identify constructability issues and either product or process bottlenecks, thereby assisting efforts to improve the platforms. DES has been previously shown to be an effective tool to evaluate and redesign construction projects (Halpin and Riggs 1992). However, it also provides previously neglected possibilities to evaluate effects of product configurations on the process architecture (and vice versa). Thus, there are strong reasons for applying database-driven DES in integrated analyses of product and process platform configurations.

From a managerial perspective these results highlight the importance of reducing variation and uncertainty in construction. The focus on engineering solutions in early design stages contributes to large variations in the construction process, which increases the complexity of planning tasks and risks of errors because of the specific peculiarities connected to on-site construction. Hence, estimates of the quality of a developed schedule are generally based on experience (Koskela 1992). The proposed approach allows more robust assessments, taking into account variations in the workers' productivity, the supply chain capacities, and uncertainties related to the construction site. The integration of production knowledge in the modules/sequences increases the ability to generate reliable schedules. In addition, the use of standardized process patterns enables managers and planners to change and re-evaluate multiple alternatives simply and conveniently. There is still some information that needs to be entered manually regarding available resources and probabilities of machine failures. However, the configuration and testing of alternative solutions is substantially less demanding than traditional construction project scheduling.

This study has several limitations that should be noted. First, it focuses on a standardized, scalable product offering limited variety for clients that usually demand products customized to their specific needs. The product portfolio approach proposed by Jiao et al. (2007) when introducing platforms has not been applied here. Instead, the authors have addressed the critical balance between flexibility and standardization (Haug et al. 2009) by combining scalable product architecture with variety in construction methods to allow some adaptation to different site conditions and project requirements. This is because bridges are generally considered to be complex and traditionally engineered to fit specific project requirements, hence developing platforms incorporating broad variety in the products could be difficult to manage because of the need for numerous, continuous updates. However, optimizing the balance between product variety and process standardization is essential for construction companies transitioning toward customized standardization (Haug et al. 2009; Gann 1996). Clearly, the high levels of product standardization applied in the platforms considered in this study restrict the ability to meet specific client needs (CN) and functional requirements (FR), and thus offer suitable products for specific market segments. More attention is required in further studies to the scope for including greater flexibility in the product architecture and database-driven DES models.

Another limitation of this rather small-scale exploratory study is that it focuses on a small part of the bridge, and full-scale studies are needed to validate the results. In addition, although effects of varying resource allocations and machinery associated with the chosen construction method have been examined, the study only examines activity level configurations. Thus, examinations of configurations at higher hierarchical levels are also needed. Furthermore, the only evaluation parameter used is the time required. This can be partly justified because increasing productivity is the main driver for industrialized civil engineering (Larsson et al. 2014), but other performance variables, particularly cost and energy consumption, should be integrated into the database to allow evaluation of overall performance of potential configurations. Construction causes vast environmental problems (Ding 2008), causing clients and other influential organizations to adopt broader project evaluation criteria, often incorporating all three aspects of sustainability (economic, environmental, and social). To meet such holistic, sustainability-oriented views of project performance further research and development is required to incorporate other performance variables in platforms and associated models.

## Conclusions

DES has been widely used to evaluate different construction methods or plans, so it can clearly be applied to evaluate configurations generated from construction product and process platforms. The key contribution of this study is the provision of an approach to determine possible options, and build a simulation model for each option, without time-consuming updates of the models. The presented results provided evidence that the introduction of database-driven simulation can support this by integrating product and process information, even in discontinuous, project-based industrial sectors. The results specifically demonstrated that database-driven simulation can be used to evaluate effects of different configurations of construction methods on working time requirements. Further, it showed that simulations can be used to identify bottlenecks related to product and process architecture, thereby assisting efforts to optimize the construction process. The proposed approach offers new opportunities for project planners and project managers to reduce the complexities, uncertainties, and errors associated with traditional methods for scheduling construction projects.

After a formal description of the DES model, the paper described an application of the model in which four configurations of the product and process architecture of a semi-prefabricated bridge concept were evaluated. This provided empirical evidence that the model can support overall platform evaluation from a time perspective. The results particularly showed that the database-driven DES model can evaluate various construction methods and help managers to choose appropriate options to meet specific project requirements. The paper is intended to contribute to understanding of the utility of database-driven DES for evaluating and developing product and process platforms in civil engineering, thereby helping both managers and researchers to improve systems for planning civil engineering projects, and reduce the major uncertainties that exacerbate scheduling problems and cost overruns.

## References


AbouRizk, S. (2010). "Role of simulation in construction engineering and management." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000220, 1140–1153.

Alvanchi, A., Azimi, R., Lee, S., AbouRizk, S. M., and Zubick, P. (2011). "Off-site construction planning using discrete event simulation." *J. Archit. Eng.*, 10.1061/(ASCE)AE.1943-5568.0000055, 114–122.

Andreasen, M. M., Mortensen, N. H., and Harlou, U. (2004). "Multi product development—New models and concepts." *Proc., 15th Symp. on Design for X*, H. Meerkamm, ed., Design Society, Bristol, U.K., 75–86.

Baldwin, C. Y., and Clark, K. B. (2000). *Design rules: The power of modularity*, MIT Press, Cambridge, MA.

Bonev, M., Michael, W., and Hvam, L. (2015). "Utilizing platforms in industrialized construction." *Constr. Innovat.*, 15(1), 84–106.

Ding, G. K. (2008). "Sustainable construction—The role of environmental assessment tools." *J. Environ. Manage.*, 86(3), 451–464.

Elgaard, P., and Miller, T. D. (1998). "Designing product families." *Design for Integration in Manufacturing, Proc., 13th IPS Research Seminar*, J. O. Riis, ed., Aalborg Univ., Aalborg, Denmark, 267–275.

Fischer, M., Aalami, F., Kuhne, C., and Ripberger, A. (1999). "Cost-loaded production model for planning and control." *Proc., 8th Int. Conf. on Durability of Building Materials and Components*, M. A. Lacasse, and D. J. Vanier, eds., National Research Council of Canada, Ottawa, 2813–2824.

Franz, L. S. (1989). "Data-driven modeling: An application in scheduling." *Decis. Sci.*, 20(2), 359–377.

Gann, D. M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan." *Constr. Manage. Econ.*, 14(5), 437–450.

Goodrum, P. M., Zhai, D., and Yasin, M. F. (2009). "Relationship between changes in material technology and construction productivity." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2009)135:4(278), 278–287.

Gosling, J., and Naim, M. M. (2009). "Engineer-to-order supply chain management: A literature review and research agenda." *Int. J. Prod. Econ.*, 122(2), 741–754.

Hajjar, D., and AbouRizk, S. (2002). "Unified modeling methodology for construction simulation." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2002)128:2(174), 174–185.

Halpin, D. W., and Riggs, L. S. (1992). *Planning and analysis of construction operations*, Wiley, New York.

Haug, A., Ladeby, K., and Edwards, K. (2009). "From engineer-to-order to mass customization." *Manage. Res. News*, 32(7), 633–644.

Jansson, G., Johnsson, H., and Engström, D. (2014). "Platform use in systems building." *Constr. Manage. Econ.*, 32(1–2), 70–82.

Jansson, G., Lundkvist, R., and Olofsson, T. (2015). "The role of experience feedback channels in the continuous development of house-building platforms." *Constr. Innovat.*, 15(2), 236–255.

Jensen, P., Lidelöw, H., and Olofsson, T. (2015). "Product configuration in construction." *Int. J. Mass Custom.*, 5(1), 73–92.

Jensen, P., Olofsson, T., and Johnsson, H. (2012). "Configuration through the parameterization of building components." *Autom. Constr.*, 23, 1–8.

Jeong, J. G., Hastak, M., and Syal, M. (2006). "Supply chain simulation modeling for the manufactured housing industry." *J. Urban Plann. Dev.*, 10.1061/(ASCE)0733-9488(2006)132:4(217), 217–225.

Jeong, K., Wu, L., and Hong, J. (2009). "IDEF method-based simulation model design and development framework." *J. Ind. Eng. Manage.*, 2(2), 337–359.

Jiao, J., Simpson, T., and Siddique, Z. (2007). "Product family design and platform-based product development: A state-of-the-art review." *J. Intell. Manuf.*, 18(1), 5–29.

Johnsson, H. (2013). "Production strategies for pre-engineering in house-building: Exploring product development platforms." *Constr. Manage. Econ.*, 31(9), 941–958.

Kim, K., and Gibson, G. E. (2003). "Interactive simulation modeling for heavy construction operations." *Autom. Constr.*, 12(1), 97–109.

Konig, M., Koch, C., Habenicht, I., and Spieckermann, S. (2012). "Intelligent BIM-based construction scheduling using discrete event simulation." *Proc., 2012 Winter Simulation Conf.*, C. Larogque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, eds., ACM Press, New York, 1–12.

Koskela, L. (1992). *Application of the new production philosophy to construction*, Center for Integrated Facility Engineering, Stanford Univ., Stanford, CA.

Kusiak, A. (2002). "Integrated product and process design: A modularity perspective." *J. Eng. Des.*, 13(3), 223–231.

Lampel, J., and Mintzberg, H. (1996). "Customizing customization." *Sloan. Manage. Rev.*, 38(1), 21–30.

Larsson, J., Eriksson, P. E., Olofsson, T., and Simonsson, P. (2014). "Industrialized construction in the Swedish infrastructure sector: Core elements and barriers." *Constr. Manage. Econ.*, 32(1–2), 83–96.

Lu, W., and Olofsson, T. (2014). "Building information modeling and discrete event simulation: Towards an integrated framework." *Autom. Constr.*,44, 73–83.

Martinez, J. C., and Ioannou, P. G. (1994). "General purpose simulation with stroboscope." *Proc., 26th Conf. on Winter Simulation*, J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila, eds., Society for Computer Simulation International, Vista, CA., 1159–1166.

Melton, R. H., Culbreth, C. T., Roberts, S. D., and Joines, J. A. (2001). "Automation in modeling: Using automation for finishing room capacity planning." *Proc., 33rd Conf. on Winter Simulation*, B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds., Institute of Electrical and Electronics Engineers, Washington, DC, 959–967.

Merriam, S. B. (1998). *Qualitative research and case study applications in education. Revised and expanded from case study research in education*, Jossey-Bass, San Francisco.

Meyer, M. H., and Lehnerd, A. P. (1997). *The power of product platforms—Building value and cost leadership*, Free Press, New York.

Nahmens, I., and Bindroo, V. (2011). "Is customization fruitful in industrialized homebuilding industry?." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000396, 1027–1035.

Nasereddin, M., Mullens, M. A., and Cope, D. (2007). "Automated simulator development: A strategy for modelling modular housing production." *Autom. Constr.*, 16(2), 212–223.

Pan, W., Gibb, A. G., and Dainty, A. R. (2012). "Strategies for integrating the use of off-site production technologies in house building." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000544, 1331–1340.

Randell, L. G., and Bolmsjo, G. S. (2001). "Database driven factory simulation: A proof-of-concept demonstrator." *Proc., 33rd Conf. on Winter Simulation*, B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds., Institute of Electrical and Electronics Engineers, Washington, DC, 977–983.

Robertson, D., and Ulrich, K. (1998). "Planning for product platforms." *Sloan. Manage. Rev.*, 39(4), 19–31.

Salvador, F., Forza, C., and Rungtusanatham, M. (2002). "Modularity, product variety, production volume, and component sourcing: Theorizing beyond generic prescriptions." *J. Oper. Manage.*, 20(5), 549–575.

Segerstedt, A., and Olofsson, T. (2010). "Supply chains in the construction industry." *Supp. Chain. Manage.*, 15(5), 347–353.

*Simio version 7* [Computer software]. Simio LLC, Pittsburgh.

Skoogh, A., and Johansson, B. (2008). "A methodology for input data management in discrete event simulation projects." *Proc., 40th Conf. on Winter Simulation*, S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, and J. W. Fowler, eds., ACM Press, New York, 1727–1735.

Sturrock, D. T., and Pegden, C. D. (2011). "Recent innovations in Simio." *Proc., 2011 Winter Simulation Conf.*, S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, eds., ACM Press, New York, 52–62.

Tannock, J., Cao, B., Farr, R. and Byrne, M. (2007). "Data driven simulation of the supply chain—Insights from the aerospace sector." *Int. J. Prod. Econ.*, 110(1), 70–84.

Thuesen, C., and Hvam, L. (2011). "Efficient on-site construction: Learning points from a German platform for housing." *Constr. Innovat.*, 11(3), 338–355.

Ulrich, K., and Eppinger, S. (2008). *Product design and development*, 5th Ed., McGraw-Hill/Irwin, New York.

Voordijk, H., Meijboom, B., and Job, D. H. (2006). "Modularity in supply chains: A multiple case study in the construction industry." *Int. J. Oper. Prod. Manage.*, 26(6), 600–618.

Winch, G. M. (2003). "How innovative is construction? Comparing aggregated data on construction innovation and other sectors—A case of apples and pears." *Constr. Manage. Econ.*, 21(6), 651–654.

Wu, I., Borrmann, A., Beißert, U., König, M., and Rank, E. (2010). "Bridge construction schedule generation with pattern-based construction methods and constraint-based simulation." *Adv. Eng. Inform.*, 24(4), 379–388.

Yu, H., Tweed, T., Al-Hussein, M., and Nasseri, R. (2009). "Development of lean model for house construction using value stream mapping." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2009)135:8(782), 782–790.

