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Longitudinal Case Study Analysis to Identify an Innovation Process for Contractors in Megaprojects

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Construction megaprojects often exhibit high degrees of innovation due to their singularity. They are captivating and we must expect the innovation process to be the same. To identify and describe the innovation process of contractors is our objective; a process model of innovation is our primary contribution. Since little relevant information is available, descriptive research on the innovation process by contractors might benefit a better understanding. Longitudinal studies observing innovation promise to generate the deepest insight possible because innovation itself takes time. We conducted research in four projects as case studies alternating between action research, observation, primary and secondary source documents, and interviews for data collection using grounded theory for data evaluation. Literature from the fields of construction management, organizational management, social psychology and cognitive science helped to embed the data into theory. The data reveal a highly complex, iterative and messy process with nine overlapping process groups. The contractors were never able to define problems completely and used simplifying heuristics. Satisficing behavior and bounded rationality replaced optimization.

Keywords: Innovation process, megaprojects, problem solving, what-if questions, satisficing

Introduction

Construction megaprojects often show a large degree of innovation (Slaughter and Shimizu, 2000; Brockmann et al., 2016). However, there exists no rich model of the innovation process leading to this result. Such a model would detail the innovation process in more than just a few consecutive stages. It would have to give answers to the why, how, where, what, when, and who of innovation. A rich model should not only provide understanding for the scholar but also enable managers to guide and influence the process.

How can we establish such a model? We believe it is preferable to proceed by extracting data from megaprojects in a descriptive approach, following the decisions and actions of the people involved. Experienced managers and engineers plan and execute megaprojects and they establish best practices by trial and error. The innovation process model shall reflect these best practices. Academic criticism of the model will be part of the conclusions. Results will show that a successful innovation process for construction megaprojects is not a journey (Van de Ven et al., 2008) but a very bumpy high-speed drive into the unknown with engineers who relentlessly push for innovation.

The paper has the following structure:

(1) Approaches to generate innovation and definition
(2) Existing innovation process models
(3) Research strategy
(4) Data collection and summary
(5) General model of the innovation process
(6) Conclusions

Our stated objective is to describe the innovation process in a general model; therefore, we take a descriptive approach by asking and observing project participants. To this purpose, we have conducted four case studies. Only further studies will allow calling the model general.

Approaches to generate innovation and definition

Rosenberg (1990, p. 169) summarizes the motives of private companies to engage in research: "Thus, it is doubtful that business decision-makers often sit down and ask, in an abstract way: Should we do basic research? How much basic research should we do? Obviously, private firms feel no obligation to advance the frontiers of basic science as such. Presumably, they are always asking themselves how they can make the most profitable rate of return on their investment."

Turning attention to construction megaprojects (simply defined, these are projects with a volume of more than 1 billion USD, Miller & Lessard, 2000), we will notice their singularity. Task, social, cultural, operative and cognitive complexities are at the limits of human understanding and differ largely from one megaproject to the next. In such cases, basic research will not increase the return on investment because benefits are limited in scope. Singularity distinguishes megaprojects from mass production in pharmaceutical or chemical industries where innovative products sell millions of times. While the return on investment in construction seldom benefits from basic research, it might well benefit from applied research generating new solutions for one project. If these conclusions are correct and project teams generate applied innovations for megaprojects, then we also have an explanation why they are not traceable through accounting systems. They are not booked into an account "R&D" but into one with the name of the megaproject under consideration.

There is no shortage of definitions for the term "innovation" and they serve different purposes (Baregheh et al. 2009). In the context of an innovation process for megaprojects, such a definition must be process-oriented, encompassing, and business-oriented. For our purpose, we formulate the following definition: Innovation in construction of megaprojects consists of: (1) processes leading to the implementation of new products, technologies or solutions for the organization, (2) which are at least new to the performing contractor, and (3) generate a business advantage (higher profits and competitiveness).

Existing innovation process models

The academic literature on innovation is extensive. For our purpose, it is sufficient to discuss four stage-based models of the innovation process. The models serve as reference points. Zaltman et al. (1973) and Van de Ven et al. (2008) described the innovation process in general; Tatum (1987) and Laborde / Sanvido (1994) have done the same for the construction industry. The models are stage-based and shown in table 1. The stages are arranged in such a way, that comparable ones line up.

