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Innovation in Megaprojects and the Role of Project Complexity

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Innovation in Megaprojects and the Role of Project Complexity

This article examines innovation in megaprojects and the way in which project complexity plays a role in innovation. Megaprojects are experiencing increasing levels of innovation as a means to deal with complexity and to improve the delivery of megaprojects. So far the relation between innovation and project complexity is under-explored in the megaproject management literature. Based on a cross-case study of two megaprojects, the paper critically evaluates the dimensions of innovation and the relation with project complexity. It also reveals interactions between innovation dimensions. Project complexity is considered a contingency factor in the influence of innovation on project performance. Policy recommendations include evaluating the adoption of innovation against a reduction of complexity, and improving integration of innovation in the planning of megaprojects.

Keywords: innovation; megaproject; complexity; case study

Introduction

The inability of megaprojects to innovate their delivery and adapt to changing and unexpected circumstances is one of the reasons for project failure (Davies and Gann 2017). Due to the high risk and uncertainty with megaprojects, the level of innovation is low with clients and contractors relying on proven and standardized techniques, technologies, and approaches (Van Marrewijk et al. 2008; Maghsoudi et al. 2016; Davies et al. 2009). Besides risk and uncertainty, other inherent features of megaprojects impede their ability to be innovative, including their temporary nature (Davies et al. 2015), size, complexity, the separation of design and construction, and risk attitudes (Brockman et al. 2016; Barlow and Köberle-Gaiser 2008). Recently, there seems to be a drive towards increasing levels of innovation in megaprojects (Holzmann et al. 2017) with project complexity (Ozorhon and Oral 2017) being one of the reasons for these innovations.

While there is a general understanding that complexity contributes to poor performance outcomes (e.g. Bosch-Rekveldt et al. 2011; Lessard et al. 2014), so far, we know surprisingly little about the role of complexity in innovations in megaprojects, with some studies considering complexity as a barrier and others as a driver of innovation. The literature on innovations in organizations is vast, but only when projects were seen as temporary organizations in organizations (Shenhar et al. 2016) did innovation in project management gain attention. Moreover, the literature has typically focused on smaller scale projects, with complex projects having received far less attention (Shenhar et al. 2016). This paper aims to contribute to improving the delivery of megaprojects by providing a better understanding of innovation in megaprojects while considering complexity. The research objective to facilitate this aim is defined as follows: to analyse the role of complexity in innovation in megaprojects. The main research question to be addressed is: what are the relations between innovation and project complexity dimensions in megaprojects?

This research is founded on organizational innovation and complexity theory. Particularly, we contribute to contingency theory as a branch of complexity theory (Bakhshi et al. 2016). In this study we show how project complexity is a possible contingency factor for the management of innovation in megaprojects. Complexity is key in understanding the relationship between project performance and various conditions such as technological forwardness (Lessard et al. 2014).

In addition, we contribute to organizational innovation theory by expanding this to temporary organizations used to deliver megaprojects. The complexity of megaprojects' organization as well as their temporariness influences their innovation prospects. An organizational approach to innovation is therefore most appropriate for this research.

In order to achieve our research objective we conduct a multi-case cross-case study providing empirical evidence of innovation in two megaprojects. This approach is most suitable for theory-building approach in our research because the qualitative data from the cases can explicate the relations between the complex set of constructs involved in both innovation and project complexity dimensions. This approach is particularly suitable for theory-building research using case studies to answer questions related to 'how' in unexplored research areas (Eisenhardt and Graebner 2007) as in our study.

This paper is structured as follows. Section 2 discusses the literature on innovation in megaprojects and the organizational innovation framework that is utilized in this study. Section 3 illustrates how contingency theory is adopted in this research and presents the main dimensions of project complexity. Section 4 describes the methodology, section 5 and 6 present the findings of the case study analysis. Section 7 discusses the theoretical framework and implications, and the main conclusions are presented in section 8.

Innovation in Megaprojects

In this article we focus on infrastructure investment projects and adopt the definition by Flyvbjerg (2014, 6) of a megaproject as 'large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people'. Innovation in megaprojects can be defined as 'the successful commercial exploitation of new ideas. It includes the scientific, technological, organizational, financial, and business activities leading to the introduction of a new (or improved) product or service.' (Dodgson et al. 2008, 2).

Considering our focus on organizational innovation, this paper adopted the framework proposed by Crossan and Apaydin (2010) to assess innovation in megaprojects. It is the most recent, highly-cited, and comprehensive framework of organizational innovation, integrating different dimensions of innovation. It incorporates the two roles of innovation, innovation as a *process* focusing on how innovation takes place, and innovation as an *outcome* focusing on the product and services that were produced. Below we will briefly describe these innovations for the different dimensions of organizational innovation. One dimension, nature, can apply to both innovation as a process and innovation as an outcome, and refers to whether the innovation is tacit or explicit.

Innovation as a Process

Five dimensions are distinguished for innovation as a process: level, driver, direction, source, and locus. *Internal drivers* include technical challenges (Procter and Kozak-Holland 2019), previous project failures (Davies et al. 2015; Whyte 2019), or improving performance (Worsnop et al. 2016; He et al. 2019; Sergeeva and Zanello 2018). Knowledge and resources in the form of capital and human resources are also internal drivers of innovation (Gui et al. 2018) with collaboration between parties playing a key role in bringing knowledge and resources together. *External drivers* of innovation in megaprojects include market opportunities for private parties, socio-environmental and sustainability requirements (Spitzeck et al. 2013; Tinoco et al. 2016), economic conditions (Gann and Salter 2000), and changes in regulation or political environment (Sergeeva and Zanello 2018).

Locus is defined as the extent of the innovation process and can be open or closed. Innovation in megaprojects are often considered open innovations because they often unfold beyond individual organizations (Worsnop et al. 2016) and the innovation process is not isolated to one firm (Badi and Pryke 2015).

Original or independent innovations (Gui et al. 2018) are *internal sources* of innovation. In addition, stakeholders within the project organization who promote and support innovation initiatives can also be internal sources of innovation. *External sources* of innovation can either refer to adoption or adaptation. Innovations invented elsewhere are *adopted innovations*. They can be innovations acquired from other projects, industries (Davies et al. 2015), or countries (Winch 1998; Gui et al. 2018). Innovations that integrate or recombine existing technologies, and innovations that transfer and apply mature technologies (Gui et al. 2018) can be considered *adaptations*.