# PAPER III

**Leadership in Civil Engineering: Effects of Project Managers' Leadership Styles on Project Performance**

Johan Larsson, Per Erik Eriksson, Thomas Olofsson, Peter Simonsson

Published in

*Journal of Management in Engineering, (2015), 31(6)*

# Leadership in Civil Engineering: Effects of Project Managers' Leadership Styles on Project Performance

Johan Larsson[1]; Per Erik Eriksson[2]; Thomas Olofsson[3]; and Peter Simonsson[4]

**Abstract:** Successful completion of a construction project requires the ability to coordinate activities of numerous individuals participating in tasks that often have high levels of complexity and uncertainty. Thus, the project manager plays crucial roles, often setting the ground rules and fostering a collective approach that strongly influence project performance. However, there are uncertainties regarding various aspects of project managers' influence, particularly related to their leadership style. Thus, the research reported in this paper explores the degrees to which leadership styles affect project outcome and specific leadership styles are appropriate in specific types of situations. The analysis is based on a questionnaire survey of views of 162 project managers employed by the largest public infrastructure client in Sweden. The results indicate that project performance (in terms of cost, time, and quality) is affected by leadership, suggesting that the project manager's leadership style is a significant project success factor. Further, the results show that certain styles are appropriate in different situations, highlighting the importance of a contingency perspective. **DOI:** **10.1061/(ASCE)ME.1943-5479.0000367.** *© 2015 American Society of Civil Engineers.*

## Introduction

Construction projects are complex sequences of activities, both planned and unplanned, performed to meet objectives that are often (but not always) strictly defined. Their success is traditionally assessed in terms of budget, schedule, and quality (Belassi and Tukel 1996; Chua et al. 1999). Recently, however, additional criteria such as health and safety, environmental sustainability, customer satisfaction, and technical performance have grown in importance (Chan et al. 2002; Eriksson and Westerberg 2011).

Factors determining the success of construction projects, often called critical success factors, are frequently debated in construction management literature. Different studies have focused on different types of success factors. Some stress the importance of factors related to human resource management, such as commitment and competence within the project management team (e.g., Chua et al. 1999). Others emphasize the importance of project management practices, such as planning and scheduling, and well-defined joint understanding of the project's scope and complexity (Songer and Molenaar 1997). A third strand of literature focuses on effects of the applied contracting and procurement strategies on project performance (e.g., Konchar and Sanvido 1998; Ibbs et al. 2003; Hale et al. 2009).

However, most literature in the construction management field does not include the project manager and leadership style in the evaluation of project success factors. According to, e.g., Turner and Müller (2005), the relationships between leadership and performance have been more commonly addressed in general management literature, in which the leadership style, competence, and personality of managers are often recognized as factors that significantly influence project performance. These concepts were addressed and formalized in the contingency school of leadership in the 1960s; e.g., Hersey and Blanchard (1969) suggesting that different leadership styles are suitable in certain situations and that no type of leader is universally suitable for all situations. Similarly, in a recent study of project management professionals, Müller and Turner (2007) concluded that different leadership styles are appropriate for different types of projects, or more strictly, projects with different characteristics. The construction industry is highly heterogeneous and project characteristics vary substantially in terms of size, complexity, customization, and time pressure (Eriksson 2010). Thus, greater understanding of the effects of different leadership styles on performance in projects with different characteristics is vital.

The Swedish Transport Administration (STA), the largest public infrastructure client in Sweden, has unique potential to influence the Swedish civil engineering sector, not only by setting norms and regulations but also by choosing contract forms and project requirements. Larsson et al. (2014) mapped barriers for industrialization of the sector in Sweden and found that STA's practices are the most influential factors. Infrastructure projects run by STA are regulated by a comprehensive standardized procedure, a process platform, including both a stage-gate process and numerous mandatory documents. This platform does not distinguish projects with different characteristics; hence STA applies the same business strategy for both large complex projects and small more standardized projects. Accordingly, STA applies a standardization strategy rather than a contingency strategy. Diverse actors, both internal and external, with various roles are involved throughout the stage-gate process, but the project manager is the only person involved during the whole project lifecycle. A project manager appointed by STA thereby has a comprehensive overview of and impact on all stages of the assigned project, from the initial internal feasibility study through procurement, construction work, and handover of the completed structures. Hence, the project managers may be critical

[1]Researcher, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden (corresponding author). E-mail: johan.p.larsson@ltu.se

[2]Professor, Division of Innovation and Design, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: pererik.eriksson@ltu.se

[3]Professor, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: thomas.olofsson@ltu.se

[4]Bridge Specialist, Swedish Transport Administration, Sundsbacken 2, SE-971 25 Luleå, Sweden. E-mail: peter.simonsson@trafikverket.se

Note. This manuscript was submitted on July 24, 2014; approved on January 24, 2015; published online on March 13, 2015. Discussion period open until August 13, 2015; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, © ASCE, ISSN 0742-597X/04015011(11)/$25.00.

success factors in their projects, but there are uncertainties regarding the variation in their leadership styles and its influence on the projects' success.

Thus, the research reported in this paper had two main aims, as follows: (1) explore effects (if any) of STA project managers' leadership style on project performance and thus if the manager should be recognized as a project success factor, and (2) assess whether different leadership styles are appropriate for different types of projects.

## Leadership Schools

Five schools have emerged in leadership literature during the last 50 years, some of which suggest that different leadership styles are appropriate in different competitive situations. According to Turner and Müller (2005) these leadership schools are all derived from general management literature, based on considerations of leadership in organizations, and have made distinct contributions (Table 1).

The behavior school that dominated in the mid-1900s focused on how leaders behave and managers act in different situations (Tannenbaum and Schmidt 1958). According to Bennis (1959) behaviors can be adopted, implying that managers can learn or be taught to be effective. The contingency school holds that no leadership style is appropriate for all situations and seeks matches between styles and situations. Advocates have provided evidence that behaviors related to (1) tasks, and (2) relations are distinctive parameters, and incorporated this two-factor concept in several theories, e.g., least-preferred coworker (LPC) contingency theory (Fiedler 1978) and path–goal theory (House 1971). The more recent schools build upon the contingency perspective. The main contribution of the visionary school, proposed by Bass (1985), is the identification of two types of leadership [(1) transactional, and (2) transformational], measured by multifactor leadership questionnaires. According to Avolio et al. (1999) components of these leadership types recognized by subsequent researchers have varied to some extent, but the essence of transactional leadership embraces contingent reward behavior, rewarding followers for achieving goals, taking actions when tasks are not executed as planned, and establishment of a clear focus on processes and goals. In contrast, transformational leadership is characterized by charisma, intellectual stimulation, and inspirational motivation through a focus on inspiring followers with new ideas.

The last two schools [(1) emotional intelligence, and (2) competency] have developed during the 2000s. The first holds that emotional intelligence influences leadership success more strongly than intellectual capability (Salovey and Mayer 1990). Four dimensions of emotional intelligence, two personal and two social, were identified by Goleman et al. (2002). Six leadership styles were derived (from the four dimensions), as follows: (1) visionary, (2) coaching, (3) affiliative, (4) democratic, (5) pacesetting, and (6) commanding. These leadership types are all suggested to be advantageous in particular types of situations, e.g., visionary may be most appropriate for a company seeking a new direction.

The last of the mentioned leadership schools is the competency school, which focuses on competencies of effective leaders (Turner and Müller 2005). According to Dulewitz and Higgs (2005) these competences can be learned, so leaders can be made. Different combinations of competencies are said to be appropriate in different situations, e.g., transactional leaders are appropriate in straightforward situations while transformational leaders are more appropriate in more complex situations.

Contingency school concepts have been criticized, e.g., by Yukl (2011), for having limited scope. A particular criticism is that the two-factor conceptualization and broad categories of leadership styles, as described for instance by Fiedler (1978), do not measure all aspects of effective leadership. However, they were applied in the theoretical framework of the research reported in this paper since the hypothetical basis is that project managers with different leadership styles are appropriate in different situations (in this paper, projects with different characteristics), so leadership style may be regarded as a significant project success factor. Furthermore, key contingency concepts have been validated, at least partially, by considerable research (e.g., Ashour 1973; Graen et al. 1970). Thus, they are outlined in more detail in subsequent paragraphs.

### *Contingency School*

Leadership is a process that according to the contingency school involves three main aspects, as follows: (1) leader, (2) followers or team, and (3) situation (House 1971). The essential idea is that the leader must assist the team (the followers) in finding a suitable path to achieve their goals and then helping them to do so (Hersey and Blanchard 1969). Hence, the success of the process will depend on a combination of all three of these aspects. Different theories within the contingency school have emerged, but all are similar in the sense that the leaders should make their styles contingent on certain aspects of the followers and the situation to improve the effectiveness of their leadership (Fiedler 1995; House 1971; Vroom and Yetton 1973).

Contingency theory suggests that two sets of leadership variables associated with followers (in this paper, project team members) are important, as follows: (1) a leader must be sufficiently acceptable to the followers for them with regards to style

**Table 1.** Modern Schools of Leadership

| School | Time period | Key contribution | Important researchers |
|---|---|---|---|
| Behavior | 1940–1960 | Leaders can be made, effective leaders adopt certain behaviors | Tannenbaum and Schmidt (1958) |
| Contingency | 1960–1980 | Effective leadership depends on the situation, seeks matches between situations and leadership styles | Fiedler (1978) and Hersey and Blanchard (1969) |
| Visionary | 1980–2000 | Two types of leadership identified, as follows: (1) transactional, i.e., goal/process-oriented, and (2) transformational, i.e., people-oriented | Bass (1985) and Keegan and Den Hartog (2004) |
| Emotional intelligence | 2000 | Emotional intelligence, with four identified dimensions, is more important than intellectual capability | Salovey and Mayer (1990) and Goleman et al. (2002) |
| Competency | 2000 | Identifies competencies of effective leaders, which can be inherited or learned | Dulewicz and Higgs (2005) |

either as an instant source of satisfaction or as directly instrumental in realizing future satisfaction, and (2) followers' perceptions of their own skills and abilities to achieve certain tasks can also affect the effectiveness of particular leadership styles (Lorinkova et al. 2013; Mitchell et al. 1975). Contingency theory suggests that both followers' characteristics and behaviors are important for achieving a satisfactory outcome (Hersey and Blanchard 1969). However, in the context of the research reported in this paper the followers, the internal resources, can be considered as a fixed parameter in the sense that these are picked from the same group of people and also have the same pools of equipment and materials available to support all projects. Furthermore, when appointing a project manager to a specific project, the other project members have not been allocated to the project. The selection of project manager can therefore not be based on the characteristics of the followers.

The contingency school recognizes three main factors related to the situation, as follows: (1) task, (2) formal authority system, and (3) primary work group (Turner and Müller 2005). Each of these three factors can influence the leadership situation in one of three ways, as follows: (1) motivational factors, (2) constraints for the behavior of the followers, and (3) rewards for the behavior of the followers. However, these variables may also affect the impact of various leadership styles. In the research reported in this paper the situation is mainly related to the task in terms of different project characteristics, which may require different leadership styles, while the formal authority system is fixed due to the standardized process platform used in all projects.

Regarding the leader aspect, the contingency school recognizes four leadership styles (House 1971), as follows: (1) achievement-oriented, (2) directive, (2) participative, and (4) supportive. Regarding the achievement-oriented leadership style, leaders who adopt this style are supportive but assign demanding tasks to the followers and expect them to make maximal efforts to complete them. Thus, they are highly result-driven and expect others to behave in the same manner. The second leadership style is the directive, the most structured of the four. It includes telling followers not only what tasks to do, but also how to perform those (Lorinkova et al. 2013). Leaders who adopt the third style, participative, tend to share work-related problems with the team, by discussing them and suggesting potential solutions as inputs for the decision-making process. They are often perceived as engaging and inspiring, concerned with finding the best possible solutions for problems. Finally, supportive leaders show genuine concern about the followers' well-being, treating them equally and ensuring that everyone is heard in group situations, regarding team building and creating joint goals as more important than individual achievement (House 1971).

However, the four leadership styles described by House (1971) lack distinctiveness to some extent. A similar set of leadership styles was subsequently developed by Adizes (1976); producer, administrator, entrepreneur/developer, and integrator (PAEI). There are clear similarities between the four leadership styles recognized within the contingency school by House (1971) and the PAEI leadership styles. However, the PAEI model emphasizes the differences between the styles more strongly, which enhance the discriminant validity of the model. In addition, the entrepreneur, who is innovative and focused on long-term achievements, is not included in the initial contingency school typology. This type of leadership style is also evident within the transformational leadership described by Bass (1985). Therefore, in the research reported in this paper the four PAEI leadership styles by Adizes (1976) have been used to investigate possible matches between specific leadership styles and STA projects with specific characteristics (situations).

## Producer, Administrator, Entrepreneur/Developer, and Integrator Model

The methodology presented by Adizes (1976) was designed to assist organizations to reach and remain in a dynamic state that optimally balances flexibility and control as situations change throughout the organizational lifecycle. Obtaining a suitable balance between control and flexibility is critical in civil engineering projects (Osipova and Eriksson 2013), thus leadership styles providing such a balance are presumably most appropriate in the chosen empirical context. The PAEI model is essentially based on organization-oriented contingency theory, assuming that there is no single optimal type of organization (Adizes 1979), and recognizing the fit or alignment of organizational resources to environmental opportunities and threats (Aldrich 1979). The leadership styles included in the PAEI model and recognized by the contingency school is highly symbolic, and both hold that under normal circumstances people can operate in all four, but that all leaders are naturally strongest in only one of the styles. The four types of leaders described by Adizes (1976), and used in the research reported in this paper, are briefly discussed, as follows:

1. Producers are highly energetic and active leaders. They fit best in a busy environment and like to attain tangible results quickly. They feel highly rewarded every time they can declare a task complete. Producers dislike fussy details, ambiguous situations, and abstract considerations. They are achievement-oriented and much more interested in getting a task done than in ensuring other people's well-being.
2. Administrators are quiet, cautious leaders who are not only concerned with what people should do but also how they should perform it. They need to thoroughly understand processes and situations before they can comfortably participate in addressing them. Unplanned activities feel distressingly chaotic to them. Administrators prefer to construct a system of routines and conventions for ongoing activities, so they can be conducted in the smoothest and least disruptive manner possible. Administrators bring structure, stability, and order to collective activities, by giving clear directions. They make decisions slowly and carefully because they track each detail to make certain it is handled properly.
3. Entrepreneurs (termed developers, because entrepreneur also means something else in the studied context, thus use of the term could lead to confusion) are not interested in achieving short-term results and are easily bored by routine activities. Instead, they are energized by novel challenges, exciting opportunities, and changes. Hence, they focus on larger future potential achievements rather than short-term efficiency. Their excitement is highly infectious and they love being the center of attention.
4. Integrators focus on managing interpersonal relationships that allow the organization to function collectively. They are team-builders that support followers and attend to their needs, views, and conflicts to foster a constructive working environment. Integrators are less concerned about formal roles and titles than about people pulling together to achieve their joint goals. Integrators try to align concerns and interests, turning followers into a combined and unified force, integrated with the social surroundings.