Table 1. Existing construction innovation models

Zaltman et al. (1973)	Tatum (1987)	Laborde/Sanvido (1994)	Van de Ven et al. (2008)
Knowledge awareness	Recognize forces and opportunities	Identification	Initiation period
Formation of attitudes	Create climate for innovation		
	Develop necessary capabilities		
Decision	Provide new construction technology	Evaluation	Development period
Initial implementation	Experiment and refine	Implementation	Implementation period
Sustained implementation	Implement on projects and in the firm	Feedback	

The comparison shows some similarities. However, it seems that all models neglect the idea of profit making in the business environment. The disregard of the business side violates a well-known definition by Van de Ven (1986, p. 591) who describes innovation as "managing ideas into good currency". Also missing in all models is information on how ideas are developed, who the drivers of innovation are, what heuristics these drivers use in the problem-solving process, and how they make decisions with regard to the innovation. While the models are rather simple, most texts describe the processes in detail, especially Van de Ven (2008) who expounds the important idea of how periods of divergence and con-vergence alternate during the innovation journey.

Four idiosyncrasies concerning innovation characterize the construction industry and set it apart from manufacturing: (1) Project-based innovation: Contractors spend little money on formal R&D (Laborde & Sanvido, 1994). The vast majority of innovations are project-based (Brockmann et al. 2016). (2) Awareness of innovation opportunities: This is a prerequisite when applying for tender documents for a megaproject. Most of the time, a successful prequalification is required to be eligible for tendering. The owner triggers awareness from the outside; the innovating company in manufacturing must generate it from inside (Van de Ven et al., 2008). (3) Focus of innovation: Regardless of the procurement method chosen by the owner, all tender documents define to some degree the final product (building, structure). These documents limit and guide the innovativeness of contractors. In manufacturing, no such constraints exist (Van de Ven et al., 2008). (4) Time pressure for inventions: The owner sets further limitations by the tender and construction schedules. Contractors have two main periods during which they can innovate: during tendering and when mobilizing. The contract price reflects inventions found during the tender period; further innovations during the mobilization period can improve the profitability of the project. We conclude that the existing innovation process models are not appropriately addressing these idiosyncrasies. Stages as sequential units along a time axis often do not reflect the nature of many processes adequately. The Project Management Institute (2021) proliferates the idea of overlapping phases and calls these "process groups". This facilitates the description of processes in which more than one activity is going on at a given moment in time as it proves to be the case in construction megaprojects.

Research strategy

We carried out the research from 1988 to 2016 as a series of longitudinal case studies. These are especially well suited to find answers to the questions of how and why (Yin 2003). Taylor et al. (2011)

call for longitudinal studies, multiple units of analysis and triangulation to meet the burden of proof. The presented data cover a period of 35 years (longitudinal) from four megaprojects in Denmark, Thailand, Taiwan and Qatar (multiple units) using action research, observation, primary and secondary source documents and interviews which allows for triangulation.

The selected cases avoid many known barriers to innovation in construction. (1) Small size as barrier: Megaprojects are large projects per se. (2) Fragmented supply chain as barrier: A comparison of traditional design/bid/build, integrative design/build and even more integrative engineering procurement and construction (EPC) contracts makes it possible to observe whether the contractor's innovation process depends on the type of procurement method. (3) Competence of contractors as barrier: All chosen cases involved technically competent contractors as sponsors with worldwide reputations. (4) Influence of the owner as barrier: It seems likely that an owner has an influence on the amount of innovation but not on the cognitive innovation process of the contractors. (5) Standards and regulations as barrier: It is always possible to apply for single case approvals that deviate from prevailing regulations and standards. This requires resources on the contractor's side and the likelihood of their availability in megaprojects is greater than in average projects. In sum, megaprojects are rather ideal cases, as the barriers discussed in the relevant literature largely do not apply to them. The following choice of cases permits to evaluate the influence of two barriers, fragmentation and separation of design and construction.

Table 2. Case studies

Project	Country / Time	Stakeholders	Delivery method
Great Belt Tunnel (Rail)	Denmark (1988 – 1997)	Contractor	Design-Bid-Build
BangNa Expressway	Thailand (1995 – 2000)	Contractor	Design-Build
Taiwan Highspeed Railway	Taiwan (1998 – 2007)	Contractor	Design-Build
Qatar Integrated Railway	Qatar (2008 – 2022)	Owner	EPC

Data collection and summary

As stated above, the data were collected by action research, observation, primary and secondary documents, as well as 35 interviews.

(1) Action research was carried out at the Great Belt Tunnel, the BangNa Expressway, and the Qatar Integrated Railway Project.
(2) Observation was carried out at the Taiwan Highspeed Railway Project on the sites of seven joint ventures.
(3) Primary documents were accessible at the Great Belt Project and the BangNa Expressway. Secondary documents were used for all four projects.
(4) 35 interviews were conducted mainly with project managers and other top managers at the Taiwan Highspeed Railway Project. The interviewees not only reflected their experience in this project but also experiences from prior projects. The interviews were transcribed and coded using a grounded theory approach. Grounded research is iterative and the data emerged after several rounds of coding.