Innovations can occur at different *levels* (individual, group, or firm level). In megaprojects it is most often at firm or institutional level, or at group level in project-based firms (Gann and Salter 2000).

Direction refers to how the innovation starts and develops, whether top-down or bottom-up. Bottom-up innovation seems most common in megaprojects, with various studies illustrating innovation through collaboration (Han et al. 2018; Hobday 1998; Spitzeck et al. 2013; Veenswijk et al. 2010).

Innovation as an Outcome

Innovation as an outcome refers to 'what kind' of innovation. This category includes four dimensions: form, magnitude, referent, and type.

Form dimension is divided in three classes. First, *product or service innovations*, such as the design of a project or (construction) technology. Second, *process innovations*, which is the 'introduction of new production methods, new management approaches, and new technology that can be used to improve production and management processes' (Wang and Ahmed 2004, p. 305). Third, *business model innovations*, which refers to creating value or transforming the delivery of the value such as the bundling of different entities for design and construction (Johnston 2011), innovative tendering (Veenswijk et al. 2010), and new procurement approaches (Sergeeva and Zanello 2018).

Magnitude is the degree of newness of the innovation outcome with respect to the referent and typically divided into incremental and radical innovations (e.g. Brockmann et al. 2006; Dodgson et al. 2015).

The *referent* dimension defines the basis to what the newness is referred to, such as the firm, the industry, or even the world (Brockmann et al. 2016). The new type of cost-plus contract in Heathrow Terminal 5 is an innovation with the industry as the benchmark; it was the first time it was used in the UK construction industry (Davies et al. 2009).

The *type* of innovation distinguishes between technical and administrative innovation. *Technical innovations* deliver products or services directly related to the core activities of an organization and might include products, processes, and technologies (Crossan and Apaydin 2010). *Administrative innovations* relate directly to the managerial aspects of the organizations' core activities and include the organizational structure, administrative processes and human resources (Crossan and Apaydin 2010; Brockmann et al. 2016). Both technical and administrative innovations have been identified in megaprojects, including BIM (Koseoglu et al. 2019), new governance regimes, new organizational structures such as the use of Integrated Project Teams (Davies et al. 2009; Davies et al. 2015).

Table 1 provides a summary of the dimensions of both innovation categories.

Table 1. Classification of Innovation Dimensions (Adapted from Crossan and Apaydin 2010)

Dimension	**Description**
Innovation as a process	*'How' innovation comes about*
Driver	Available knowledge and resources, technical challenges, collaboration (internal) or a market opportunity, economic conditions or imposed regulations (external)
Locus	The extent of the innovation process: open (beyond individual organization) or closed innovation
Source	Ideation, original innovations, and innovation promotors (internal) or adoption of innovation invented elsewhere and adaptation of innovations (external)
Level	Whether innovation concerns individual, group or firm processes
Direction	How the innovation starts and develops: e.g. bottom-up or top-down
Nature	Whether the innovation is tacit or explicit
Innovation as an Outcome	*'What kind' of innovations*
Form	Differentiates between: i) product or service, ii) process, and iii) business model innovations: e.g. creating or transforming the delivery of the value
Magnitude	The degree of newness of the innovation outcome with respect to the referent, e.g. incremental or radical

Type	Distinguishes between: i) administrative innovations such as organizational structure, and ii) technical innovations.
Referent	Benchmark which defines the newness of the innovation as an outcome
Nature	Whether the innovation is tacit or explicit

Project Complexity

Contingency theory applied to the study of megaprojects implies that projects should be considered within their context and there is not ‘one size fits all’ project management approach, rather a contingent approach is needed. As the effect of one variable on the success of a project is moderated by a contingency (Donaldson 2001), a change in contingencies should lead to adaptation of the project (management) in order to be successful. The congruence of the project to the external contingencies influences the overall performance (Hanisch and Wald 2012). Thus only a right fit between the levels of innovation and complexity results in project success. Only recently has contingency theory been adopted in project management research, and the contingency factors being considered are few (Söderlund 2004). Some studies have considered project complexity as a contingency factor (e.g. Puddicombe 2006, 2009; Salomo et al. 2007) in studies on project performance but not in relation to innovation in megaprojects.

Many studies have focused on distinguishing between types or dimensions of project complexity. *Structural* complexity is one of the most often addressed dimensions of project complexity in the literature (e.g. Baccarini 1996; Shenhar and Dvir 1996; Remington and Pollack 2008; Geraldi et al. 2011; Dunović et al. 2014; Chapman 2016). It refers to the interactions between independent elements, taking into account the size (or number), variety and extent of interdependence. This structural complexity covers both technical and organizational elements in megaprojects (Baccarini 1996). Later studies proposed additional types of project complexity. Notably, Shenhar and Dvir (1996) introduced technological uncertainty and structural complexity, which they then later updated with two additional dimensions of novelty and pace (Shenhar and Dvir 2007).

We do not intend to provide an exhaustive overview of types and frameworks of project complexity. Instead, to evaluate the project complexity of megaprojects we will select a framework that is comprehensive and well-established in the literature to ensure the validity and reliability of our findings. In this respect, we consider only frameworks that have been published in peer-reviewed journal papers and are highly cited. Two comprehensive highly recognized frameworks of project complexity are by Geraldi et al. (2011) and Bosch-Rekveldt et al. (2011).

Geraldi et al. (2011) identify five dimensions of project complexity, i.e. structural, uncertainty, dynamics, pace, and socio-political complexity. Uncertainty and dynamics can be considered overarching types of complexity as they may relate to different aspects, such as technical or organizational aspects. Pace refers to attributes such as urgency and time criticality. Lastly, socio-political complexity refers to factors related to the political, emotional, and human aspects (Shenhar et al. 2016; Holzmann et al. 2017).