## Hypotheses and Research Model

Points highlighted in the previous review indicate that different leadership styles are appropriate for different types of projects, so the leadership style of managers is likely to be a critical success factor for the performance of projects in terms of time, cost, and quality. The underlying rationale is that there is no universally optimal leadership style; instead each leadership style is suitable in different situations. In a project management context, different project characteristics serve as contingency factors that can be used to distinguish situations in which different leadership styles may be suitable. Many researchers have discussed how different project characteristics affect the management and governance of construction projects (e.g., Chang and Ibbs 2006; Eriksson 2010; Liao et al. 2011). Characteristics that often are emphasized include the (1) size or duration of the project, (2) speed or burn rate of the project, (3) contract type, and (4) project complexity. These four project characteristics found in prior literature are particularly important in civil engineering projects. Thus, these are the contingency factors considered in the research reported in this paper.

Regarding the first contingency factor, the size or duration of the project, prior research on mega projects suggests that the management and governance approaches required in large projects with long durations differ from those required in small projects (del Puerto et al. 2014; Han et al. 2009). In the research reported in this paper this contingency factor was measured by duration (months). The second contingency factor, burn rate (the speed at which projects proceed and consume money), is operationalized as turnover in Swedish Krona (SEK) divided by duration (months). Prior research has highlighted problems with delays and schedule overruns (Assaf et al. 2006; Sweis et al. 2008), indicating that the speed at which projects proceed should be taken into account when managing and governing projects. The third contingency factor, the contract form (project delivery system), has been intensively discussed in both previous studies (e.g., Konchar and Sanvido 1998; Ibbs et al. 2003) and the Swedish civil engineering industry. The STA is currently increasing frequencies of design–build (DB) contracts; hence potential effects of these contacts on the industry's productivity are highly interesting in the current environment. The fourth contingency factor, the complexity of the project, has been shown (unsurprisingly) to strongly influence project management and complicate delivery (e.g., Gidado 1996; Gransberg et al. 2013). Civil engineering projects normally involve a larger number of actors, and the number increases with increases in complexity. Thus, complexity (measured in terms of the number of actors involved in the project) was included in the research reported in this paper.

To meet the aims of the research reported in this paper, effects of alignment of the four PAEI leadership styles with these four project characteristics were assessed on key aspects of project performance. More specifically, specific hypotheses were tested regarding effects of each of the four leadership styles proposed by Adizes (1979) on STA infrastructure projects differing in burn rate, duration, contract type, and complexity. Numerous other potentially interesting issues and associated hypotheses could be addressed, but due to limitations in data collection and space for the paper only one hypothesis for each leadership style is formulated (as described in subsequent paragraphs) and tested.

High-speed projects tend to need fast and concrete decisions/deliveries to be successful (Eisenhardt 1989). Burn rate is a measure of the speed at which projects proceed and consume money. Hence, high burn rates are indicative of projects with high time pressures and critical schedule-related challenges, which thus require an intense focus on efficiency and rapid delivery. In two survey studies responded to by 147 and 93 clients, consultants, and contractors, Chan and Kumaraswamy (1997) found that clients' slow speed of decision-making was one of the most important factors for project delays. Hence, client project managers focusing on efficiency and speed (i.e., producers) are critical in projects with high burn rate. Producers manage projects energetically, are motivated by concrete goals, and according to Adizes (1979) can perform well in time-pressured situations. However, quality may be impaired because producers focus on achieving fast and efficient results that can be measured objectively, rather than long-term qualitative achievements. Hence, it is hypothesized in the research reported in this paper that producers, who focus on fast and efficient decision-making, may have positive effects on cost and time performance, but no impact on quality, in projects with high time-pressure. The four hypotheses are presented next.

### *Producers Have Positive Effects on Time and Cost Performance in Projects with High Burn-Rates*

This paragraph elaborates on Hypothesis 1. Large construction projects are executed over very long time periods; years rather than weeks or months. The traditional approach to project management can be described as a predict-and-control perspective, in which administration-focused managers try to plan, structure, standardize, and control project processes (Koppenjan et al. 2011). In projects with long duration (large projects) it is important to document and archive decisions and actions taken to enhance organizational memory about previous events. Due to the often high rates of staff turnover in large projects, decisions and actions that are not adequately documented and archived may be forgotten. This may have detrimental effects on performance, including needs for rework and poor matches between interconnected subsystems implemented at different times during the project. Hence, particularly robust administration and documentation is generally needed in large projects to achieve good quality, and potentially time-efficiency and cost-efficiency. Administrators can, according to Adizes (1979), function well in controlled situations steered by rigid systems with a need for extensive documentation. However, since documentation requires time and money, the effects of administrators on time-efficiency and cost-efficiency are less straightforward to evaluate, thus in this paper the focus is on administrators' effects on quality.

### *Administrators Have a Positive Effect on Quality in Projects with Long Duration*

This paragraph elaborates on Hypothesis 2. The two main types of contracts used in Swedish infrastructure projects are (1) design–build, where the client has a contractual relationship for both design and construction with a single actor, e.g., a contractor; and (2) design–bid–build (DBB), where designs are completed before the contractor is procured (Molenaar et al. 1999). Design–build contracts are well-suited for enhancing an innovative climate in complex projects (Potter and Sanvido 1994; Eriksson et al. 2014), and hence for projects that need high degrees of new solutions. However, they only provide improved opportunities for innovation; the client also needs to provide drivers. Accordingly, Chan et al. (2014) argue that an innovative climate has to be fostered by the leadership, and provide empirical indications that a transformational leadership is positively associated with an innovative climate, while a more structured leadership has a negative effect on innovation. Developers, who could be regarded as a class of transformational leaders, are associated with creativity, and according to Adizes (1979) have high abilities to solve problems and create innovative solutions in challenging situations, but are easily bored by more monotonous situations. Hence, it is argued in this paper that developers may promote a more innovative climate that has positive effects on performance in DB contracts.

### Developers Have Positive Effects on Time, Cost, and Quality in Projects Based on DB Contracts

This paragraph elaborates on Hypothesis 3. The complexity of a project has two main elements, i.e., (1) organizational, and (2) technological (Baccarini 1996; Gidado 1996). Organizational complexity refers to the numbers of interdependent actors that need to coordinate their activities and deliveries for successful project completion (Gidado 1996). Construction projects, according to Baccarini (1996), often involve high organizational complexity and hence require strong coordination. In an analysis of construction projects, Chang and Shen (2014) found a correlation between effective coordination and good project performance, and that the quality of coordination is a more important factor for project performance than the quantity. Miller et al. (2000) present three leadership characteristics that enhance the chances of effective coordination, and hence success in projects involving heterogeneous teams, as is often the case in construction, as follows: (1) an open style of leadership, (2) a good sense of humor, and (3) a sincere interest in staff well-being. These three characteristics represent integrators well, and should lead to a good ability to integrate numerous units (Adizes 1979) and thus be well-suited for complex construction projects.

### Integrators Have Positive Effects on Time, Cost, and Quality in Complex Projects

This paragraph elaborates on Hypothesis 4. A research model for testing the formulated hypotheses by multivariate regression analysis is schematically illustrated in Fig. 1. The independent variables are project managers' leadership styles based on the PAEI model (Adizes 1979). The dependent variables are three parameters of project performance, as follows: (1) time, (2) cost, and (3) quality. The respondents' age, gender, and duration of project management experience are used as control variables to test their potential effects on project performance. A split sample approach is applied in the model to test whether different leadership styles are appropriate for projects with different characteristics, as suggested by Crawford et al. (2005).

## Method

### Sample and Data Collection

The data used to test the hypotheses were collected through a questionnaire survey targeting a population consisting of all 213 project managers employed by the Swedish Transport Administration. Although there are also many project managers working for independent consultancy firms the targeted population provides suitable representation of project managers in the Swedish civil engineering sector. Investment projects at STA are initiated by the organization's society department, which has a formal duty to analyze and prioritize prospective infrastructure projects, then set ground rules and formulate internal orders for them. The internal orders must be subsequently approved by the investment department, which has ultimate responsibility for meeting performance targets until finished products are handed over to the operation and maintenance department. A manager is appointed for each project by the investment department when the internal order is approved. A comprehensive process platform is then engaged in performance of the project, and various resources (internal and external) support the project manager, but the project manager is the only actor who is involved throughout the whole project. In terms of contingency school vocabulary the model locks parameters of the followers (internal resources allocated to the project after the appointment of a project manager) and the formal authority system within the situation (process platform; Hersey and Blanchard 1969). Hence evaluating the leader (project manager) against task characteristics within situations (projects with different characteristics) is relatively straightforward.

A questionnaire was formulated based on both previous literature and semistructured interviews with three STA project managers, then slightly modified after a pilot study with a group of five respondents. The final questionnaire was then sent to the respondents (project managers) by e-mail. Respondents were given 2 weeks (in December 2013) to complete the questionnaire; two reminders were sent out during this time. Since the response rate (63%) was considered insufficient an additional reminder was sent out in January 2014, which sufficiently increased it (to 87%). Of the 185 questionnaires that were finally received 23 were removed from the final sample because too much information was missing. Thus, 162 completed questionnaires were finally analyzed, representing a response rate of 76%. Since the expressed reason that several respondents declined to participate was lack of time, most nonresponses and late responses were probably due to the same reason. Thus, potential nonresponse bias was assessed by comparing early and late responses (Armstrong and Overton 1977). No significant differences were found between responses of (1) early respondents (collected in December), and (2) late respondents (collected in January) when analyzing effects of the independent leadership factors between the two groups. This suggests that nonresponse bias is not a substantial problem in the survey study of the research reported in this paper.

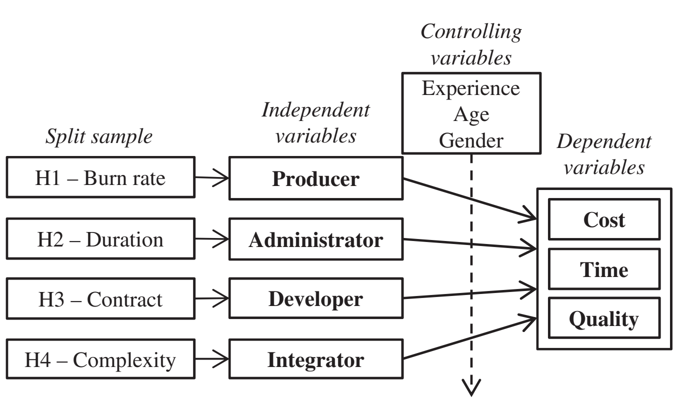



**Fig. 1.** Schematic illustration of the research model

### Measurements

The survey examined effects of project managers' leadership styles on different aspects of project performance. To classify their leadership styles, the respondents were asked to answer how well different statements fitted their view of their project leadership style (e.g., "I help my team to focus on joint established goals") according to a five-point Likert scale (from 1 = not at all to 5 = very well). As shown in Table 2, the questionnaire included questions (items) related to three descriptors for each of the four PAEI leader types (Adizes 1976), as follows: (1) producer (Items 1–3), (2) administrator (Items 4–6), (3) developer (Items 7–9), and (4) integrator (Items 10–12). The items were collectively constructed, after the literature review, which provided foundations for identifying keywords to distinguish managers with the four leadership styles. These keywords, inspired by Adizes (1976), were integrated into the items concrete goals, achieving fast results and focusing on the present

**Table 2.** Scale Descriptions and Items

| Item | Description |
|---|---|
| Producer 1 | I steer towards concrete goals and allow employees to decide how to perform tasks themselves |
| Producer 2 | It is more important to achieve rapid results than think about how we should achieve them |
| Producer 3 | I like to have a lot to do and focus on the present rather than on the future |
| Administrator 1 | I focus more on how my staff carry out a task than the actual result of the task |
| Administrator 2 | It is important that my staff have clear and structured tasks |
| Administrator 3 | I want clear systems to follow so that projects proceed with minimum disruption |
| Developer 1 | It is important for me to constantly seek new challenges |
| Developer 2 | I focus on large future goals rather than on daily operating requirements |
| Developer 3 | I encourage my employees to be innovative and to focus beyond short-term goals |
| Integrator 1 | I help my team to focus on joint established goals |
| Integrator 2 | It is important for me to meet everyone's different interests in order to turn us into a team |
| Integrator 3 | I listen to employees' opinions and needs to create a good working environment |
| Time 1 | The project was performed in a time-effective manner |
| Time 2 | The project was completed more quickly than most similar projects |
| Time 3 | The project was completed at least as quickly as expected |
| Cost 1 | The project was performed in a cost-effective manner |
| Cost 2 | The project was as costly as expected or cheaper |
| Cost 3 | The actual costs of the project were equal to or lower than the initially budgeted costs |
| Quality 1 | The final product/delivery was consistent with our specified performance requirements |
| Quality 2 | The performance of the end product met the needs of society |
| Quality 3 | The final product/delivery reached the expected quality |

for producers; structure and clear systems for administrators; challenges, future goals and innovative for developers; and team and joint goals for integrators. The final variables were tested by the pilot group of respondents before inclusion in the questionnaire survey.

Respondents were also asked to provide information about the (1) cost, (2) time, and (3) quality, of their last project; the three most frequently used parameters to measure project performance (Westerveld 2003). More specifically, as shown in Table 2, the respondents were asked to make qualitative judgments about how well three statements fitted their view of the performance of their last project in terms of each of these parameters (e.g., the project was performed in a time-effective manner) according to a five-point Likert scale (from 1 = not at all to 5 = very well).

In addition to the Likert questions several variables concerning project characteristics were included and subsequently used in the split sample approach for multivariate regression analysis. Two sets concern the turnover and duration of the managers' last projects. Responses to these questions were grouped into two approximately equally sized sets of low and high values as a basis for splitting the sample. The respondents were also asked to state the type of contracts involved in the specific project, design–bid–build or design–build, and again the responses were analyzed using a split sample approach. In addition, respondents' were asked to give their view of the complexity of their last project (in terms of the number of stakeholders with different interests involved) according to a five-point Likert scale (from 1 = not at all complex to 5 = highly complex). Three control variables were used in the multivariate regression analysis, as follows: (1) the respondent's duration of experience as a project manager, (2) the respondent's gender, and (3) the respondent's age. Experience and age were transformed into five-point scales (with equal intervals) before use in the regression analysis, while gender only has two alternatives and was therefore used as a binominal variable.