To present such data effectively is difficult. The following table 2 summarizes the findings and an exemplification of the model using a data set is presented later in the paper (data example for the innovation model).

Table 3. Data Summary

Category	Results
Why do contractors engage in innovation?	Increase profit and/or competitiveness
How do contractors engage in innovation?	Project-based research with problem-solving and emergent solutions
Where do contractors engage in innovation?	Head office, project managers and engineers on site
What kind of innovations come up?	Product and technological innovations, innovations in the technical, management, and legal organization
Who is driving the innovation?	Bid team, project team

In the data, we could not clearly detect champions of innovation belonging to one single group. Instead we found different groups in a relentless, aggressive pursuit of innovative solutions.

General model of the innovation process

From the data emerged a general model of the innovation process consisting of two parts: (1) project planning as a circular activity with ten partial plans and (2) nine partially overlapping process groups.

Project planning

Project planning is an activity that is indispensable for all construction projects. This is the domain where contractors can always innovate regardless of the procurement method. The information generated is required to submit a bid. While there is no way around project planning, the detailing depends on the type, size and complexity of the project. The estimator performs project planning for small and mid-size projects. A team of specialists as part of the bid team is crucial for preparing a bid for large-scale projects. Megaprojects are without exception unique and the differences between tunnel or bridge projects or even between two bridge projects are substantial. Consequently, the team of specialists must develop a novel solution in accordance with the boundary conditions of the focal project: project planning for megaprojects is an innovative activity by necessity.

Project planning consists of ten partial plans next to project design according to observations in the chosen case studies: (1) estimating, (2) scheduling, (3) determination of the construction technology, (4) make-or-buy decisions, (5) resource planning, (6) site installation, (7) logistics, (8) management organization (9) technical organization and (10) legal organization. Remembering profit maximization as paramount goal, we can formulate the task for a contractor: minimize the costs as they depend on the other nine partial plans.

Nine partially overlapping process groups

The project members and interviewees did not describe an innovation process. However, from observation by action research and some information from interviews, we were able to establish nine process groups of a typical innovation process: (1) awareness of a problem, (2) analysis of the problem, (3) searching the set of known solutions, (4) determining the gap, (5) what-if questions, (6) satisficing, (7) adequacy of resources, (8) organizational decision making and (9) implementation.

Process group 1: awareness of a problem: With regard to megaprojects, the “problem” starts with the decision to submit a bid. Due to their uniqueness, megaprojects require novel solutions. Companies that engage in megaprojects are well aware of the consequences and the resources required. The bidding phase will typically cost several million US$. Depending on the delivery method, the contractor needs to find a solution for the problems of project planning alone (design/bid/build) or for the design and project planning (design/build and EPC). The fundamental focus is on the overall solution for the new project. Finding the best possible overall solution means to accept suboptimal solutions for some of the partial plans given the time constraints in construction innovation and the complexity of the problems. Problem awareness is shown as a singular impact in figure 1. Yet in reality, this is often a lengthy process including expression of interest, information gathering, prequalification, screening of the documents and finally commitment to the project. However, the commitment happens at a given time.

Process group 2: analysis of the problem: Megaprojects are complex and the information given or required is overwhelming. As the contractor tries to understand the design (conceptual design or detailed design), additional information is most often of vital importance. The analysis is not always a rational process as time pressures necessitate taking short cuts and this involves prioritizing. In our data, there exist many examples of problems, which the contractor did not understand at a point in time. The following process groups force the project team to repeat certain parts of the problem analysis to generate a thorough understanding: developing a solution and analyzing the problem overlap.

Process group 3: searching the set of known solutions: The search criteria are not clear and therefore the search process is ill defined. In the case studies, proprietary knowledge databases with data on past megaprojects did not exist. The reason for this might be the novelty of megaprojects and the lack of commonalities between megaprojects. Informal brainstorming or discussion groups are typical ways of accessing previous project knowledge. While managers and engineers develop solutions, they also remember solutions from previous projects and use them in problem solving.

Process group 4: analysis of the gap: Because of the singularity of megaprojects, a large gap between previous projects and the focal one is inevitable. Most of the time, the transfer of previously generated solutions will provide highly unsatisfactory results whereas at other times it is simply impossible. The gap analysis lays open the degree to which the focal megaproject is novel.