Bosch-Rekveldt et al. (2011) developed the TOE (Technical, Organizational, and Environmental) complexity framework. Each of these categories contains subcategories and elements providing further levels of detail in the typology of project complexity. For example, technical complexity incorporates the elements goals, scope, tasks, and experience. In line with Baccarini's (1996) classification, structural complexity is covered both by the technical dimension and the organizational dimension.

The models by Geraldi et al. (2011) and Bosch-Rekveldt et al. (2011) were conducted in about the same time frame and both use extensive literature reviews to develop their classification. The resulting models also incorporate similar elements albeit classified differently. The main differences between the frameworks is their focus and context. The classification by Geraldi et al. (2011) is based on a set of studies that incorporates both (theoretical) complexity and complicatedness of projects in different settings, whereas Bosch-Rekveldt et al. (2011) focuses on large engineering projects specifically. Since our study concerns megaprojects (in the construction industry), the concept of complexity is more appropriate than that of complicatedness and the model by Bosch-Rekveldt (2011) is considered most suitable and will be utilized in this study.

The TOE framework consists of three levels. At the highest level are the categories technical, organizational, and environmental complexity. These three categories are further divided in the level of subcategories and level of elements within each subcategory providing a broad framework for the study and assessment of a project's complexity. The subcategories and a brief description are presented in Table 2.

Table 2. Subcategories and elements of the TOE framework (Bosch-Rekveldt et al. 2011)

Category	**Description**
Technical	*Technical content of the project: 'what' of the project*
Goals	Number, clarity, alignment of goals
Scope	Largeness and uncertainty in scope; quality requirements of project deliverables
Tasks	Number, variety and dependencies between tasks; Interrelations between technical processes; conflicting norms and standards
Experience	Newness and experience with technology
Risk	Technical risks
Organizational	*Organizational and softer aspects (people): 'how' of the project*
Size	Size in CAPEX, engineering hours, project team, site area, project duration; number of locations; compatibility of different project management methods and tools.
Resources	Resource and skills availability and number; contract types; interfaces between different disciplines
Project team	Number of different nationalities and languages; cooperation JV partner
Trust	Trust in project team and contractor
Risk	Organizational risk
Environmental	*Influences from the environment: 'who' of the project*
Stakeholders	Number stakeholders and their dependencies and variety of perspectives; political influence; company internal support
Location	Weather conditions; remoteness of location; interference with existing site; experience in the country
Market conditions	Internal strategic pressures; stability of the project environment; level of

	competition
Risk	Risks from environment

Methodology

Research approach

The research approach adopted in this paper is a mixed approach of positivism with elements of constructivism. The positivist approach is utilized to develop a model that manages the complex relationships between the dimensions of project complexity and innovation in megaprojects. However, since projects are inevitably interacting in a wider environment (Pellegrinelli 2011), aspects of the constructivism approach are recognized, such as there being more ways to observe relations between project complexity and innovation components.

We use an inductive approach to search for patterns of relationships among and between innovation and complexity constructs (Eisenhardt and Graebner 2007). This theory-building research is suitable because our study is interested in ‘how’ or ‘what’ questions (Eisenhardt and Graebner 2007; Seaton and Schwier 2014) related to linkages between project complexity and innovation which are scarcely explored. These type of questions are most suitable to be addressed by *case study strategy*.

While there are some studies on innovation in complex projects (e.g. Hobday 1998; Barlow 2000; Liu and Leitner 2002; Roehrich et al. 2019; Shenhar et al. 2016) in-depth investigations towards the relations between project complexity and innovation in real projects are not yet reported. We therefore adopt *an (inductive) exploratory case study* strategy.

We use multiple-cases studies as this allows for the possibility of varied outcomes (Stewart 2012) which fits our constructivist approach. It provides insight into the circumstances under which innovation (as a process or an outcome) and project complexity emerge. The multiple comparative case study approach also improves the robustness of the research (Yin 2013).

Case selection

Since the purpose of our research is to develop theory rather than test it, theoretical sampling is appropriate (Eisenhardt and Graebner 2007). Cases are selected because they are particularly suitable for revealing or highlighting relationships between constructs. They are chosen based on the contribution of theory development within the set of cases (Eisenhardt and Graebner 2007). The cases need to be similar enough to allow comparison (Stake 2013) but with a useful level of variation on the dimensions of interest (Seawright and Gerring 2008). We have chosen two case studies of the same project type, high-speed rail, that differ in their levels of project complexity, in this case organizational complexity (conventional versus non-conventional organizational set-up). Using cases of different project types would result in excessive variation of this dimension. For this study we select cases that are known to have innovative aspects either as a process or as an outcome.

Besides these theoretical consideration in case selection, accessibility to data (Rowley 2002) is used as a factor. This criterion is often used by scholars in case study research (Seawright and Gerring 2008).

Cases require detailed information on their planning and implementation as well as on their innovation. The cases that have been selected in this research concern the TGV Méditerranée (TGV Med) in France and the HSL-South in the Netherlands. The majority of the articles on innovation in megaprojects focus on the United Kingdom (e.g. Gann and Salter 2000; Brady 2011; Davies et al. 2009; Gil et al. 2012; Badi and Pryke 2015; Davies et al. 2015; Dodgson et al. 2015) or the USA (e.g. Johnston 2011;

Kwak et al. 2014). By conducting case studies in countries that have been under-researched this research makes an empirical contribution.

Data collection

The cases are based on documentary secondary data using written materials such as journal papers, books, and governmental reports. Sources that address the planning, implementation or innovation of the project are considered, while those that address the operational issues are outside of the scope of this paper.

The TGV Méditerranée case study is based on two main sources. The first is an empirical research study of the TGV Med, as part of a wider research study of Decision-making in the Planning, Appraisal and Delivery of Mega Transport Projects by the Omega Centre for Mega Projects in Transport and Development. A global Centre of Excellence in Future Urban Transport sponsored by Volvo Research and Educational Foundations (VREF). The second main source of information is an academic journal paper by Leheis (2012) who conducted an extensive in-depth case study of the TGV Med. Besides these two main sources, this case study uses two additional academic papers for triangulation. Most material on this project are technical papers or do not address innovations.