### *Analysis*

The data were imported into *SPSS version 22* software for statistical analysis. Since responses with a lot of missing data had already been removed, the few remaining missing values were replaced by mean values. Prior to the statistical analysis, all variables were examined for potential outliers (none were found) and confirmed to be normally distributed.

Principal component analysis (PCA) was applied to transform information concerning leadership styles (as described by 12 questionnaire items) and project performance measures (nine items) into smaller sets of latent variables (factors) to explore trends in the dataset (Hair et al. 2006). The PCA uses all the variance in a data set (in contrast to common factor analysis, which only uses the common variance). Thus PCA factor solutions are more robust. Varimax rotation was used to maximize independence of the factors from one another (i.e., minimize the correlation amongst them), which is relevant when factors are subsequently used in multiple regressions (Hair et al. 2006).

After the PCA, multiple regression analysis was applied to explore the relative influence of the four leadership styles extracted from the factor analysis on project performance. Multiple regressions allow the prediction of a single dependent variable from several independent variables in the same equation (Hair et al. 2006). Split samples were used to explore potential effects of the considered project parameters (complexity, duration, type of contract and burn rate, as defined previously) on relationships between leadership styles and project performance.

## Results and Discussion

Of the 162 respondents, 107 were men and 55 women. The average age of the respondents was 45 years and the average experience as a project manager just under 7 years. No significant difference in experience between female and male respondents (6.3 and 7.0 years, respectively) was detected in the sample. The DBB contracts were used in most (67%) of the projects they reported. Since some of these projects were very large their median cost and duration (45 million SEK and 36 months, respectively) are more relevant than the corresponding mean values.

### *Principal Component Analysis*

The PCA was applied to investigate the suitability of the 12 items designed to assess the respondents' leadership styles (Table 2). The

**Table 3.** Summarized Results for the Factor Analysis of Independent Variables

| Leadership behaviors | Mean[a] | SD | Factor loadings[b] P | A | D | I | Variance explained (%) | Cronbach's alpha |
|---|---|---|---|---|---|---|---|---|
| Producer 2 | 2.73 | 0.99 | 0.803 | — | — | — | — | — |
| Producer 3 | 2.78 | 0.95 | 0.832 | — | — | — | 14.03 | 0.515 |
| Administrator 2 | 3.85 | 0.83 | — | 0.771 | — | — | — | — |
| Administrator 3 | 3.89 | 0.94 | — | 0.868 | — | — | 13.89 | 0.55 |
| Developer 1 | 3.68 | 0.87 | — | — | 0.903 | — | | — |
| Developer 2 | 3.42 | 0.72 | — | — | 0.917 | — | 19.01 | 0.865 |
| Developer 3 | 3.91 | 0.80 | — | — | 0.430 | 0.638 | — | — |
| Integrator 1 | 3.84 | 0.76 | — | — | — | 0.802 | — | — |
| Integrator 2 | 3.99 | 0.74 | — | — | — | 0.811 | — | — |
| Integrator 3 | 4.20 | 0.68 | — | — | — | 0.815 | 24.17 | 0.783 |

[a]All variables measured using a Likert scale from 1 to 5.
[b]All included factor loadings exceed 0.30. A = administrator; D = developer (the designation for entrepreneur in this paper, to avoid ambiguity in this context); I = integrator; and P = producer.

results showed that two of them caused problems and thus were excluded, as follows: (1) Administrator 1 (designed to be associated with Factor 2) had large cross loadings, and (2) Producer 1 (designed to be associated with Factor 1) contributed to an unexpected factor that could not be explained by literature on leadership styles. After excluding these two items from the analysis, a four-factor solution was obtained, with a Kaiser–Mayer–Olkin (KMO) index value of 0.680, well above the recommended threshold of 0.5 for sampling adequacy, and highly significant sphericity ($p < 0.001$, according to Bartlett's test), indicating that all correlations were significantly different from zero. The means, SDs, and factor loadings for all items, together with the proportion of variance explained and reliability of the factors are reported in Table 3. The factor loadings for each of the items are between 0.638 and 0.929, indicating that they are all highly relevant. The first two factors have relatively low reliability (CA = 0.5–0.6), which is not surprising due to the exclusion of Producer 1 and Administrator 1, as factors based on only two items often have low reliability. For both the producer and administrator factors, based only on two items, the Pearson correlation coefficients are reported, $r = 0.34$ and 0.38, respectively. These correlations, which are satisfactory, should exceed 0.15, but more importantly the correlations within these factors are stronger than those towards items associated with other factors (and hence other leadership styles). Thus, these items were retained in the final model since their contributions are important for the content validity of their constructs and the overall model, which is consistent with guidelines of Hair et al. (2006). Factors 3 and 4, associated with developers and integrators, respectively, have satisfactory reliability values, well above the recommended threshold of 0.7. The four extracted factors account for approximately 71% of the total explained variance, well above the rule-of-thumb threshold; 60% according to Hair et al. (2006). The results show that the four extracted factors match the four PAEI leadership styles (Adizes 1979), and thus were used as independent variables in the regression analyses.

The PCA was also applied to reduce the nine project performance items (Table 2) to latent variables. Three were extracted, adequately matching the considered (1) cost, (2) time, and (3) quality performance variables (Table 4). Some weaker cross loadings were also detected by the PCA, but all variables were retained since the main loadings were substantially stronger. The three-factor solution generated from the performance variables described by the nine items accounts for approximately 79% of the total explained variance, with a high KMO (0.805) and highly significant sphericity (again $p < 0.001$ according to Bartlett's test), and high reliability for all three factors according to Cronbach's alpha values (0.848–0.868).

### Multivariate Regression Analysis

Hierarchical regression analyses were performed to test the formulated hypotheses concerning the relationships between leadership styles and project success in different situations. In the first step, effects of the control variables were examined by sequential

**Table 4.** Summarized Results for the Factor Analysis of Dependent Variables

| Project performance | Mean[a] | SD | Factor loadings[b] Time | Cost | Quality | Variance explained (%) | Cronbach's alpha |
|---|---|---|---|---|---|---|---|
| Time 1 | 3.57 | 1.06 | — | 0.799 | 0.356 | — | — |
| Time 2 | 2.83 | 1.17 | — | 0.853 | — | — | — |
| Time 3 | 3.15 | 1.37 | — | 0.821 | — | 26.21 | 0.848 |
| Cost 1 | 3.52 | 1.09 | — | 0.328 | 0.760 | — | — |
| Cost 2 | 3.50 | 1.22 | — | — | 0.867 | — | — |
| Cost 3 | 3.29 | 1.30 | — | 0.305 | 0.816 | 25.87 | 0.861 |
| Quality 1 | 4.01 | 0.88 | 0.856 | — | — | — | — |
| Quality 2 | 4.21 | 0.84 | 0.873 | — | — | — | — |
| Quality 3 | 4.05 | 0.89 | 0.901 | — | — | 27.01 | 0.868 |

[a]All variables measured using a Likert scale from 1–5.
[b]All included factor loadings exceed 0.30.

**Table 5.** Results of the Multiple Regression Model for Testing the Research Model and Hypotheses

| Hypothesis[a] | H1 time M1 | H1 time M2 | H1 cost M1 | H1 cost M2 | H2 quality M1 | H2 quality M2 | H3 time M1 | H3 time M2 | H2 cost M1 | H2 cost M2 | H3 quality M1 | H3 quality M2 | H4 time M1 | H4 time M2 | H4 cost M1 | H4 cost M2 | H4 quality M1 | H4 quality M2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Experience PM | 0.15 | 0.11 | 0.23[b] | 0.19 | 0.22[b] | 0.18 | 0.07 | 0.09 | −0.13 | −0.08 | 0.08 | 0.13 | 0.28[c] | 0.25[b] | 0.36[d] | 0.31[c] | 0.22 | 0.21 |
| Age | 0.08 | 0.07 | 0.17 | 0.12 | 0.05 | 0.01 | 0.08 | 0.11 | 0.11 | 0.10 | 0.08 | 0.08 | −0.09 | −0.11 | −0.08 | −0.12 | −0.04 | −0.11 |
| Gender | −0.11 | −0.10 | −0.25[c] | −0.23[b] | −0.18 | −0.20 | −0.08 | −0.05 | −0.21 | −0.14 | 0.02 | 0.05 | −0.10 | −0.10 | −0.32[c] | −0.33[d] | −0.12 | −0.14 |
| Producer | — | 0.10 | — | 0.20[b] | — | −0.03 | — | −0.10 | — | 0.22 | — | 0.13 | — | 0.16 | — | 0.19[b] | — | −0.05 |
| Administrator | — | −0.01 | — | −0.05 | — | −0.09 | — | 0.08 | — | 0.08 | — | 0.09 | — | −0.05 | — | −0.06 | — | −0.04 |
| Developer | — | 0.02 | — | −0.11 | — | −0.02 | — | 0.09 | — | 0.07 | — | 0.06 | — | −0.08 | — | −0.16 | — | −0.16 |
| Integrator | — | 0.27[b] | — | 0.30[c] | — | 0.17 | — | −0.21 | — | −0.09 | — | 0.17 | — | 0.23[b] | — | 0.37[d] | — | 0.34[c] |
| $R^2$ | 0.06 | 0.14 | 0.19 | 0.32 | 0.09 | 0.13 | 0.02 | 0.07 | 0.08 | 0.15 | 0.02 | 0.10 | 0.08 | 0.15 | 0.21 | 0.37 | 0.06 | 0.16 |
| $R^2$ adjusted | 0.01 | 0.03 | 0.15 | 0.23 | 0.05 | 0.03 | −0.05 | −0.11 | 0.01 | −0.01 | −0.06 | −0.07 | 0.03 | 0.04 | 0.17 | 0.29 | 0.01 | 0.05 |
| Significance | 0.36 | 0.30 | 0.01 | 0.00 | 0.09 | 0.27 | 0.82 | 0.90 | 0.33 | 0.50 | 0.88 | 0.78 | 0.22 | 0.25 | 0.00 | 0.00 | 0.33 | 0.22 |
| $R^2$ change | — | 0.09 | — | 0.12 | — | 0.03 | — | 0.05 | — | 0.07 | — | 0.08 | — | 0.08 | — | 0.16 | — | 0.10 |
| $F$ change | — | 1.32 | — | 2.36 | — | 0.60 | — | 0.47 | — | 0.76 | — | 0.83 | — | 1.17 | — | 3.40 | — | 1.57 |
| Significance $F$ change | — | 0.28 | — | 0.07 | — | 0.66 | — | 0.76 | — | 0.56 | — | 0.51 | — | 0.34 | — | 0.02 | — | 0.20 |

Note: All regression coefficients throughout Table 5 are beta values.
[a]H1 = Hypothesis 1; H2 = Hypothesis 2; H3 = Hypothesis 3; H4 = Hypothesis 4; M1 = controlling variables; and M2 = independent variables.
[b]$p < 0.10$.
[c]$p < 0.05$.
[d]$p < 0.01$.

insertion into the model. Whereas age had no effect, the control variables [(1) experience as project manager, and (2) gender] proved to be significant for project success in general, and influence conclusions regarding some of the tested hypotheses, which are discussed in subsequent paragraphs.

Tests of each of the four hypotheses revealed some interesting results in terms of beta coefficients (indicating relative influence) and level of significance (Table 5). As predicted, producers appeared to perform well in high speed projects (Hypothesis 1) in terms of cost performance ($\beta = 0.20$, $p < 0.10$), but their effects on time performance did not significantly differ from those of other types of managers. This result supports previous findings from e.g., Eisenhardt (1989) that high-speed projects require energetic and goal-oriented managers that are able to make fast decisions in order to achieve satisfactory outcome. Two of the control variables also significantly influenced cost performance, as follows: (1) experience as a project manager positively ($\beta = 0.23$, $p < 0.10$), and (2) femininity negatively ($\beta = -0.25$, $p < 0.10$) in high-speed projects. A likely explanation for the expected result that experience has a positive influence on performance in civil engineering projects is that unpredictable events frequently occur in them and require managers to make quick decisions, often based on experience and intuition (Ashley et al. 1983). The finding that women have a negative influence on performance in high-speed projects was not anticipated. However, according to various authors (e.g., Powell and Ansic 1997) women are less prone to take risks than men, and thus perform less well in high-speed projects due to the frequent need to take speedy and often risky decisions for success (Chan and Kumaraswamy 1997). However, these results provide no indications that women are less successful than men in terms of the quality delivered. The explanatory power of the model is quite high for cost performance (adjusted $R^2 = 0.23$).

No statistically significant results were detected concerning Hypothesis 2 (that administrators have a positive effect on quality in projects with long duration). A possible reason for this is the link, in the research reported in this paper, between an administrative leadership style and a highly structured approach to tasks, guided by clear systems. In an industry like civil engineering (construction) where most projects are unpredictable and difficult to plan in advance, not only control but also flexibility is essential to obtain satisfactory results (Koppenjan et al. 2011). Thus, administrators' lack of flexibility could explain why they were not found to have a positive influence on any of the project performance indicators used.

No statistically significant results concerning Hypothesis 3 (that developers have positive effects on time, cost, and quality in projects based on DB contracts) were obtained either. However, the results indicate that developers have a significant negative effect ($\beta = -0.18$, $p < 0.10$) on cost-efficiency in projects based on DBB contracts. This is consistent with the classification of developers by Adizes (1979) as leaders who often get bored and do not perform well in situations that are tightly governed by rules, bureaucratic procedures, and rigid authority systems.