Process group 5: what-if questions: When the known solutions are inadequate, then what-if questions are a simple heuristic to generate new solutions. Pursuing this constant questioning long enough is a very powerful tool to develop innovations. The data provide very few and only minor examples of a genial solution presented more or less unexpectedly. It is a tedious work process, in which managers and engineers carve out the innovations gradually. Part of this work is the constant balancing of often contradicting demands between the partial plans. The degree of innovation depends on the resolve of the bid team and later the project team to keep asking what-if questions and going into the next round of adjustments to the partial plans. Here again, we observed people showing the doggedness of pit bulls.

Process group 6: satisficing: We constantly observed satisficing as a behavior to end the search when looking for innovations in megaprojects. The complexity of megaprojects does not allow defining a finite set of variables that describe a given problem (Li and Love 1998). From this follows the inability to clearly structure and analyze the problem. Some of the consequences from decision-making will remain unknown. In addition, the number of possible solutions is infinite. The innovators in megaprojects face therefore three impossibilities: (1) the impossibility to determine all variables defining the problem, (2) the impossibility to structure the problem completely and (3) the impossibility to gauge the sets of alternatives and consequences. When a problem is ill structured, the solution cannot be completely rational; the innovators must also rely on intuition. They must content themselves with a solution that looks good enough to themselves. This is satisficing behavior.

Process group 7: adequacy of resources: A newly developed solution must be buildable. This is what differentiates an invention from an innovation. For a contractor the question is whether he has command of the required resources. Financial strength is a basic requirement for megaprojects but more crucial is the human capital of a company: does it have access to the right people who can implement the inventions, is there enough knowledge within the company and is the required learning process possible? This includes necessarily a step into the unknown. Sometimes, this is a large step requiring a lot of good judgment and courage: the courage of pit bulls. For this, the ability to learn assumes paramount importance.

Process group 8: organizational decision-making: Organizational decision-making is at the core of organizational theory. Task ambiguity and bounded rationality characterize decision making for innovations in megaprojects. A sizeable amount of literature exists on decision-making in organizations within behavioral organization theory. Influential are the works of March (1988) and Cyert and March (1992). Social psychology covers another aspect of decision-making, e.g. the phenomenon of groupthink (Janis, 1972). Of great interest are the contributions from cognitive science (Kahneman, 2011). Individuals or groups take decisions throughout all stages of the innovation process. Organizational decision-making in this context is the process of agreeing to or rejecting an innovative solution by those who carry the business responsibility. A typical way of coming to a decision is in a meeting with a presentation of the problem, alternatives and the proposed solution with its pros and cons. Our data from observation show that the decision process in the case studies often were concluded in such a meeting. Informal groups with members of the bid team and decision makers often prepare the decision in face-to-face communication. As ambiguity pervades the process, rationality is only one aspect and personal preference is another; risk attitudes play an important role. There are also several instances of groupthink with negative outcomes in the data set. In consequence, the main decision-making meeting is prepared and followed up; it is a lengthy process.

Process group 9: implementation: There is a clear difference in the risk appetite between the bidding team and the project team after contract signature. The latter is responsible for successful implementation of the inventions turning them into innovations. We observed that the project team rejected some inventions or parts thereof (BangNa Expressway). This must not necessarily be disadvantageous as it might regulate overambitious inventions. It is a two-fold approach, first with an emphasis on the desirable and then on the achievable. The project teams never rejected an important part of an invention; differences only arose on the fringes. Project participants did not describe the different steps in the innovation process as phases but as over-lapping process groups (fig. 1).

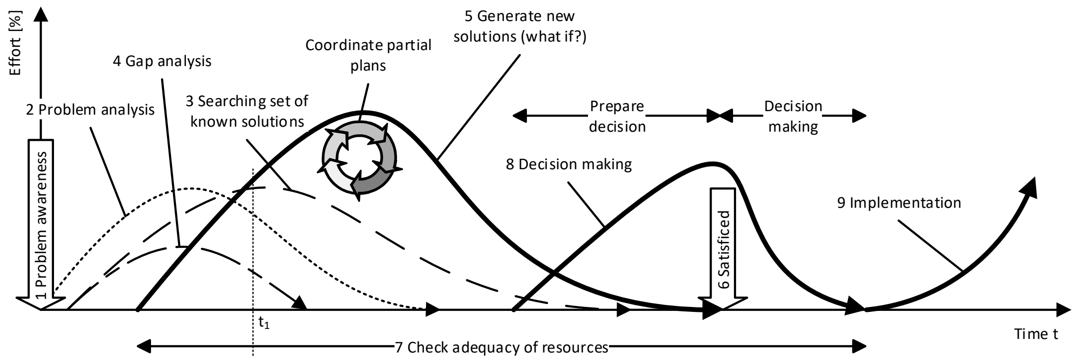

Figure 1. Innovation model for megaprojects

Data example for the innovation model

One example from the data set can serve to back-up the model: the design innovation for the BangNa expressway.