For the HSL-South case study, the main source of information are two extensive reports by the Temporary Committee for Infrastructure Projects (TCI 2004a, 2004b). This committee was established by the Dutch Parliament to inquire the manner in which Parliament had supervised the decision-making and implementation of two large infrastructure projects one of which the HSL-South. Another key source is the report by Hertogh et al. (2008) from the Netlipse Knowledge network on best practices and lessons learned in large infrastructures in Europe. In addition seven relevant journal papers and books have been utilized for triangulation purposes.

The secondary data that is gathered provide an extensive view on the project development from initiation through implementation and opening. This data allows us to assess the project's complexity and innovation dimensions.

Data analysis

The case study analysis approach consists of two phases. In the first phase, for each of the cases, we use the secondary data to assess the complexity of the project using Bosch-Rekveldt et al. (2011) TOE framework and the innovation dimensions using Crossan and Apaydin's (2010) framework. We evaluate whether there is any association between the complexity and innovation dimensions in the projects. In the second phase, we compare the cases to reveal any similar, contradicting or complementary findings. The findings are used to develop a framework and tentative propositions about the relation between project complexity and innovation.

Case Study Analysis

TGV Méditerranée

The TGV Med is a high-speed railway line of 250 km between Valence and Marseille, and to Nîmes. The project began in January 1989 when the French government asked SNCF (Infrastructure provider) to conduct studies into an extension of the TGV from Lyon to Marseille, Italy and Spain (de Carlo 2006). The project opened in June 2011. First, we will identify the main elements of the technical, organizational, and environmental complexity of the project. Then we will use the innovation framework to assess the innovations in the TGV-Med project and any association with the complexity we identified.

Complexity of the TGV Med

The *technical complexity* of the TGV Med is mainly defined by the task element. Naturally with a project of this scale, there is a high number and variety of tasks and interdependencies between them. However, on the other sub-categories, including goal, scope, and experience, the project shows low levels of complexity. The increased operating speed from 280 km/h to 300 km/h did put some constraints on the implementation, but it otherwise used traditional excavation methods for the construction, so the newness of the technology was low and SNCF's experience was high.

Size is the main element of *organizational complexity* of the TGV-Med. The size of the site area and the number of locations in the project was large, creating a high level of geographical dispersion. Other elements of organizational complexity were relatively low in this project. SNCF had worked with the State before, and financial resources and contract types were similar as in other projects.

The *environmental complexity* is characterized by the stakeholders and the location of the project. The variety of stakeholders' perspectives about the route of the project led to conflicts and enduring protests. From the time that the public became aware of the TGV extension project, strong protests movements sprang up demanding information and dialogue (de Carlo 2006). The French president as well as the mayor of Lille intervened in decisions regarding route choice but also local politicians and residents tried to influence the decision-making process (Leheis 2012). This intensified the protest and demonstrations against the project (de Carlo 2006). This resistance was mostly caused by a lack of consultation and democratic decision-making on the one hand and reservations for a new line and particularly a high-speed system on the other hand. There were tensions between high-ranking elected officials, promoting the project as a means to strengthen regional development, and local elected officials, communicating local supporters' oppositions of the TGV Med. Furthermore, the location made the project complex. The TGV Med operates in an area where heavy rainfalls occurs, and is close to the Durance River which is subject to violent flooding (Perlet 2002). The project faced numerous geographic and geological constraints; it had to go through a heavily urbanized zone, which was already saturated, yet alternative routes would go through protected landscape.

Innovation and the role of complexity

Innovation as a process. Both *internal and external drivers* of innovations were present in the TGV Med. The innovative cooperation between the State and infrastructure owner SNCF, as well as between SNCF engineers and architects/ landscape designers can be characterized as an internal driver to innovative implementation of the project. The *external drivers* of innovations were resistance from the public over environmental concerns, and changes in legislation. The changes in legislation gave rise to an innovative new decision-making procedure (Bianco Circular) that allowed a broad spectrum of stakeholders including local residents to submit their observations during the development process (Hayes 2002; de Carlo 2006). Changes in European Law were a driver for new organizational structures, in particular the RFF (see administrative innovations below).

Environmental complexity both in terms of location and differing stakeholder perspectives played a role in creating these drivers. The proposed route of the TGV Med was a major point of debate. The different perspectives created drivers towards improved collaboration and decision-making processes (de Carlo 2006). For example, the collaboration was aimed towards putting measures in place to integrate the project more effectively in the environment, to reduce resistance due to environmental concerns and to get on with the project (Leheis 2012).

The *sources of innovation* were internal, with SNCF (and to some extent the State) promoting innovation initiatives. These are the main stakeholders in the project also illustrating that the innovation process was not isolated to SNCF but involved organizations working together. The innovations in TGV Med can therefore be considered open innovations (*locus*).

Innovation as an outcome. The project is characterized by various types of *administrative innovation*s, in particular new ways of working and new organizational structures.

New ways of working includes the establishment of the College of Experts and the open decision-making process. The College of Experts were tasked to appraise studies conducted by SNCF, and validate the TGV project. While these kinds of evaluations are not uncommon, it is innovative because of the composition and competences of the Committee, i.e. experts were selected by *both* the State and the associations. Moreover, the Querrien Commission was established and organized meetings that integrated local politicians into the negotiation process who previously were usually excluded from the decision-making process.

A novel open decision-making process was adopted including the State, local elected representatives and residents, while traditionally SNCF only liaised with key elected officials in the areas concerned. In particular, the State started to play an increasing role in the decision-making by sending a government advisor rather than a technical advisor from SNCF to meet actors and negotiate the route.

Environmental complexity, due to the diverse stakeholders' perspectives, but also as a consequence of lack of trust by local politicians and residents questioning the legitimacy of SNCF studies, had an influence on the establishment of these new ways of working. They were aimed to bring stakeholders together to reach acceptance and realisation.

Other administrative type of innovations related to the various new organizational structures that were established in the TGV Med including the adoption of an on-site project manager, the decentralisation of project management, and the formation of Réseau Ferré de France, RFF. RFF was a new body that assumed ownership of the project, while the SNCF remained the main service provider and still acted as the project manager. An on-site project manager was appointed because of the distance of the construction work with the main office in Paris. Project management was divided into territorial divisions (equivalent to sub-directorates) with greater level of autonomy than the traditional centralized SNCF management to better deal with requests from associations and elected representatives on the ground. Considering these innovations in the organizational structure, they originate from complexity related to the size (organizational complexity element) and location of the project (environmental complexity element).