However, the results confirm that complex projects need managers who are good coordinators and team builders. Integrators were associated with significant positive effects for all three performance parameters ($\beta = 0.23$–$0.37$; $p < 0.10$ or $<0.05$) in complex projects, supporting Hypothesis 4. This is in line with findings by Chang and Shen (2014) that effective coordination of construction projects has a positive effect on performance. The experience of the project manager also had significant positive effects on both time ($\beta = 0.25$, $p < 0.10$) and cost ($\beta = 0.31$, $p < 0.05$), while femininity of the project manager had a significant negative effect ($\beta = -0.33$, $p < 0.01$) on cost performance for complex projects. That more experienced project managers excel in complex projects is consistent with intuitive expectations, and has previously been reported, e.g., by Stuart and Abetti (1990), but it is more difficult to explain why female project managers perform less well than males in such contexts. Previous studies, e.g., Burke and Collins (2001), have found positive associations between femininity and efficient leadership. Further, they found that women adopt a transformational leadership style (the most effective, according to Avolio et al. 1999) more often than men. In marked contrast, the analysis indicates that female managers have a negative influence on performance, especially cost performance, in complex projects. A possible explanation is that quick and risky decisions are often required in complex projects (as in high-speed projects) and, as already mentioned, women are generally more risk-averse than men (Powell and Ansic 1997). The explanatory power of the model is also quite high for cost performance (adjusted $R^2 = 0.29$). An additional finding is that integrators also seem to have positive effects on high-speed projects, possibly at least partly because civil engineering projects (part of construction industry), as stated by Baccarini (1996), often involve high organizational complexity. Furthermore, in high-speed projects different activities must increasingly be conducted simultaneously rather than sequentially, which increase the need for coordination and integration among project actors and their activities.

To summarize, results of the analyses (presented in Table 5) confirm the overall hypothesis that leadership styles influence project performance in different situations. Leadership style should therefore be included in the list of critical success factors previously identified in the construction management literature, e.g., by Chua et al. (1999) and Chen et al. (2012). The results also partially confirm Hypothesis 1, since producers had positive effects on costs of projects with high burn rates, and validate Hypothesis 4 (integrators have positive effects on time, cost, and quality in complex projects). However, Hypothesis 2 (administrators have a positive effect on quality in projects with long duration) and Hypothesis 3 (developers have positive effects on time, cost, and quality in projects based on DB contracts) were rejected. It was found that developers have a significant negative effect on cost performance in projects based on DBB contracts.

## Conclusions

This paper offers several contributions to the literature on construction management. The first relates to the overall hypothesis, that leadership style is a critical success factor that influences project performance (Nauman et al. 2010) in terms of cost, time, and quality criteria. Hence, leadership style should be included in the list of critical success factors previously identified in the construction management literature and warrants further attention in future research. In addition, it provides several insights concerning the specific tested hypotheses, regarding the suitability of specific leadership styles in specific types of situations. These results highlight the importance of a contingency perspective on leadership. The empirical context of civil engineering projects has provided a unique set of contingency factors, in terms of four project characteristics, as follows: (1) complexity, (2) burn rate, (3) duration, and (4) type of contract. Hence, the writers have been able to exemplify conditions under which the general contingency theory applies to project management in the civil engineering sector. Overall, the results are consistent with prior findings of general management studies that emphasize the importance of choosing managers with appropriate leadership styles for situations with different characteristics to optimize performance.

From a managerial perspective these results highlight the importance of clients selecting project managers with suitable leadership styles based on project characteristics to achieve satisfactory project performance. From a contingency perspective the results indicate that high-speed projects with high time pressure should be managed by leaders who can be characterized as either producers or integrators, whereas complex projects should be managed by integrators. Moreover, developers perform better in DB projects than in DBB projects. These findings also indicate that experienced project managers should be appointed to projects with high organizational complexity in order to achieve satisfactory project performance. The human impact on project performance is great even though the projects are operated by a comprehensive process platform. An important managerial implication is therefore that public clients need to improve their understanding of different project characteristics and their requirements for different management in terms of style and experience of the project manager.

The exploratory investigation, of the research reported in this paper, of effects of project managers' leadership styles on project performance has several limitations. First, only one hypothesis was formulated and tested regarding each leadership style, each related to one project characteristic. In future research additional project characteristics could be investigated as contingency factors, such as uncertainty, histories of relationships with other project actors, newness of technology, and so on. Including additional project characteristics would enable the identification and characterization of more circumstances in which each leadership style may be suitable. In terms of the questionnaire, 10 out of 12 items related to leadership styles in civil engineering projects proved to have satisfactory correlations with their intended leadership style constructs (as indicated by PCA loadings). Problems were detected with only two items [(1) Producer 1, and (2) Administrator 1], intended to distinguish producers and administrators, respectively; in this respect, one of the items correlated unexpectedly with integrators, revealing some weaknesses in the associated construct, which could have biased the results. The other had weak loadings and cross correlation with both producers and developers. Both of these items were deleted before further analysis. Another item (Developer 3) was initially intended to distinguish developers, but instead the PCA detected a strong correlation with integrators (and it was included in the integrator construct after discussions with five respondents about its interpretation). A further weakness of the results is that the independent and dependent variables were collected from the same source, which increases the risk for common method bias. It would therefore be useful to examine whether the interactions observed in the research reported in this paper are replicated in data from multiple sources with different performance measures. Future research should focus on improving the constructs for the different leadership styles to obtain a more fine-grained instrument with a larger number of suitable descriptors. Further, it would be of great interest to compare the results with results of analyses of effects of leadership styles in other more industrialized construction contexts, since civil engineering is rather conservative.

## References

Adizes, I. (1976). "Mismanagement styles." *Calif. Manage. Rev.*, 19(2), 5–20.

Adizes, I. (1979). "Organizational passages—Diagnosing and treating lifecycle problems of organizations." *Organ. Dyn.*, 8(1), 3–25.

Aldrich, H. E. (1979). *Organizations and environments*, Prentice–Hall, Englewood Cliffs, NJ.

Armstrong, J. S., and Overton, T. S. (1977). "Establishing nonresponse bias in mail surveys." *J. Market.*, 14(3), 396–402.
Ashley, D. B., Uehara, K., and Robinson, B. E. (1983). "Critical decision making during construction." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1983)109:2(146), 146–162.
Ashour, A. S. (1973). "The contingency model of leadership effectiveness: An evaluation." *Organ. Behav. Human Perform.*, 9(3), 339–355.
Assaf, S., and Al-Hejji, S. (2006). "Causes of delay in large construction projects." *Int. J. Project Manage.*, 24(4), 349–357.
Avolio, B. J., Bass, B. M., and Jung, D. I. (1999). "Re-examining the components of transformational and transactional leadership using the multifactor leadership." *J. Occup. Organ. Psychol.*, 72(4), 441–462.
Baccarini, D. (1996). "The concept of project complexity—A review." *Int. J. Project Manage.*, 14(4), 201–204.
Bass, B. M. (1985). *Leadership and performance beyond expectations*, Free Press, New York.
Belassi, W., and Tukel, O. (1996). "A new framework for determining critical success/failure factors in projects." *Int. J. Project Manage.*, 14(3), 141–151.
Bennis, W. G. (1959). "Leadership theory and administrative behavior: The problem of authority." *Admin. Sci. Q.*, 4(3), 259–301.
Burke, S., and Collins, K. M. (2001). "Gender differences in leadership styles and management skills." *Women in Manage. Rev.*, 16(5), 244–257.
Chan, A. P., Scott, D., and Lam, E. W. (2002). "Framework of success criteria for design/build projects." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2002)18:3(120), 120–128.
Chan, D., and Kumaraswamy, M. (1997). "A comparative study of causes of time overruns in Hong Kong construction projects." *Int. J. Project Manage.*, 15(1), 55–63.
Chan, I. Y., Liu, A. M., and Fellows, R. (2014). "Role of leadership in fostering an innovation climate in construction firms." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000271, 06014003.
Chang, A. S., and Ibbs, W. (2006). "System model for analyzing design productivity." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2006)22:1(27), 27–34.
Chang, A. S., and Shen, F. Y. (2014). "Effectiveness of coordination methods in construction projects." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000222, 04014008.
Chen, Y. Q., Zhang, Y. B., Liu, J. Y., and Mo, P. (2012). "Interrelationships among critical success factors of construction projects based on the structural equation model." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000104, 243–251.
Chua, D. K. H., Kog, Y. C., and Loh, P. K. (1999). "Critical success factors for different project objectives." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1999)125:3(142), 142–150.
Crawford, L., Hobbs, B., and Turner, J. R. (2005). *Project categorization systems*, Project Management Institute, Newton Square, PA.
del Puerto, C. L., and Shane, J. (2014). "Keys to success in mega project management in Mexico and the United States: Case study." *J. Constr. Eng. Manage.*, 1–7.
Dulewicz, V., and Higgs, M. (2005). "Assessing leadership styles and organisational context." *J. Managerial Psychol.*, 20(2), 105–123.
Eisenhardt, K. M. (1989). "Making fast strategic decisions in high-velocity environments." *Acad. Manage. J.*, 32(3), 543–576.
Eriksson, P. E. (2010). "Partnering: What is it, when should it be used and how should it be implemented?" *Constr. Manage. Econ.*, 28(9), 905–917.
Eriksson, P. E., Olander, S., Szentes, H., and Widén, K. (2014). "Managing short-term efficiency and long-term development through industrialized construction." *Const. Manage. Econ.*, 32(1–2), 97–108.
Eriksson, P. E., and Westerberg, M. (2011). "Effects of cooperative procurement procedures on construction project performance: A conceptual framework." *Int. J. Project Manage.*, 29(2), 197–208.
Fiedler, F. E. (1978). "The contingency model and the dynamics of the leadership process." *Adv. Exp. Social Psychol.*, 11, 59–112.
Fiedler, F. E. (1995). "Cognitive resources and leadership performance." *Applied Psychol.*, 44(1), 5–28.
Gidado, K. I. (1996). "Project complexity: The focal point of construction planning." *Constr. Manage. Econ.*, 14(3), 213–225.
Goleman, D., Boyatzis, R., and McKee, A. (2002). *The new leaders*, Little and Brown, London.
Graen, G., Alvares, K., Orris, J. B., and Martella, J. A. (1970). "Contingency model of leadership effectiveness: Antecedent and evidential results." *Psychol. Bull.*, 74(4), 285–296.
Gransberg, D., Shane, J., Strong, K., and Lopez del Puerto, C. (2013). "Project complexity mapping in five dimensions for complex transportation projects." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000163, 316–326.
Hair, J. F., Black, B., Babin, B., Anderson, R. E., and Tatham, R. L. (2006). *Multivariate data analysis*, Prentice–Hall, London.
Hale, D., Shrestha, P., Gibson, E., and Migliaccio, G. (2009). "Empirical comparison of design/build and design/bid/build project delivery methods." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000017, 579–587.
Han, S. H., Yun, S., Kim, H., Kwak, Y. H., Park, H. K., and Lee, S. H. (2009). "Analyzing schedule delay of mega project: Lessons learned from Korea train express." *IEEE Trans. Eng. Manage.*, 56(2), 243–256.
Hersey, P., and Blanchard, K. H. (1969). "Life cycle theory of leadership." *Training Dev. J.*, 23(5), 26–34.
House, R. J. (1971). "A path goal theory of leader effectiveness." *Admin. Sci. Q.*, 16(3), 321–339.
Ibbs, W., Kwak, Y. H., Ng, T., and Odabasi, M. (2003). "Project delivery systems and project change." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2003)129:4(382), 382–387.
Keegan, A. E., and Den Hartog, D. N. (2004). "Transformational leadership in a project-based environment: A comparative study of the leadership styles of project managers and line managers." *Int. J. Project Manage.*, 22(8), 609–617.
Konchar, M., and Sanvido, V. (1998). "Comparison of U.S. project delivery systems." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1998)124:6(435), 435–444.
Koppenjan, J., Veeneman, W., van der Voort, H., ten Heuvelhof, E., and Leijten, M. (2011). "Competing management approaches in large engineering projects: The Dutch Randstadrail project." *Int. J. Project Manage.*, 29(6), 740–750.
Larsson, J., Eriksson, P. E., Olofsson, T., and Simonsson, P. (2014). "Industrialized construction in the Swedish infrastructure sector: Core elements and barriers." *Constr. Manage. Econ.*, 32(1–2), 83–96.
Liao, P. C., O'Brien, W. J., Thomas, S. R., Dai, J., and Mulva, S. P. (2011). "Factors affecting engineering productivity." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000059, 229–235.
Lorinkova, N., Pearsall, M., and Sims, H. (2013). "Examining the differential longitudinal performance of directive versus empowering leadership in teams." *Acad. Manage. J.*, 56(2), 573–596.
Miller, D. M., Fields, R., Kumar, A., and Ortiz, R. (2000). "Leadership and organizational vision in managing a multiethnic and multicultural project team." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2000)16:6(18), 18–22.
Mitchell, T. R., Smyser, C. M., and Weed, S. E. (1975). "Locus of control: Supervision and work satisfaction." *Acad. Manage. J.*, 18(3), 623–631.
Molenaar, K. R., Songer, A. D., and Barash, M. (1999). "Public-sector design/build evolution and performance." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(1999)15:2(54), 54–62.
Müller, R., and Turner, J. R. (2007). "Matching the project manager's leadership style to project type." *Int. J. Project Manage.*, 25(1), 21–32.
Nauman, S., Khan, A. M., and Ehsan, N. (2010). "Patterns of empowerment and leadership style in project environment." *Int. J. Project Manage.*, 28(7), 638–649.
Osipova, E., and Eriksson, P. E. (2013). "Balancing control and flexibility in joint risk management: Lessons learned from two construction projects." *Int. J. Project Manage.*, 31(3), 391–399.
Potter, K. J., and Sanvido, V. (1994). "Design/build prequalification system." *J. Manage. Eng.*, 10.1061/(ASCE)9742-597X(1994)10:2(48), 48–56.
Powell, M., and Ansic, D. (1997). "Gender differences in risk behaviour in financial decision-making: An experimental analysis." *J. Econ. Psychol.*, 18(6), 605–628.
Salovey, P., and Mayer, J. D. (1990). "Emotional intelligence." *Imag. Cogn. Personality*, 9(3), 185–211.

Songer, A. D., and Molenaar, K. R. (1997). “Project characteristics for successful public-sector design-build.” *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1997)123:1(34), 34–40.

*SPSS version 22* [Computer software]. Cary, NC, SAS Institute.

Stuart, R. W., and Abetti, P. A. (1990). “Impact of entrepreneurial and management experience on early performance.” *J. Bus. Ventur.*, 5(3), 151–162.

Sweis, G., Sweis, R., Hammad, A., and Shboul, A. (2008). “Delays in construction projects: The case of Jordan.” *Int. J. Project Manage.*, 26(6), 665–674.

