

IMPROVING THE DELIVERY PROCESS FOR ENGINEERED-TO-ORDER PRODUCTS – LESSONS LEARNED FROM POWER DISTRIBUTION EQUIPMENT

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ABSTRACT

Scholars and practitioners have long advocated the benefits of reduced lead times. Moreover, most, if not all members of a delivery process would gain from reduced lead times. However, the construction industry has been slow to radically reduce lead times, particularly for Engineered-To-Order (ETO) products. This paper presents key findings from a four-year study, where the objective was to improve the performance of the delivery process of ETO products with particular interest in lead time reduction of power distribution equipment. Data were collected from the US and Finland from owners, users/operators, architects, electrical engineers, project management firms/general contractors, electrical contractors, and equipment manufacturers.

The paper summarizes the main causes for the long lead times, ranging from 79 to 133 weeks, highlights improvement suggestions, and describes potential barriers. The data surprised the authors and industry practitioners in many ways, e.g., with respect to the relative distributions of the various phases in the delivery process, the labor hours spent on competitive bidding, and the high number of changes. The improvement suggestions were estimated to reduce the process lead time by 20-40% of the total delivery time. Also, at least 15-20% of labor hours may be saved throughout the process.

KEY WORDS

Engineered-to-Order product, equipment, lead time, lean construction, manufacturing procurement, process improvement, switchboard

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INTRODUCTION

Studies have shown that managing material supply in construction projects is of major importance because, in general, roughly speaking around half of the project cost comes from material and equipment (Tanhuanpää et al. 1999), and most project delays are due to the lack of material (CII 1988 p. 1). Processing that adds value to materials and information amounts to only a small percentage of total time (Jarnbring 1994, Arbulu and Tommelein 2002, Arbulu 2002). Most of the non-value-added tasks (e.g., waiting) and problems (e.g., poor information flow) are overlooked (Vrijhoef and Koskela 1999). This is because often no single stakeholder is in the position to deal with the issues alone. In addition, material supply has traditionally been perceived from a solely transformation view rather than a simultaneous consideration of transformation, flow, and value views. An example of the above is the challenging lead time reduction of Engineered-To-Order (ETO) products, which we present in this paper. This process includes the design (engineering, detailing), procurement, manufacturing (fabrication and assembly), and shipping of the equipment.

Lead time is an anticipated time to complete a process, such as the delivery process of an ETO product. Long lead times of product delivery often dictate the pace of the construction project. Figure 1 illustrates the relationship of the delivery lead time of an ETO product and project lead time.

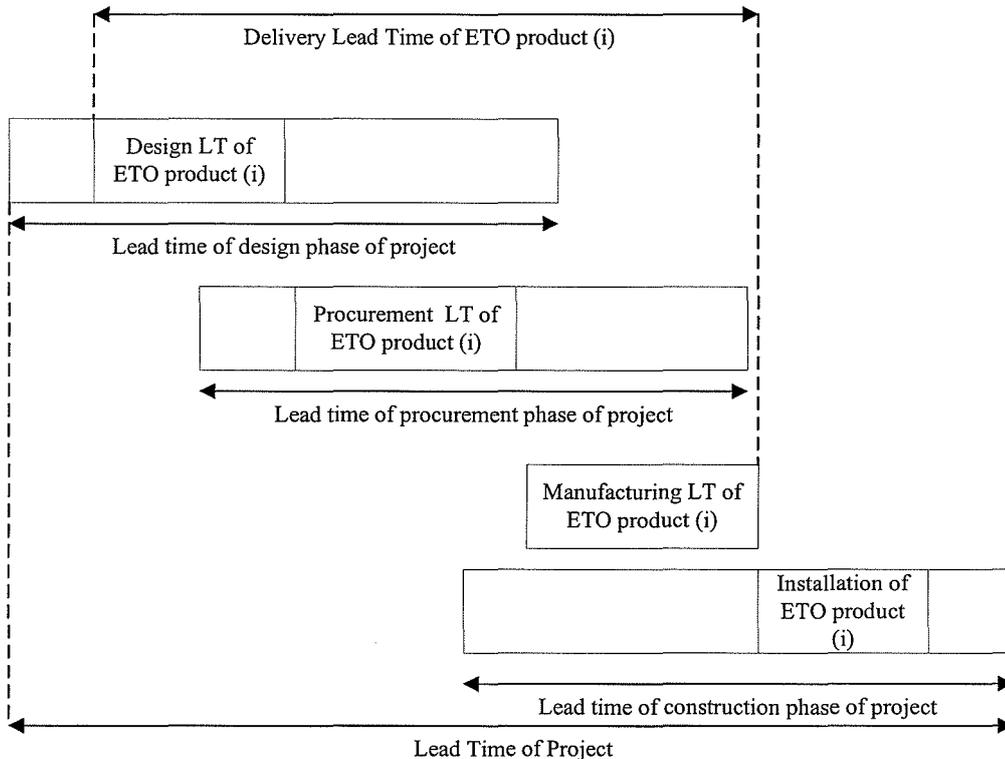


Figure 1: Relation between product and project delivery lead times (i emphasizes that i:th product is just one among many others in each phase)