A *product innovation* was seen in the form of the Bianco Circular, a piece of legislation that changed the decision-making process and also acted as the legal basis for the work of the College of Experts.

The *referent* of these innovations are the level of the firm, thus, they are new for the SNCF but may not be new for other organizations. Innovations differed in their degree of newness of the innovation (*magnitude*), with new ways of working and changes in the organizational structure being incremental innovations, while the establishment of new organizational units considered more radical innovations.

HSL-South

HSL-South is high-speed railway line of about 125 km between Amsterdam and the Belgian border. Procedures started in 1986 and the formal decision to build was made in 1996. The project opened in September 2009. First we will identify the main elements of the technical, organizational, and environmental complexity of the project. Then we will use the innovation framework to assess the innovations in the HSL-South project and any association with the complexity we identified.

Complexity of the HSL-South

The goals of the HSL-South project were well-established. First of all, to link the Netherlands to the European network of high-speed railway lines. Second, to improve accessibility to Schiphol airport and substituting air travel to contribute to the environment goals (Giezen et al. 2015). Third, from the start of the project, private involvement was one of the objectives (TCI 2004a). The *technical complexity* of this project is thus not originating from a lack of clarity in goals, but rather it is defined by its task and experience components. As with many large projects, the number and variety of tasks was large. However, in this case it was so large that the Dutch government decided to divide the project into three parts, i) substructure, ii) superstructure, iii) operation. This further increased the technical complexity of the projects because of its additional dependencies between the three parts.

Moreover, the project deployed the European Rail Traffic Management System (ERTMS), the new European railway signalling system. At the time of decision, technical details of the system were still not finalized and no standards and practical experience with the technology existed (Baggen et al. 2010). The newness of the technology and construction techniques, and the lack of experience with the technology contribute to the technical complexity of the project.

Size and resources are the main elements of the *organizational complexity* of the HSL-South. The size in capital expenditure and the size of the site area were large and the planned duration long. As mentioned before, the government considered the project too extensive to be put to tender as a whole and tendered the three parts separately. The number of contracts put a constraint on the resources of the overall project. According to Koppenjan and Leijten (2005: 190), the contracts were so complex that 'no one within the Ministry really knew what the consequences would be'. The government did not have sufficient skills available to manage the novel ERTMS and PPP delivery method (TCI 2004b). TCI (2004b) concludes that the HSL-South project management organization lacked the necessary 'capacity to deliver'.

The *environmental complexity* in the HSL-South project is first of all characterized by the location of the project. For example, the choice for new construction methods, particularly the decision for the bored Green Heart Tunnel, was partly because of the geological conditions and partly because of environmental concerns (Hertogh et al. 2008). Besides, stakeholders and the diverse perspectives on the project (Salet et al. 2013) make up its environmental complexity. The various perspectives resulted in conflicts between stakeholders around the (fast and efficient) transport connection and the environmental impact. The project was heavily influenced by politics. For example, the decision to adopt ERTMS, given its incompleteness, could be seen as a political motivation.

Lastly, the environmental complexity was also seen in the market conditions. The government believed tendering the project as one large contract would not have reached the desired level of competition (TCI 2004a, Koppenjan and Leijten 2005). Tendering it as one large contract was also met with opposition (TCI 2004a) as it was considered it would not fit well with the Dutch construction and engineering market. Moreover, contractors would face too many risks and uncertainties and would likely require insurance against these risks (TCI 2004 in Priemus 2009).

Innovation and the role of complexity

Innovation as a process. Sources of innovation were both internal and external. The government was a strong internal source of innovations particularly promoting a high speed line with ERTMS technology and PPP arrangement. This also shows the environmental complexity, with the government as one of the main stakeholders, having a clear preference for the project and these attributes, despite clear concerns, while at the same time creating technical and organizational complexity due to the lack of experience and skills (TCI 2004b).

Yet many of the innovations were externally initiated, innovations were adopted from other projects and other countries. High-speed railway lines have been in operation for several decades but for the Netherlands it is a new phenomenon. It involves new designs, and a different embedding in the urban context. Processes and practices elsewhere, such as the British PPP experience or the new tunnel boring techniques, were taken over and adapted to the HSL-South context. Furthermore, HSL-South features a 25kV AC supply, which is one of the existing European systems for high-speed rail, but is new in the Dutch rail infrastructure which is normally featured with 1,500V DC (Railway technology 2017).

The decision to adopt innovations was a direct result of the technical complexity of the project, and particularly the lack of experience with the new technologies, methods, and delivery methods.

With the government the main initiator of the innovations, the innovations were introduced top-down (*direction*).

Innovation as an outcome. The *form* of innovations in the HSL-South project can be characterized by product innovations and business model innovations. The project involved new construction techniques including new tunnel drilling techniques (product innovation), which were partly the result of the environmental complexity related to the projects' location.

The business model innovations were mainly related to innovative procurement and contracting of the project (TCI 2004a; Giezen et al. 2015; van Marrewijk 2017). The HSL-South used three different contracting types, i.e. i) Design & Construct (D&C) for the substructure, ii) Design, Build, Finance & Maintain (DBFM) for the superstructure (Infraspeed Consortium), and iii) 'operate' concession agreement for the transport contract (Hispeed) (Hertogh et al. 2008). The reason for this split is found in all three TOE complexity categories.

Besides the contracting innovation, another business model innovation in this project concerned the financial control approach of the project. The Ministry of Transport set a task-oriented budget and relied heavily on the principle of steering by budget, a newly established principle (TCI 2004a).

Both technical and administrative *types* of innovation were part of the HSL South project. One of the main technical innovations was the deployment of the ERTMS, while the new ownership structure of the HSL-South project can be considered an administrative innovation. The structure of the organization changed throughout the different phases of the project development. Initially the project was a direct responsibility of the Ministry of Transport but since 2007 the HSL-South Project

Director had taken over full responsibility (Hertogh et al. 2008). Moreover, a new project organization was set up that incorporated employees with different specialist competencies, were flexible and innovative (Giezen et al. 2015; van Marrewijk 2017).