Tannenbaum, R., and Schmidt, W. H. (1958). “How to choose leadership pattern.” *Harv. Bus. Rev.*, 36(2), 95–101.

Turner, J. R., and Müller, R. (2005). *The project manager’s leadership style as a success factor on projects: A literature review*, Project Management Institute, Newton Square, PA.

Vroom, V. H., and Yetton, P. W. (1973). *Leadership and decision-making*, Univ. of Pittsburgh Press, Pittsburgh.

Westerveld, E. (2003). “The project excellence model®: Linking success criteria and critical success factors.” *Int. J. Project Manage.*, 21(6), 411–418.

Yukl, G. (2011). “Contingency theories of effective leadership.” *The Sage handbook of leadership*, Sage, Thousand Oaks, CA, 286–298.

**Erratum for "Leadership in Civil Engineering: Effects of Project Managers' Leadership Styles on Project Performance" by Johan Larsson, Per Erik Eriksson, Thomas Olofsson, and Peter Simonsson**

DOI: 10.1061/(ASCE)ME.1943-5479.0000367

Johan Larsson
Researcher, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: johan.p.larsson@ltu.se

Per Erik Eriksson
Professor, Division of Innovation and Design, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: pererik.eriksson@ltu.se

Thomas Olofsson
Professor, Division of Structural and Construction Engineering, Luleå Univ. of Technology, SE-971 87 Luleå, Sweden. E-mail: thomas.olofsson@ltu.se

Peter Simonsson
Bridge Specialist, Swedish Transport Administration, Sundsbacken 2, SE-971 25 Luleå, Sweden. E-mail: peter.simonsson@trafikverket.se

Due to an editorial error during production, the "Hypotheses and Research Model" section misrepresents the support for the hypotheses. The support for each hypothesis appears in the paragraph immediately preceding it. ASCE regrets the error.

In the originally published Table 4, there is a mismatch between the time, cost, and quality columns and rows. The factor loadings and project performance have been corrected in the following table:

**Table 4.** Summarized results for the factor analysis of dependent variables

| Project performance | M | SD | Factor loadings | | | % of variance explained | Cronbach's alpha |
|---|---|---|---|---|---|---|---|
| | | | Time | Cost | Quality | | |
| *Time 1* | 3.57 | 1.06 | .799 | .356 | | | |
| *Time 2* | 2.83 | 1.17 | .853 | | | | |
| *Time 3* | 3.15 | 1.37 | .821 | | | 26.21 | 0.848 |
| *Cost 1* | 3.52 | 1.09 | .328 | .760 | | | |
| *Cost 2* | 3.50 | 1.22 | | .867 | | | |
| *Cost 3* | 3.29 | 1.30 | .305 | .816 | | 25.87 | 0.861 |
| *Quality 1* | 4.01 | 0.88 | | | .856 | | |
| *Quality 2* | 4.21 | 0.84 | | | .873 | | |
| *Quality 3* | 4.05 | 0.89 | | | .901 | 27.01 | 0.868 |

Note: All included factor loadings exceed 0.30. All variables measured using a Likert scale from 1 to 5.

# PAPER IV

## Exploring capabilities to manage innovation projects in production

Johan Larsson, Lisa Larsson

Submitted for publication in

*International Journal of Technology Management*

*Int. J. of Technology Management, Vol. x, No. x, xxxx*

# Exploring capabilities to manage innovation projects in production

Johan Larsson, Lisa Larsson

**Abstract:** This paper seeks to increase understanding of firms' capability to manage production innovations through an exploratory in-depth case study of innovation projects in three engineer-to-order (ETO) firms active in different competitive production sectors. The results indicate that most factors for successful innovation management identified in prior literature are relevant in this context, but some appear to be extremely important while others have minor influence. Further, in the firms' contexts, innovations often involve complex interactions between both process and product changes, all of which should be considered during development. The findings provide new indications of important factors for firms' management of production innovations in ETO settings, which have received relatively little research attention.

**Key words**: Innovation capability, Innovation management, Production innovation, Engineer-to-order, Construction, Manufacturing, Production development

## Introduction

The increasing competitiveness in today's markets, and increasing demands from both consumers and society, are affecting not only product development but also production processes (Bras, 2009). Awareness of environmental issues, climate change, and the associated need for more sustainable production, has also increased in recent decades (Hart, 1997), thereby raising pressure to introduce innovative production solutions to reduce not only costs, but also energy and material consumption. Technological developments and innovations are seen as key solutions for firms to meet the increasing customer demands and global pressures (e.g. Hart, 1997). The increasing need for customization is resulting in increasing numbers of firms in diverse sectors moving towards engineer-to-order (ETO) production strategies, in which the customer is typically involved in early design stages (Gosling and Naim, 2009) and production flow is driven by customer orders. Caron and Fiore (1995) found that ETO firms often operate in project-specific environments where one-off products are tailored to customers' needs. Consequently, for many firms today competitive advantage lies mainly in their ability to generate products with enhanced production processes (Schroeder et al., 1989), and hence provide products of more value for the customer than their competitors. Nevertheless, despite the increasing importance of production aspects, prior innovation management literature has mainly focused on product development (Becheikh et al., 2006) rather than production innovation (interpreted here as a novel value-creating change of a production related activity).

However, it is widely recognized that managing innovations successfully is vital for firms' ability to compete and improve financial results. In addition, various factors that influence firms' capability to manage innovations have been identified, e.g. by Tatum (1987) and Cooper (1999); Pellicer et al. (2014). Some of these factors are internal, acting at the project execution or firm level. Others are external, i.e. embedded in the context, which sets the conditions for successful innovation management (Sexton and Barrett, 2003; Rothwell, 1992; Pellicer et al., 2014; Huske et al., 2015). However, many of the factors have been identified and discussed in general innovation literature, and only about 1 % of innovation research has focused exclusively on process innovation (Becheikh et al., 2006). Thus, these factors' effects on the success of production innovation have received little attention, although there are indications that their importance depends on both the type of innovation concerned (Lager and Hörte, 2002) and the context (Blindenbach-Driessen and van den Ende, 2006). Thus, better understanding of how variations in these aspects affect the management of innovations is required.

This paper explores firms' capability to manage production innovation projects in an ETO context, and compares factors that have influenced actual production innovation processes in ETO firms to factors which previously claimed importance for successful management of innovation projects. More specifically, management of the development of innovative production solutions (to increase competitive strength), is analyzed through an explorative multiple case study of three innovation projects at different ETO firms. The results add knowledge about influential factors for successful management of innovation projects in an ETO setting, and interactive effects of the factors on firms' production innovation capabilities. The results may provide starting points for improving production innovation capability in ETO firms more widely.

The paper begins with a brief review of prior literature on influential factors for managing innovation projects. The following section describes the research design and the applied multiple case study approach. The findings are then presented and discussed. Finally, conclusions are presented, highlighting the contributions and limitations of the study, and proposals for further research.

## Managing innovation projects

Innovation projects require careful management for success, because their characteristic features include uncertainty, complexity, diversity and interdependence (Boer and During, 2001). Prior literature on influential factors for successfully managing innovation projects has mainly focused on product innovation (e.g. Rothwell, 1992; Pellicer et al., 2014; Cooper, 1998) at various levels, from individual innovation projects to firm or industry levels (Rothwell, 1992). Sets of both internal and external (contextual) factors have been identified, which interactively set firms' capability to realize innovation projects. The next two sections discuss a number of factors with widely recognized importance.

### Organizational influences

Organizational, or internal, influences refer to factors within firms that affect innovation projects and their outcomes. Realizing innovations is a challenging task that must be adequately planned and resourced (Cooper, 1999; Tatum, 1987). Managing innovation projects requires a high quality *development process* covering every stage of innovation projects (Cooper, 1998; Pellicer et al., 2014). Traditional innovation models are often designed as a funnel or pipeline with go/kill decisions along the path to (hopefully) exclude negative outcomes, as careful pre-development screening increases chances of success (Rothwell, 1992). However, this linear view of the innovation process, with technology "push" and market at end has been replaced in newer generations of models, which link R&D with firm goals and place more emphasis on chain management (Berkhout et al., 2006). According to these types of innovation models, institutional factors such as governmental regulations dramatically affect dynamic interactions both within and between networks of projects (ibid.). Similarly, Sexton and Barrett (2003) note that successful innovation management requires appropriate responses to institutional influences, realized by appropriate organizational capabilities and guided by appropriate innovation processes.

An important organizational influence during realization of innovation projects is *senior management commitment*, i.e. active engagement and support from managers throughout the process (Rodriguez et al., 2008). Senior management support is essential for the provision of adequate funds and resources for innovation projects, formation and encouragement of suitable teams, help to overcome problems, and fostering communication and collaboration (Cooper and Edgett, 2004; Griffin, 1997; Swink, 2000). Senior managers' attitudes towards risk are also important, as they must be willing to accept occasional failures as inevitable events in business (Menon et al., 1997). Excessive managerial risk aversion may foster inter-functional conflict as parties try to avoid responsibility for failures and focus on less risky tasks rather than complex, multi-departmental activities (Rodriguez et al., 2008). Hence, senior management commitment should incorporate open-mindedness to facilitate creation of a learning organization and innovation-oriented culture (Blayse and Manley, 2004; Rothwell, 1992).

The involvement of certain *key individuals* in an innovation project also increases chances of success (Rothwell, 1992). Innovation is an essentially human activity, and Boer and During (2001) emphasize the importance of roles in the process, such as idea generator, champion, sponsor, project leader, gatekeeper and problem owner, each of which requires a certain combination of intellectual or cognitive attributes, behavioral attributes, and position (responsibility and/or power base). According to Robert and Fusfeld (1981), the importance of the key individuals varies over time during a project's progress. For example, idea generation is crucial in initial stages, while commitment and leadership are needed once a project is established to ensure its progress.

In addition to these key individuals, successful outcomes may require dedicated *cross-functional project teams* (Cooper, 1998; Larson and Gobeli, 1988; Pellicer et al., 2014), i.e. groups of collaborators drawn from various functional units (Pinto et al., 1993). Such teams can bridge boundaries and generate ideas, learning opportunities and improvements more effectively than individuals, according to Tidd et al. (2001). McDonough (2000) and Santa et al. (2011) conclude that cross-functional teams enhance project performance, provided that they have clear and common goals.

External communication and *collaboration* are also important for exploiting scientific and technological know-how (Rothwell, 1992; Pellicer et al., 2014; Blayse and Manley, 2004). Indeed, strategic external collaboration has been a cornerstone of industrial development for so long that it is often taken for granted in manufacturing industries (Gann, 1996). However, to acquire and exploit external knowledge and practices firms need "absorptive capacity" (Bönte and Keilbach, 2005), which is strongly dependent on firms' prior relevant knowledge stock (Cohen and Levinthal, 1990). Furthermore, there is a dilemma in inter-firm collaboration, as the flow of knowledge and information between partners may facilitate success, but it raises risks of an unintended outflow of core knowledge that might severely compromise their competitiveness (Jordan and Lowe, 2004; Heiman and Nickerson, 2004). Trust is therefore an essential element in the formation and maintenance of successful collaborative alliances (Fawcett et al., 2012).

*Customer orientation* in innovation projects is also vital for satisfactory outcomes as it facilitates the detection of customer needs and requirements (Pellicer et al., 2014; Cooper, 1998), thereby helping to ensure that innovations meet their needs (Rothwell, 1992). Close connection with potential customers and markets also boosts absorptive capacities, and hence the acquisition of relevant knowledge and experience (Blayse and Manley, 2004).

Internal *knowledge utilization* refers to the transfer and exploitation of knowledge between projects (Blayse and Manley, 2004; Rothwell, 1992), for example, using state-of-the-art production equipment in innovation projects or monitoring technological developments to identify opportunities to innovate (Pellicer et al., 2014). However, the information and knowledge of individuals can only be distributed internally and used in business once it has been converted into a transferable form (Jantunen, 2005). Thus, although unplanned opportunity seizing is possible without a systematic knowledge-utilization procedure, in order to sustain a high degree of innovativeness processes for deliberately incorporating acquired knowledge are essential (Jantunen, 2005).

**Institutional influences**

Institutional influences often refer to factors beyond organizational and project levels (Hueske et al., 2015). They are often national or tied to a specific industry, and beyond the control of any individual firm or people involved in innovation projects. They include contextual factors such as culture, norms, routines and regulations (Kadefors, 1995), which shape the innovative climate by affecting actions and interactions between actors and networks (Malerba, 2007). For instance, the regulatory frameworks set by governments may restrict (or trigger) innovation initiatives (Tourigny and Le, 2004; Hueske et al., 2015). Studies on ETO strategies often claim that regulations and the early decoupling of the client may hamper innovation initiatives that are separated from the business project environment (Pries and Janszen, 1995; Gosling and Naim, 2009; Larsson et al., 2014). Institutions can be concluded as cultural rules that act as templates for the way we perceive our environment and act (DiMaggio and Powell, 2012).

## Research method

Case studies are beneficial in fields that are still in an exploratory stage, since they can provide rich data, give insights into complex behavior, and identify new aspects and phenomenon (Yin, 2013; Eisenhardt, 1989). Characteristics of innovation processes include uncertainty, complexity and diversity (Boer and During, 2001), most previous innovation studies have focused on products rather than processes, and production innovation processes in ETO settings have been largely neglected to date. Thus, an exploratory multiple case study seemed the most suitable approach for the planned investigation. Furthermore, innovation projects that have resulted in substantial changes in firms' production processes were selected for analysis, since they are likely to be more uncertain and complex than incremental projects. Hence, criteria for selecting firms and cases were based on possibilities for acquiring in-depth data rather than representativeness and breadth. All three focal firms are active in industries where customized products are offered to customers, but operate in different industries: aerospace, house building, and bridge construction. Despite the difference in industries, all of them heavily rely on innovative production for competitive advantage and their core R&D departments and operations are based in Sweden, although they sell their products in transnational markets. Table 1 summarizes information about the firms and the studied innovation projects.