The delivery lead times often have considerable “slack time”, because there is a tendency to separate design, procurement, manufacturing, and installation lead times, and then to separately allocate significant “slack time” to each of the “functional” lead times. Design lead time is the time for defining and specifying product characteristics. Procurement lead time is the time for product acquisition. Manufacturing lead time refers to Hopp and Spearman’s customer lead time (2000 pp. 321-313), the time between placing an order with a manufacturer and receiving what was ordered. Installation lead time is the time reserved for installing the equipment in the building. In reality the boundaries are not always so crisp and the various lead times tend to overlap.

Since typically each of the phases are considered in isolation from each other, it significantly increases the overall delivery lead time and complicates the overall improvement of the delivery process as discussed later in this paper. As a result, due to long lead times, too many design decisions have to be made early and based on vague assumptions, which often leads to suboptimal solutions, quality defects, and rework. In many cases, the feedback loops from the field to the supplier are so long and inefficient that some quality defects continue to repeat throughout production even after problems have been identified. This is further propelled by the characteristically high uncertainty and variability in the construction industry (Tavistock Institute 1966, Koskela 1999).

Understanding the problems and opportunities in current delivery processes (e.g., O’Brien and Fisher 1993, Elfving et al. 2002, Tommelein et al. 2003) and applying TFV theory (Koskela 2000) as a framework, the authors studied the delivery process of power distribution equipment (PDE) in three large construction projects, which included 408 pieces of PDE. In this paper we report the key findings with particular interest in lead time reduction of PDE, which we believe can be generalized to some extent to other ETO products.

The following sections are devoted first to a brief description of the applied research methodology, then to summary presentation of the three case studies, followed by a description of key findings and conclusions, including a discussion about future research.

ISSUES EXPLORED IN ETO DELIVERY PROCESS

In order to gain a more holistic perspective on this paper it is useful to be aware of the research questions that drove our study. The main question was:

“How can the performance of the supply chain of ETO products be improved?” This question was further broken down into three sub-questions:

- What are the design, procurement, and manufacturing processes for an ETO product?
- What problems exist and why do they exist in the delivery process of an ETO product?
- What changes in lead time reduction would yield what type of benefits and at what cost?

This paper reports just one part of our research and focuses on the two latter bullet points. An in-depth literature review on supply chain management and on ETO process management as

well as a detailed comparison of the cases are presented in Elfving (2003) and Elfving et al. (2003).

METHODOLOGY

A hybrid exploratory-explanatory case study approach (Robson 2002) was applied. The authors obtained data from three large construction projects, which had recently been completed or were under construction. The data gathering took place between August 2002 and January 2004. Data was collected through observations, records analysis, and interviews or workshops with owners, users/operators, architects, electrical engineers, project management firms/ general contractors, electrical contractors, and equipment manufacturers. 115 interviews were conducted, some during the six workshops that were facilitated. The purpose of the workshops was to bring representatives from each supply chain tier to the same place at the same time. This helped them to better understand the issues beyond their own narrow niche specialization and to identify improvement opportunities that could enhance the whole process instead of a piece of the process. It also helped the authors to validate the findings. In the first workshop, the participants mapped the current state map, in the second workshop, the current state map was verified and problems were identified, and in the third workshop, improvement opportunities were identified and a future state map was generated. Data was analyzed with the help of process maps, performance measures, and computer-based simulations. For details of the methodology see Elfving (2003).

DESCRIPTION OF CASES

The first case study, Bay Street, is a 1 million-square-foot urban development project in Emeryville, California including in 5 separate buildings. The project includes 400,000 square feet (45,000m²) of retail, with 65 shops, 9 restaurants and an AMC Theatre (with 16-screens and over 3,300 seats), over 2,000 parking spaces in multi-level structured facilities and surface lots. It has 6 main switchboards, 8 MCCs, and 150 panelboards.