The innovations can be considered at an institutional level, with the national government's experience as the benchmark for assessing the degree of newness. Using this *referent* the product innovations can be considered *radical* innovations, as construction techniques and tunnel boring techniques had not been used in the Netherlands before. Similarly, the business model innovations were new to the Dutch government and thus a radical new way of working.

From an industry level the technical innovation of ERTMS can also be considered radical as it was not yet implemented anywhere in the world. In contrast the administrative innovations are mostly incremental in the HSL-South project.

Cross-case Analysis

In this section we will evaluate whether there are any similarities between the innovations that were adopted in the cases and the project complexity. First, we will provide an overview of innovations and discuss how project complexity was a reason for initiating these innovations. After this, we discuss if and how the innovation had an impact on project complexity or on other innovations in the project.

Project complexity as a reason for innovation

Table 3 shows the innovation dimensions and the related project complexity categories that were the cause for the respective innovations. The cases showed that several of the innovation dimensions had a relation with environmental complexity and technical complexity, while organizational complexity mainly played a role in dimensions related to innovation as an outcome.

Table 3. Project complexity as a reason for innovation

Innovation dimension		**Project complexity dimension**
Innovation as a process		
Driver (external)	resistance*, changes in legislation*	T: task, low due to experience E: stakeholders, trust
Source (internal)	State†, infrastructure owner*	E: stakeholders
Source (external)	adoption of HSL/PPP/ electrification	T: experience
Direction	top-down	-
Locus	open*	-
Innovation as an outcome		
Form (product)	Bianco Circular*, new construction techniques (tunnel boring)	E: stakeholders, location
Form (business model):	procurement, financial control model	T: task, experience O: size, resources E: market condition
Type (administrative):	new ways of working*, new organizational structures*, ownership structure	E: stakeholders, trust, location O: resources
Type (technical):	ERTMS, tunnel boring	E: location, stakeholders
Magnitude:	incremental†, radical†	-
Referent:	firm*, institution	-

With: * TGV, † both

Sources and drivers of innovation were formed due to environmental complexity. The cases illustrate that the variety of stakeholder perspectives and the (number of) location(s) of the project caused protests and resistance to the projects. In both cases, protests from stakeholders regarding the environmental impact of the project resulted in changes to the proposed route. Initial routes were ‘engineers’ routes’, optimal solutions from an engineering’s perspective, i.e. the shortest route with a minimal number of engineering structures to minimize costs and risks. However, while optimal from an engineering perspective they did not sufficiently consider environmental integration which resulted in opposition. This opposition in turn became an *external driver* for innovation, innovative solutions were being sought to deal with the resistance.

External sources of innovation were also the result of the lack of experience with a technology (technical complexity), for example in the HSL-South case innovations invented elsewhere were adopted because the project organization themselves lacked experience with these technologies. On the other hand, the TGV Med case showed us that having this experience (low level of technical complexity) could be an *internal driver* for adopting innovations because the project organization is familiar with them.

In both cases the government plays a main role as innovation promotor (*internal source*). The source did influence the direction and magnitude of innovation. For example, in the HSL-South case, the innovations were pushed by the project promotor from the start of the project. More incremental innovations were introduced in later stages.

Form and type of innovations were also initiated to manage stakeholder elements of environmental complexity. These were solutions to resolve stakeholder concerns such as a bored tunnel to protect the environment (product/technical innovations) or improved decision-making processes that give stakeholders a voice by new formal procedures or legislation (business model/administrative innovations). In addition, business model form and administrative type of innovations were initiated when the projects needed to create new delivery methods and engage in new partnerships to manage the lack of experience and resources within the organization (technical and organizational complexity). The degree of *organizational complexity* is higher in the HSL-South compared to TGV Med when considering the resources and skills available. This is mainly the consequence of the funding sources. The HSL-South was the first privately financed PPP project in the Netherlands. As a consequence novel ways or working and organizing were needed, giving rise to a higher degree of innovations. In contrast, the TGV Med adopted a financing structure similar to those of previous high speed railway lines in France, reducing the organizational complexity and as such innovations were more incremental.

The *magnitude* of innovations can vary within different types and forms of innovation. With magnitude being defined with the referent as the benchmark, and both cases having a different referent base, it is difficult to compare the extent to which incremental and radical innovations are similar or different from each other. However, it appears that process and administrative innovations tend to be incremental, whereas product and technical innovations are more likely to be radical. For example, the degree of newness regarding technical innovations in the HSL-South project were of considerable.

Result of innovation

Table 4 shows the innovation dimensions (same as in Table 3) and whether and how these influenced complexity and innovation in the projects. Some innovations have triggered the adoption of other innovations, or the adoption of a specific innovation has made the project more complex.

Table 4. Result of innovation on degree of innovation and complexity

Innovation dimension		**Result**
Innovation as a process		
Driver (external)	resistance*, changes in legislation*	I: Form (product) I: Type (administrative)
Source (internal)	State†, infrastructure owner*	I: Type (administrative) I: Type (technical: ERTMS) I: Form (product, business model: PPP)
Source (external)	adoption of HSL/PPP/ electrification	I: Form and type T: experience O: resource
Direction	top-down	-
Locus	open*	-
Innovation as an outcome		
Form (product)	Bianco Circular*, new construction techniques (tunnel boring)	T: experience
Form (business model):	procurement, financial control model	I: Type (administrative) T: Task, experience O: size, resources

Type (administrative):	new ways of working*, new organizational structures*, ownership structure	T: task O: size, resources
Type (technical):	ERTMS, tunnel boring	T: task O: resources
Magnitude:	incremental†, radical†	TOE: risk
Referent:	firm*, institution	-

The cases revealed some imminent relations between innovation as a process and innovation as an outcome dimensions. There is a clear relation between innovation as a process and innovation as an outcome. For example, a relation between who supports the innovation (source) and what the innovation is (type, form). In the HSL-South we saw the government support the HSL, PPP, and EMTRs innovations which were adapted from other countries and are form and type innovations within the context of the Netherlands. Similarly in the TGV Med, a relation between the initiator of innovation and the outcome of the innovation in terms of the type were revealed. Moreover, how innovations are driven influences the type and form, as the TGV Med case showed a change in legislation resulted in administrative and product innovations.