**Table 1** Information about the studied firms and innovation projects

| *Case* | *Areas of activity* | *No. of employees* | *Innovation project* | *Project duration (Idea-implement)* |
|---|---|---|---|---|
| *Case A* | Aerospace | >250 | Production method for space application | 1996-2020 (planned) |
| *Case B* | House building | <250 | Production method for bathroom floor | 2003-2005 |
| *Case C* | Bridge construction | >250 | Production method for bridge construction | 2011-2013 |

Data for the case study were gathered through multiple methods (interviews, observations and secondary data collection). However, the primary method was semi-structured interviews with respondents playing key roles in each project, in order to obtain rich insights regarding perceptions of the innovation process from a range of wide practitioners' perspectives. An interview guide was used to maintain coherence in the data collection, which (in addition to items regarding background information) included the following questions:

- What was the trigger and outcome of the innovation project?
- How and where was the idea generated?
- How was the innovation project executed?
- What participants have been involved in the project?
- How has collaboration been conducted during the project?
- How has knowledge been utilized during the project?
- What factors have affected the outcome of the project?
- What obstacles have the project encountered?

Departure from the original questions was permitted, to pursue interesting and particularly relevant insights that emerged during interviews (Eisenhardt, 1989). All interviews (which were 40-100 minutes long) were

recorded to enable investigator triangulation (Patton, 2002), although some of the interviews were conducted by only one of the researchers.
Complementary information about the firms and their industrial environments were obtained from observations at their sites, which provided valuable opportunities to collect data and analyze interactive effects of identified factors. Secondary data were also collected from publicly available sources, and in some cases internal documentation. Any clarification of secondary data required was covered during interviews and observations. Table 2 summarizes methods used during the case study. The multiple source approach enabled data triangulation, which helps strengthen the construct validity of case studies (Patton, 2002).

**Table 2** Summary of data collection methods for each case

| *Methods* | *Case A* | *Case B* | *Case C* |
|---|---|---|---|
| Interviews (Respondents) | Project manager R&D | Factory manager | Department manager R&D |
| | Business development & marketing manager | Academic representative | Department manager |
| | Production developer | Production manager | |
| | Process Engineer | | |
| | Chief Engineer | | |
| Observations | Regular observations at firm during 2015 as part of a joint research project | Observations at firm including tours of the factory | Regular observations at firm during 2010-2015 as part of a joint research project |
| Secondary data | Website | Website | Website |
| | Annual reports | Annual reports | Annual reports |
| | Technical reports | | Technical reports |
| | Presentations | | |

The analysis began by summarizing responses in the interviews and transferring them into a database for further analysis. They were then subjected to thematic analysis where the empirical data related to each question were addressed and categorized into general themes to make the data more manageable and meaningful (Gibbs, 2002). Coding into categories is essential in qualitative research since it greatly facilitates interpretation of the acquired data. For example, the organizational influences identified in prior literature (e.g. Cooper, 1998; Rothwell, 1992), for successfully managing innovation projects provided a conceptual schema to cluster the empirical data. Within-case analysis was undertaken to find unique patterns from each innovation project

(Eisenhardt, 1989). This was then followed by a cross-case analysis to find common or differentiating characteristics according to the proposed method by Yin (2013). The interview data were triangulated, to some extent, by observations and secondary data collected in the case study. This allowed complementation, interpretation and to some degree validation of the interview data. During the data analysis, iterations between emerging results, theory, and empirical data for the case study were performed to consolidate the developing conclusions (Eisenhardt, 1989; Yin, 2013). Follow-up sessions with the respondents have been conducted to increase the validity of the analysis and confirm the case study interpretations drawn from the data collection (Yin, 2013).

## Case study findings

This section presents empirical findings from our exploratory case study from contextual, organizational and project level perspectives. The ideas for the innovations in the studied cases all arose more or less through chance. There have been needs to meet, but most of the solutions have come from seizing opportunities rather than structured idea-generation to solve a problem. One respondent expressed this as follows: "Balls come bouncing by and sometimes we happen to grasp one". Although all three cases are embedded in ETO industries, they adopt different approaches to realize innovations. The aerospace industry (represented by Case A) is highly driven by technical innovations with high investments in R&D, while construction innovations (represented by Cases B and C) are traditionally more incremental and local. The mature construction industry seems to accept significant innovations more slowly. However, firm B is active in prefabricated house manufacturing, which is considerably less mature than most of the construction sector, hence it retains a strongly innovative spirit and progress is frequently rapid. The main problem is often gaining acceptance from more conservative stakeholders, especially in Case C, partly because there is a large, very dominant public client in Sweden for bridge construction. Strict regulations and security demands are associated with all these three cases due to their complex products used in high-risk applications. Regulations are often designed to match standard procedures, and it can be difficult to acquire approval for radical new innovations without adaption of the regulations. The next three sections describe each of the studied cases in detail.

#### Case A – Aerospace

The aerospace case concerns the development of a new production method for producing space rocket nozzles, involving creation of a sandwich structure with channels for cooling agent by welding metal sheets together rather than welding tubes into a cone shape. The timeframe for developing the nozzle technology is more than 20 years, from a pre-development project in 1996 to the first planned in-flight use in 2020. The main objectives of the pre-development phase for this new nozzle technology were to identify potential improvements for current rocket nozzle production procedures, and to develop better designs and processes in terms of lead-time, flexibility, cost and reliability. The production method incorporates various techniques that have been developed in sub-projects over time as new needs have emerged. Some of these sub-technologies have been transferred to other products, and some have been absorbed and adapted from other products.

The project team has actively sought collaboration and carefully chosen partners (from industry, research centers, and academia) with specific technological knowledge to fill gaps in their own knowledge base and participate in development. Since extensive testing is required for this high-risk product and the full-scale tests are costly, the firm has collaborated with an engine manufacturer in later stages of the project.

The project was dormant for a few years due to changes in allocation of funds when solving a major failure related to a currently used rocket nozzle had higher priority. However, due to belief in its potential, engaged individuals have picked up the thread and driven further development. The business unit is known internally for having an innovative climate with freedom of ideas, creativity and a strong drive to develop new technologies (which together with focused investments in core market technology development and application foster competitive advantage). The technical knowledge and innovativeness were contributing factors when a global group recently acquired the originally Swedish firm.

Awareness of the technology and its reliability has been raised through presentations at aerospace industry conferences (following the acquisition of patent protection). The industry has generally been receptive to the technology and seen its potential. However, customers have not been willing to be the first to accept significantly different qualifications, preferring to use proven technology. Much effort has therefore been spent in assuring the receiving market of the new technology's reliability.

**Case B – House building**

The studied innovation project in Case B involves realization of an innovative method for producing bathroom floors, in which a prefabricated polyester basin with integrated drain is installed, rather than the traditional production method, including use of leveling compound, primer and a waterproofing layer. The innovation was triggered by the possibilities it provided to reduce transport problems, reduce assembly damage and avoid a production bottleneck identified at the factory. The traditional production method involved long waiting times, and thus was unsuitable for production lines, in which all steps need to be coordinated, as in factory-production of houses. The idea for this innovation emerged in informal discussions between the factory manager and the owner of the material supplier, who both saw the business potential. Since the factory manager was a senior manager at the firm, the decision to start a development project could be taken soon after discussion with knowledgeable people connected to the firm.

Firm B did not have a structured development process in place for handling radical innovation projects and the process could be considered iterative, but reasonably efficient due to the involvement of the senior manager (with low centralization as a small, internal development group with strong decision power is involved). The innovation project has been driven in collaboration with the material supplier, creating an innovative climate. The factory manager functions as project manager and innovation champion, with both decision power and strong technical knowledge. A strong connection to academia was established at an early stage, which has facilitated absorption of new technical knowledge and provided access to a required test environment. Other required resources such as architects and plumbers have been assigned to the project when necessary. Internal production knowledge was involved during the project to secure a suitable working environment and the production flow. The project has been rigorously documented, often by the academic representative since all testing has been done at a university. Such documentation was essential since the innovation had to be certified before introduction to the market. The bathroom floor is produced in such a novel manner that it needed to pass industry quality norms before certification was possible.

The introduction to the market was straightforward since the house manufacturer owns a real estate firm that handled the first attempts. The innovation was first tested incrementally; by applying it in a specific type of building (thus the internal production implementation was also incremental). The fact that the early attempts to produce the innovation were handled with entirely internal resources facilitated feedback and continuous improvements. However, the material supplier that had been involved during the whole development did not understand the consequences of altering the innovation late during implementation. Any changes that affect the innovation have to be documented and verified due to the required certification. This problem together with the fact that the material supplier did not have enough production capacity when full-scale production started resulted in a new material supply firm with a production line tailored for this innovation.

**Case C – Bridge construction**

The innovation project studied in Case C involves realization of a new way of constructing bridges, involving use of prefabricated components and stainless steel structures rather than traditional on-site construction methods. Thus, the product contains both advanced technological solutions and an innovative construction method that can improve both the productivity and cost-effectiveness of the construction process. The innovative production idea was generated by an experienced bridge designer, who owns a single consultant firm and presented the idea to firm C's R&D department manager through a mutual acquaintance, who saw business potential. Drawings and calculations by the idea generator were used to support the decision to start an internal development project by firm C. The R&D department manager, together with an internal bridge engineer, considered the support documents and a decision to start an innovation project was taken in consultation with senior management.

Firm C does not have a structured development go/kill process in place for managing innovation and the process applied can be regarded as iterative. The development team has handled decisions continuously, often based on gut feeling, and rigorous documentation was lacking during the development process. The centralization is low as a small, internal development group is involved. The project has been run to some extent under the radar of senior management and driven by the R&D department manager, who acts as an engaged manager and innovation champion in possession of decision power. Thus, an internal bridge engineer with technical knowledge was assigned to develop the idea together with the idea generator, who functions as a supporting expert. During the project the development group has also been collaborating with a steel material supplier, which has often revised the proposed solutions to match their own production system. In the early phases of development, the production department was not represented, leading to weak connection with the production personnel. Customer needs and requirements, in terms of regulations, were taken into account. However, the customer was not involved during the development and the innovation was not accepted before introduction into the market (actual construction projects), where customer acceptance is crucial.

Production is always conducted in full-scale construction projects, as no test environment is available. Different clients, both private and public, have been served to date. Due to the lack of production knowledge during development, the first attempt to construct the concept involved a less rigorous production process. Problems that occurred were subsequently used as feedback in the development of a more robust production process. None of the attempts to produce the bridge to date have been similar, but the process is continuously improving.

The lack of documentation during development affected both internal and external acceptance, as agents in the environment must be convinced that the innovation can provide superior outcomes to previous production methods. The first attempt to produce the innovative concept was made for a private client since public clients, such as the Swedish Transport Administration, require more rigorous documentation, and impose stricter rules and norms. The early design phase during the construction project, where the product is engineered to fit local settings, was controlled by the idea generator. However, the idea generator did not understand the new role as expert adviser, leading to problems due to insufficient communication with the production personnel. Thus, an external consultant was engaged in the second attempt to construct the concept, due to the lack of internal ability to manage the rigorous requirements of the public client's design procedure. The external consultant did not grasp the concept appropriately and found more incentives to please the client than the contractor, again leading to insufficient collaboration and communication.

The difficulties encountered in collaborating with the external consultant during construction projects have prompted firm C to expand its design department and (thus) increase internal knowledge. The objective is to acquire the ability to internally handle all design and development requirements for construction projects.

## Discussion

As already mentioned, this study explores factors influencing capabilities for managing actual production innovation projects in ETO settings, and compares them to factors with previously claimed importance for successful management of innovation projects. Table 3 presents an assessment of the degrees to which factors identified in previous literature (e.g. Rothwell, 1992; Pellicer et al., 2014; Cooper, 1998) have been present in the studied innovation projects and their impact on the projects' progress and/or outcome. Significant and neutral respectively mean that the factor concerned has and has not significantly affected the progress and/or outcome of the production innovation.

**Table 3** Relative strengths of organizational influences in the studied cases, and their impact on project progress and/or outcome

| *Factors* | *Performance Case A* | *Performance Case B* | *Performance Case C* | *Impact on project progress/outcome* |
|---|---|---|---|---|
| *Development process* | Medium | Low | Low | Neutral |
| *Senior mgmt. Commitment* | Medium | High | Low | Significant |
| *Key individuals* | High | High | High | Significant |
| *Cross-functional project team* | High | Medium | Low | Significant |
| *Collaboration* | High | High | Medium | Significant |
| *Customer orientation* | Medium | Medium | Low | Neutral* |
| *Knowledge utilization* | High | High | Low | Significant |

Notes: *No significant impact on production innovation, but entailed product changes.

The empirical findings indicate that factors that affect the capability to manage innovation are both type and context dependent which is in line with Lager and Hörte (2002) and Blindenbach-Driessen and van den Ende (2006). Further, high performance in some factors has shown potential to help overcome weaker performance in other factors. For example, findings show that a strong innovative climate with engaged key individuals can overcome lack of senior management commitment or a structured development process similar to findings from Rodriguez (2008).

Management commitment is often dependent on a certain level of prediction of the results, reducing the risk of failure (Rodriguez, 2008). In the studied production innovations, a high level of uncertainty is visible due to the difficulty of predicting character or magnitude of outcome. This leads to senior management supporting other less risky activities involving known technology or processes. Process improvements, such as production innovations, are often measured in terms of time and cost reductions (Boer and During, 2001), and the aim of the studied innovation projects has mainly been to reduce these two in the production process. It has however not been clear how large this reduction can be expected to be and if other parameters or activities along the production process are affected, positively or negatively. Due to good internal knowledge utilization, large unexpected benefits are also seen outside the intended production process.

The lack of senior management commitment seen to some extent in two of the cases indicates that the progress of the projects has instead been highly dependent on key individuals with strong belief in the solution and internal drive to make progress. Empirical findings indicate that people (key individuals) have made the difference between success and failure and have therefore proved to be essential for enabling the innovations, in accordance with previous findings (e.g. Boer and During, 2001).

Implementation of innovations that are process related, such as production innovations, can be more difficult to implement than product innovations, according to Boer and During (2001), due to the required adaption of many internal functions. Hence, these types of innovations often need internal acceptance to be successfully implemented. However, empirical findings indicate that establishing a cross-functional team early in the process reduces the difficulty of implementation. Applying the right functional competences is extremely important for realization of process innovations, according to Lager and Hörte (2002). Furthermore, the right people and partners must be available at the right time in the innovation process (Robert and Fusfeld, 1981). The studied cases show that when a project shifts from creative and flexible stages to more formally controlled stages, individuals who can impose a systematic approach are needed rather than an idea generator, to lock the scope. This is especially evident in new production processes, which require both expensive equipment and extensive training in testing phases, and once they start to be implemented few changes are accepted.