(1) Problem awareness: The later successful joint venture was aware of the need to find an innovative solution when applying for the tender documents.
(2) Problem analysis: Previous projects had two separated expressways, one for each direction with two lanes. For the BangNa project there was only space for a center column supporting a combined superstructure with six lanes. Thus, a novel solution was required.
(3) Searching the set of known solutions: The joint venture had prior experience with the construction of two expressways in Bangkok.
(4) Gap analysis: The gap between previous solutions and the project were the space constraints for the substructure (piles, pile caps, piers).
(5) Generate new solutions: A first round of what-if questions led to a solution with separate superstructures on a large crossbeam on top of a center column. The joint venture found the solution not innovative enough and tasked another designer to find a better solution. This designer asked the question what would happen if the directional lanes would be combined in one superstructure without a large crossbeam. While this constituted the largest cross-section ever designed for segmental construction, the designer and the joint venture concluded it would be possible.
(6) Satisficing: After finding this solution, the joint venture stopped pushing what-if questions.
(7) Check adequacy of resources: The joint venture trusted the designer to detail the solution and its own competence to implement it.
(8) Decision-making: This process included coordination between the joint venture partners and the different levels in their companies.
(9) Implementation: The project was successfully implemented from 1995 to 2000.

Conclusions

The objective was to extract from our data a theoretical model of the innovation process in construction. The presented model is the result of the data interpretation. As always in construction with its endless variations, the model cannot claim to be the only approach to innovation. However, our data on megaprojects suggest that this is a very typical model of innovation. While the process is always incremental (what-if?), the end result of the process can be substantial or even radical. The model does not capture a sudden bright breakthrough idea. There simply was no evidence for this in the data set. As the data set is limited, the model cannot claim to be universal. However, since we do not have a more defined process model, it can serve as a hypothesis in cases other than megaprojects.

The model features nine overlapping process groups and the integration of ten partial plans. This model is richer than the models presented in the general and construction literature (cf. table 1). It also contains more qualitative information. Our nominal definition of construction innovation covers a process, a focus (product, technology, and technical / management organization), an operationalization (new to the contractor) and an aim (business advantage). The model provides information in all these areas: it describes the process; the focus shifts during the alignment of the ten partial plans between product, technology and organization and the business advantage is checked during decision-making. We believe the model can help practitioners to manage the innovation process much more efficiently. The reason for the usefulness to practitioners is that the model is not normative but descriptive based on data from projects and practitioners.

The descriptive nature becomes clear when looking at the heuristics used (satisficing, expert judgment, intuition) and biases found such as groupthink or personal interests. The illustrative example give proof that the practice is not a beacon of ideal rationality but of a rationality determined by circumstances. Time pressures, complexity and cognitive limitations led to shortcuts. None of this is new in general as the relevant literature discusses heuristics and biases thoroughly (Kahneman, 2011 and Thaler, 2015). However, it is still helpful to find confirmation in the data for construction megaprojects.

The innovation process is complex: the number of possible components, their interrelation and their cross impacts are limitless in megaprojects. Only bold decisions can reduce this complexity. The innovation process is iterative: team members try constantly to align the contradictory demands of the ten partial plans. They must switch back and forth between the different phases in the model. At time t_1 in fig. 1, six activities are ongoing simultaneously: problem and gap analyses are not finished, the search for known solutions continues, generation of new solutions and coordination of partial plans has started, and the adequacy of resources is monitored. New information in one activity can have impacts on all others. The innovation process is messy: there exist no guidelines how to proceed. In all cases, the involved managers and engineers had to learn their path through the innovation process anew. Based on observation, there was never enough information, never enough structure, never enough time, never enough resources and yet decisions were due. Doggedness, gameness, courage and a certain degree of aggressiveness are the qualities required for a successful innovation process in megaprojects. Ingenuity is helpful in the team but not the determining trait.

Another important result from the data set is that contractors always managed innovations through project-based problem solving. We never observed the involvement of a R&D department (we do know that they exist in some companies but they had no influence in our cases). People welcomed emergent solutions when they detected them. We have seen that contractors checked innovative solutions for a business advantage during the decision-making process. The bid or project teams were aware of this hurdle and always considered this aspect before submitting solutions for organizational decision-making. The economic principle of profit maximization was the guiding one in the innovation processes observed. Rational behavior of the actors can only be interpreted in this context: Contractors engage in the innovation process for a business advantage.

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