In addition, relations within innovation as an outcome dimensions were seen. For example the business model innovations in HSL-South (PPP) resulted in a change in the organizational set-up (administrative innovation) as well as technical product innovations (technological tunnel design solutions).

The cases also confirmed that project complexity is a main but not the only reason to adopt innovations, in fact innovations can be introduced as a result of other adopted innovations. Particularly, the cases showed how innovations increased the technical and organizational complexity of projects. They increase the technical risks; the number, variety, and interdependency between tasks and often experience with the technology is lacking. The innovations also increase the organizational complexity by the increased size, resource and skills demands. Except for the magnitude dimension, innovation dimensions generally have a decreasing impact on the environmental complexity of projects.

Discussion

Theoretical framework

Based on the findings from the two case studies, we have developed a theoretical framework (see Figure 1).

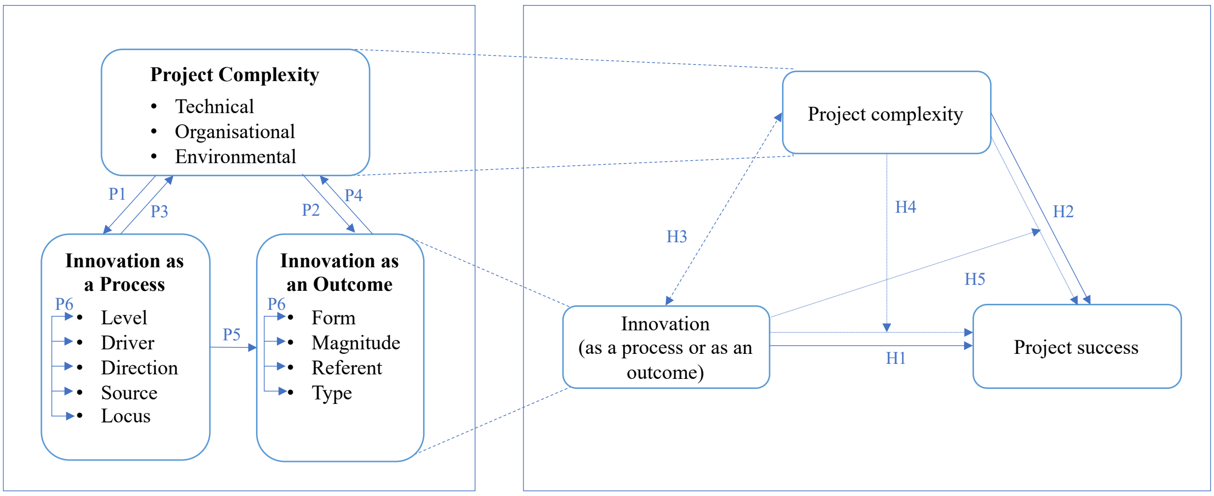

Figure 1. Framework Complexity-Innovation

The left hand side of the figure shows the relations between innovation and project complexity, the focus of this study. The right hand side of the framework shows how this fits in the wider perspective including project performance. It shows the direct relationships between innovation and project success (H1), and between project complexity and project success (H2). These direct relationships are well researched (e.g. Floricel et al. 2016; Shenhar 2001; Williams 1999; Brady and Davies 2014). An unknown direction relationship between innovation and project complexity is shown, with innovation influencing project complexity and vice versa (H3). Lastly, a moderating relationship between innovation and project success (H4) is hypothesized; under different degrees and compositions of project complexity the relation between innovation and project success varies. Thus the effectiveness of innovation is determined by the project complexity. A moderating relationship between project complexity and project success is also hypothesized (H5) with innovation as contingency factor. Our study has focused on the relationship between innovation and complexity. The interactions that we have revealed with the study suggest moderating roles of both complexity and innovation on the overall project performance. We have developed six propositions with respect to the relation between innovation and project complexity which are discussed below.

The first proposition relates to the relationship between the two roles of innovation and project complexity. The case studies revealed environmental and to some extent technical complexity relate to the innovation process elements and particularly drivers and sources of innovation. Environmental complexity and organizational complexity played a role in innovation as an outcome. Elements of complexity that played a role relate to stakeholder diversity; lack of experience, skills, or resources.

> **Proposition 1:** Project complexity influences innovation as a process dimension
>
> *Proposition 1a:* Environmental complexity caused by the diversity of stakeholders interests can act as an external driver for innovative solutions to resolve resistance to a project.
>
> *Proposition 1b:* Technical complexity caused by a lack of experience with technology can be an external source of innovation with megaprojects relying on adoption and adaptation of innovations from other projects, countries, or industries.
>
> **Proposition 2:** Project complexity influences innovation as an outcome dimension

Proposition 2a: Organizational complexity due to a lack of resources and skills can be a reason to adopt business model innovations or administrative innovations in the megaproject.

Proposition 2b. All three categories of complexity, technical, organizational, and environmental can stimulate megaprojects to adopt type and form of innovations.

The case studies also revealed that innovations can have an impact on the level of complexity and innovation in the megaprojects. This applies to both innovation as a process and innovation as an outcome dimensions. Innovation mainly has an influence on the technical and organizational complexity, while it influences environmental complexity to a lesser extent.

The extent to which innovations are invented within the project or adopted from other projects (source) influences the overall project complexity. Introducing innovations will require particular experience with technologies, resources and skills (technical complexity). A project that is highly technical complex may endeavour new business models but consequently increases its organizational complexity due to a higher number of interfaces between systems.

Proposition 3: Innovation as a process can increase the overall project complexity, particularly external sources may increase technical and organizational complexity.

Proposition 4: Innovation as an outcome dimensions have a larger impact on project complexity compared to innovation as a process dimensions, with form and type of innovation increasing technical and organizational complexity, and magnitude influencing all three categories of project complexity.