External collaboration with strategic partners is important in all innovation projects to increase knowledge (Rothwell, 1992), but it poses challenges. Establishing joint goals for production innovations, especially with external partners, can be difficult since the outcome often has internal effects. Furthermore, in process-related innovations protecting ideas can be particularly difficult due to the limited possibilities to patent processes. Hence, establishing trust in these relationships is important, as highlighted by our empirical findings. Similarly, Fawcett et al. (2012) noted that trust is crucial for building and sustaining collaborative partnerships. Furthermore, absorptive capacity — which is built on assimilated technological knowledge (Jantunen, 2005) — is important for both finding suitable partners and optimally exploiting collaboration, according to both our findings and Bönte and Keilbach (2005).

In all cases studied here the production innovation has been triggered by an internal urge to increase productivity. However, these rather substantial production innovations have also changed the products that can be offered to customers. Consequently, the firms have to consider two customers: the receiver of the changes in the production and the customer of the product(s) being produced, which may be affected if production innovation also results in changes in product offering. This highlights a unique aspect of the ETO strategy, where one-off, complex products customized for specific customers are generally produced (Gosling and Naim, 2009). Our findings show that customer involvement is not important from a production perspective, as the receiver is internal. However, it may be important to consider in order to ease acceptance of accompanying changes in product offering. When a change in an ETO product arises from production development rather than product development, the required market and customer orientation might not be present, which has been shown to hamper acceptance in markets that are wary of unproven technology. Early customer involvement is therefore important for receiver acceptance, and thus generation of a market pull, even for innovations that are primarily aimed to improve production processes. This aspect has been largely neglected in prior literature since traditional process innovation is often implemented internally and the external customer is therefore of less importance.

## Managerial implications and research outlook

The relatively unexplored field of production innovation appears to warrant further research, and the presented findings raise the following preliminary suggestions for improving a firm's production innovation capability. Finding the balance between continuous improvements and more radical innovations is key to success. Strategies for making continuous improvements in production processes have received abundant attention, but not ways to make revolutionary developmental leaps. In this business world where control is highly valued, it is not comfortable for firms to take chances and aim for the stars, not knowing quite if they will reach them. This paper highlights influential factors for such ventures, providing indications of areas to focus upon in order to successfully realize and reap the rewards of production innovations. As this is an exploratory study, these indications are more general than a detailed description of the path. Further studies are needed to better understand how firms can improve the highlighted areas. Larger studies covering more firms, other production contexts and more types of innovations (ranging from incremental to radical) would also be highly interesting for generalization and comparison.

Production innovations should not be viewed solely as process innovations even when the aim is to improve internal production processes. Product changes they may entail should also be considered. Thus, a product development perspective should be incorporated in any production innovation project. It is also important to consider both the internal production unit and the customer as influential receivers of an innovation, because if either of these parties reject it the innovation will not yield the potential benefits. Failure of internal acceptance can be avoided through ensuring that a problem owner and clear receiver of the innovation are in place from the start, while customer involvement can strongly ease customer acceptance.

The culture of the firm sets the conditions for success or failure. By creating a culture where individuals (at all levels of the firm) want to contribute to the firm's success, and are not scared of failure, they will be open-minded, find solutions to problems and create innovations. Interesting aspects for further investigation include the characteristics of a strong production innovation culture and ways to foster it to facilitate creation of more production innovations. By creating an innovative culture, production firms will also have a strong competitive weapon, building strong relations with customers wanting continuous development.

Strong relationships are also important for successful collaboration. Process-related innovations may be difficult to protect with patents, so trust is crucial in these relationships. By forming long-term collaborations with mutual interests and openness firms can contribute to both innovativeness and competitiveness.

## Concluding remarks

Our study contributes to the literature on innovation management by providing insights into the management of production development projects. The findings may serve as starting points for improving ETO firms' production innovation capabilities and further studies of innovation management in this context. Furthermore, the study provides indications of effects of these firms' organizational structure and capabilities on the management of development projects. The results are consistent with previous findings that influential factors for innovation management are not universal, and their importance depends on both the context and type of innovation (Lager and Hörte, 2002; Blindenbach-Driessen and Van Den Ende, 2006). The findings also indicate that capability is mainly influenced by soft factors, such as engaged individuals and working relationships in collaborations that are often more difficult to study, understand and improve than factors like a structured process. Firms may also need further support in terms of factors that have not been identified here, and/or in more sophisticated management strategies of identified factors. However, key conclusions that can be drawn from this study are that production innovations in the studied context often involve a complex mix of process and product changes, all, of which should be considered during development, even if the trigger for the development is to improve a process. Since the topical area of production innovation capability has been little explored, the findings from our rich case descriptions provide new indications of important areas for firms' management of innovations.

**References**

Becheikh, N., Landry, R. and Amara, N. (2006) 'Lessons from innovation empirical studies in the manufacturing sector: A systematic review of the literature from 1993–2003', *Technovation*, Vol. 26 No. 5, pp.644-664.

Berkhout, A. J., Hartmann, D., Van Der Duin, P. and Ortt, R. (2006) 'Innovating the innovation process', International Journal of Technology Management, Vol. 34 No 3-4, pp.390-404.

Blayse, A. M. and Manley, K. (2004) 'Key influences on construction innovation', Construction Innovation, Vol. 4 No. 3, pp.143-154.

Blindenbach-Driessen, F. and Van Den Ende, J. (2006) 'Innovation in project-based firms: The context dependency of success factors', Research Policy, Vol. 35 No. 4, pp. 545-561.

Boer, H. and During, W. E. (2001) 'Innovation, what innovation? A comparison between product, process and organizational innovation', International Journal of Technology Management, Vol. 22 No.1-3, pp.83-107.

Bras, B. (2009) 'Sustainability and product life cycle management-issues and challenges', International Journal of Product Lifecycle Management, Vol. 4 No. 1-3, pp.23-48.

Brière-Côté, A., Rivest, L. and Desrochers, A. (2010) 'Adaptive generic product structure modelling for design reuse in engineer-to-order products', Computers in Industry, Vol. 61 No. 1, pp.53-65.

Bönte, W. and Keilbach, M. (2005) 'Concubinage or marriage? Informal and formal cooperations for innovation', International Journal of Industrial Organization, Vol. 23 No. 3, pp.279-302.

Caron, F. and Fiore, A. (1995) 'Engineer to order' companies: how to integrate manufacturing and innovative processes', International Journal of Project Management, Vol. 13 No. 5, pp.313-319.

Cohen, W.M. and Levinthal, D.A. (1990) 'Absorptive capacity: a new perspective on learning and innovation', Administrative Science Quarterly, Vol. 35 No. 1, pp.128-52.

Cooper, R. (1998) 'Benchmarking new product performance: results of the best practices study', European Management Journal, Vol. 16 No. 1, pp.1-17.

Cooper, R. G. (1999) ‘The invisible success factors in product innovation’, Journal of Product Innovation Management, Vol. 16 No. 2, pp.115-133.

Cooper R G, Edgett S J. (2004) ‘Innovation performance and the role of senior management, Benchmarking innovation best practices’, Strategic Direction, Vol. 20 No. 5, pp.28–30.

DiMaggio, P. J. and Powell, W. W. (Eds.) (2012) The new institutionalism in organizational analysis, University of Chicago Press, Chicago.

Edmondson, A. C. and McManus, S. E. (2007) ‘Methodological fit in management field research’, Academy of Management Review, Vol. 32 No. 4 pp.1246-1264.

Eisenhardt, K. M. (1989) ‘Building theories from case study research’, Academy of Management Review, Vol. 14 No. 4 pp.532-550.

Fawcett, S. E., Jones, S. L. and Fawcett, A. M. (2012) ‘Supply chain trust: the catalyst for collaborative innovation’, Business Horizons, Vol. 55 No. 2 pp.163-178.

Gann, D. M. (1996) ‘Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan’, Construction Management and Economics, Vol. 14 No. 5 pp.437-450.

Griffin A. (1997) ‘PDMA research on new product development practices: updating trends and benchmarking best practices’, Journal of Product Innovation Management, Vol. 7 No. 4 pp.429–458.

Gosling, J. and Naim, M. M. (2009) ‘Engineer-to-order supply chain management: A literature review and research agenda’, International Journal of Production Economics, Vol. 122 No. 2 pp.741-754.

Hart, S.L. (1997) ‘Beyond greening: strategies for a sustainable world’, Harvard Business Review, Vol. 75 No. 1 pp.66-77.

Heiman, B. and Nickerson, J. (2004) ‘Empirical evidence regarding the tension between knowledge sharing and knowledge expropriation in collaborations’, Managerial and Decision Economics, Vol. 25 No. 67 pp.401– 420.

Hicks, C., McGovern, T. and Earl, C. F. (2000) ‘Supply chain management: A strategic issue in engineer to order manufacturing’, International Journal of Production Economics, Vol. 65 No. 2 pp.179-190.

Hueske, A. K., Endrikat, J. and Guenther, E. (2015) ‘External environment, the innovating organization, and its individuals: A multilevel model for identifying innovation barriers accounting for social uncertainties’, Journal of Engineering and Technology Management, Vol. 35 pp.45-70.

Jordan, J. and Lowe, J. (2004) ‘Protecting strategic knowledge: insights from collaborative agreements in the aerospace sector’, Technology Analysis and Strategic Management Vol. 16 No. 2 pp.241– 259.

Jantunen, A. (2005) ‘Knowledge-processing capabilities and innovative performance: an empirical study’, European Journal of Innovation Management, Vol. 8 No. 3 pp.336 -349.

Kadefors, A. (1995) ‘Institutions in building projects: implications for flexibility and change’, Scandinavian Journal of Management, Vol. 11 No. 4 pp.395-408.

Lager, T., and Hörte, S. Å. (2002) ‘Success factors for improvement and innovation of process technology in process industry’, Integrated Manufacturing Systems, Vol. 13 No. 3 pp.158-164.

Larsson, J., Eriksson, P. E., Olofsson, T. and Simonsson, P. (2014) ‘Industrialized construction in the Swedish infrastructure sector: core elements and barriers’, Construction Management and Economics, Vol. 32 No. 1-2, pp.83-96.

Larson, E. W. and Gobeli, D. H. (1988) ‘Organizing for product development projects’, Journal of Product Innovation Management, Vol. 5 No. 3 pp.180-190.

Malerba, F. (2007) ‘Innovation and the dynamics and evolution of industries: Progress and challenges’, International Journal of Industrial Organization, Vol. 25No. 4 pp.675-699.

McDonough, E. (2000) ‘Investigation of factors contributing to the success of cross-functional teams’, Journal of Production and Innovation Management, Vol. 17 No.3 pp.221–235.

Menon, A., Jaworski, BJ. and Kohli, AK. (1997) ‘Product quality: impact of interdepartmental interactions’, Journal of Academy of Marketing Science, Vol. 25 No.3 pp.187–200.

Olhager, J. (2003) ‘Strategic positioning of the order penetration point’, International Journal of Production Economics, Vol. 85 No. 3 pp.319-329.

Patton, M. Q. (2002). Qualitative research, SAGE Publications.

Pellicer, E., Yepes, V., Correa, C. L. and Alarcón, L. F. (2014) 'Model for systematic innovation in construction companies', Journal of Construction Engineering and Management, Vol. 140 No. 4.

Pinto, M. B., Pinto, J. K. and Prescott, J. E. (1993) 'Antecedents and consequences of project team cross-functional cooperation', Management Science, Vol. 39 No. 10 pp.1281-1297.

Pries, F. and Janszen, F. (1995) 'Innovation in the construction industry: the dominant role of the environment', Construction Management and Economics, Vol. 13 No. 1 pp.43-51.

Roberts, E.B. and Fusfeld, A.R. (1981) 'Staffing the innovative technology-based organization', Sloan Management Review, Spring, Vol. 22 No. 3 pp.19–34.

Rodríguez, N. G., Pérez, M. J. S. and Gutiérrez, J. A. T. (2008) 'Can a good organizational climate compensate for a lack of top management commitment to new product development?', Journal of Business Research, Vol. 61 No. 2 pp.118-131.

Rothwell, R. (1992) 'Successful industrial innovation: critical factors for the 1990s', R&D Management, Vol. 22 No. 3 pp.221-240.

Sackett, P.J., Maxwell D.J. and Lowenthal, P.L. (1997) 'Customizing manufacturing strategy', Integrated Manufacturing Systems, Vol. 8 No. 6 pp.359-364.

Salvador, F., Rungtusanatham, M., Forza, C. and Trentin, A. (2007) 'Mix flexibility and volume flexibility in a build-to-order environment: synergies and trade-offs', International Journal of Operations & Production Management, Vol. 27 No. 11 pp.1173-1191.

Santa, R., Bretherton, P., Ferrer, M., Soosay, C. and Hyland, P. (2011) 'The role of cross-functional teams on the alignment between technology innovation effectiveness and operational effectiveness', International Journal of Technology Management, Vol. 55 No. 1/2 pp.122-137.

Schroeder, R. G., Scudder, G. D. and Elm, D. R. (1989) 'Innovation in manufacturing', Journal of Operations Management Vol. 8 No. 1 pp.1-15.

Sexton, M. and Barrett, P. (2003) 'A literature synthesis of innovation in small construction firms: insights, ambiguities and questions', Construction Management and Economics, Vol. 21 No. 6 pp.613-622.

Swink, M. (2000) 'Technological innovativeness as a moderator of new product design integration and top management support' Journal of Product Innovation Management, Vol. 17 No. 3 pp.208-220.

Tatum, C. B. (1987) 'Process of innovation in construction firm', Journal of Construction Engineering and Management, Vol. 113 No. 4 pp.648-663.

Tidd, J., Bessant, J. and Pavitt, K. (2001) Managing Innovation-Integrating Technological, Market and Organizational Change, 5th ed., John Wiley & Sons Inc., Chichester.

Tourigny, D. and Le, C. D. (2004) 'Impediments to innovation faced by Canadian manufacturing firms', Economics of Innovation and New Technology, Vol. 13 No. 3 pp.217-250.

Yin, R. K. (2013) Case study research: design and methods, 5th ed., Sage Publications.