In addition to innovations resulting in higher levels of complexity, innovations can also result in higher levels of innovations. There is a natural relation between the innovation as a process dimensions, and the innovation as an outcome dimensions, with the former always preceding the latter (Crossan and Apaydin 2010). The cross-case analysis confirmed this relation and specifically revealed a relation between the process dimensions drivers and sources, and the outcome dimensions form and type. The external drivers are more likely to lead to administrative innovations while internal drivers are associated with product and business forms of innovations or technical types of innovations. This can be explained by the fact that these later forms and types of innovation are typically well regarded by the public and innovation supporters are therefore more likely to propose these innovations (Siemiatycki 2013).

> **Proposition 5:** Innovation as a process leads to innovation as an outcome, with sources and drivers being the main process dimensions that determine the form and type of innovation.

Lastly, the case studies only revealed few interactions within dimensions of innovation as a process or innovation as an outcome. While different innovations are introduced they do not have a clear dependency, except for business model innovations and administrative innovations.

> **Proposition 6:** Interactions between innovation as a process dimensions are mostly characterized by complementary relations, while the interactions between innovation as an outcome can be both complementary or actualising.

Theoretical implications and future research

Innovation is generally regarded as being critical for an organization's performance, and recently has there been a surge in innovation in construction megaprojects. However, there is little known about how project complexity interferes with innovation and vice versa. Most studies on innovations involve 'standard' construction projects rather than complex megaprojects. For example, (e.g. Severo et al. 2019 investigated the relation between project management practices and process and product innovations, and Song et al. (2016) focused on new product development.

We have shown project complexity plays a large role in adopting innovations, with the main impact on the following innovation dimensions: driver, source, form, and type. Further research is needed to understand the role of complexity in other innovation dimensions.

There is a particular strong influence of environmental complexity on innovations, both in terms of process and outcome. What is concerning is the fact that in both roles stakeholders were the driving force for innovations which significantly changed the projects. Technical complexity led mainly as process innovation while organizational complexity more often resulted in outcome innovations.

Our findings confirm and extent previous studies that innovation increased complexity in projects due to the higher levels of uncertainty and risk (Shenhar et al. 2016) and led to combination of innovations being introduced in the project (Slaughter and Shimizu 2000). Whether these interactions between complexity and innovation are systematic in other projects as well need to be further investigated.

While this paper has provided some first steps in revealing the role of complexity in innovations, further research is needed to investigate the impact on the overall project performance. This would involve a large sample study that allows testing the hypotheses presented in Figure 1. Megaprojects are known for frequently being over budget and delayed. Therefore, it is crucial to know whether innovations can improve project performance despite higher levels of complexity and uncertainty that these innovations bring. Innovations are being introduced to increase efficiency, but for megaprojects characterized with a high level of complexity, or with innovations that have a high degree of novelty, the risks compound (Davidson and Huot 1991), and may be detrimental to the overall project performance.

Managerial implications

The paper reveals two main policy implications. First of all, one needs to consider whether innovations are the most appropriate to deal with the project complexity or whether it is more effective to use standard approaches while attempting to reduce the complexity (Giezen 2012). Just as with the risk of technological sublime (Frick 2008; Flyvbjerg 2014), sometimes innovations seem to be implemented despite their increased uncertainty, when more standard practices could suffice.

Secondly, decisions on innovations need to be better integrated in the planning of megaprojects. So far this front-end stage of projects is not yet fully understood (e.g. Williams et al. 2019; Johansen and Rolstadås 2017) but it has a great impact on the overall project success, particularly for megaprojects (Johansen and Rolstadås 2017; Brady and Davies 2014). The study shows that several innovations were introduced in later stages as a response to the developments in the projects, e.g. the effects of the innovation. Planned innovations provide an opportunity to reflect on trade-offs between increased uncertainty and potential efficiency gains. It allows to assess whether capabilities are sufficient or should be further developed or acquired. The planned innovations could be identified in any stages of the project life cycle considering innovations vary depending on the project phase (Davies et al. 2015; Sergeeva and Zanello 2018). At the same time, megaprojects should be flexible and open for emergent innovations. They should be adaptive to innovation initiatives as a response to the challenges encountered during the project life cycle.

Limitations

While some interesting results were found in this exploratory research on the role of complexity in innovation in megaprojects, there are a few limitations. First, the research method may have the potential limitation of missing in-depth understanding of the interactions within the projects. Second, as with all case studies, the results cannot be generalized to all megaprojects in all contexts. However, the study improves our understanding of innovation combined with complexity, and contributes to the current literature in project management by proposing a contingency approach in managing innovation in megaprojects.

Conclusion

Innovations are increasingly being encouraged and adopted in megaprojects. These innovations often involve high levels of risk and uncertainty, making the project ever more complex. While project complexity has been discussed widely in the literature, less is known about the relation between project complexity and the recent trend towards increased levels of innovation. This paper provides a better understanding of the link between project complexity in innovation in megaprojects. The findings discover a bidirectional relation between project complexity and innovation dimensions, and reveal interactions between innovation dimensions.

The main findings of this study are the identification of specific impacts of technical, organizational, and environmental complexity on innovation dimensions. Environmental complexity plays a strong motivator for innovation initiatives. Megaprojects have various complementary innovations but actualising interactions between innovations are also revealed. These actualising innovations are mostly seen between the innovation as an outcome dimensions, when one innovation is necessary to realize the benefits of the former.

The study makes several significant contributions to theory and practice. First of all, using the lenses of contingency theory and organizational innovation theory, the paper provides a comprehensive understanding of innovation in megaprojects and the role of complexity. We argue that without considering project complexity as a contingency factor, innovation in megaprojects are not fulfilling their potential to improve project performance. Second, we have identified several research gaps and propose the following areas for future research to address these gaps: i) lack of understanding on all innovation dimensions, ii) deficiency in systematicity of relations between complexity and innovation, iii) limited understanding of the impact of innovation on the overall project performance with project complexity as a moderating variable. A large scale study testing these relations is recommended. The research agenda is aimed to validate current and reveal potential new relations, contributing to improving the delivery of megaprojects. This is relevant for academics and practitioners who will be able to assess levels of complexity and evaluate innovations in light of this. A careful upfront assessment of the right approach to managing the project is needed to improve megaproject delivery.

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