The second case study, Novo, is a 300,000 square foot (30,000 m²) office building for a large IT-company, in Helsinki, Finland. The building has 10 floors of which 3 subsurface. The office space is around 234,000 square foot (21,000m²) and provides workspace for about 1,000 employees; the rest is subsurface parking structure. There are 2 main switchboards, 4 MCCs, and 72 panelboards.

The third case study, Paradise Pier, is part of Walt Disney's amusement park Disney California Adventure, in Anaheim, California. Paradise Pier includes 19 facilities of which 9 are rides and the rest shops, restaurants, and maintenance facilities. Along with the vertical construction Disney also developed and built the electrical infrastructure, including two switching stations for the resort. The local utility company normally handles electrical infrastructure, thus it was not included in this study. Paradise Pier has 7 main switchboards, 12 MCCs, and 148 panelboards

LESSONS LEARNED

TIME DISTRIBUTION

Although in the Finnish case (Novo), design took the longest time, procurement, which included the approval of shop drawings, consumed a significant part of the total delivery lead time in all three cases (Figure 2). One of the main reasons for the long procurement lead times were the large document batches, which lead to long cycle times. Also, the equipment was bought through several “middlemen”, which added to the procurement time. In Bay Street, the proportion of procurement compared to other phases was particularly high because Request-For-Quotations were placed early in the process, and they incorporated significant assumptions regarding the equipment specifications because the project design was still incomplete. Therefore, design overlapped with procurement in the form of “changes”.

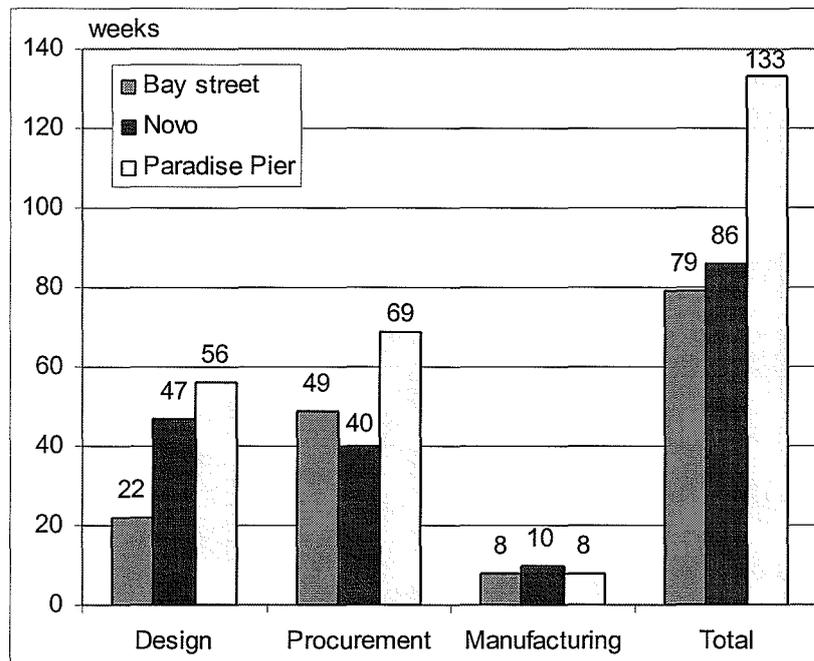


Figure 2: Lead time distribution in the three cases⁴

Besides procurement, design also consumed a large amount of the total delivery lead time. However, manufacturing lead time consumed only 12% or less of the total delivery time. Manufacturers were able to drop the lead time to three weeks or less if required (Table 1). Besides the long design and procurement lead times also the value-adding times in design and procurement phases were in all case less than 13%. Hence, the most significant reductions in the delivery lead time are achieved by improving the practices of the two first phases.

⁴ The sum of the individual phases in Novo exceeds the total 86 weeks because design and procurement phases overlap.

Table 1: Proportional lead times

Performance measure	Bay Street	Novo	Paradise Pier
Design lead time / total process delivery lead time [%]	28	55	42
Procurement lead time/ total process delivery lead time [%]	62	47	52
Manufacturing lead time/ total process delivery lead time [%]	10	12	6
Lead time of delivery process [week]	79	86	133

UNDERESTIMATED PROCUREMENT TIMES

Very little attention was paid to variability and uncertainty of the procurement times even if the procurement took significantly longer than anticipated in all cases and the applied procurement method caused a significant amount of waste throughout the delivery process. Moreover, the procurement times in the project schedules were deterministic values based on past experience and ad hoc assumptions, apparently without explicit consideration of the contributing factors, such as multitasking and commitment (Elfving and Tommelein 2003). The disregard for the variability and reliance on “received traditions” (Schmenner 1993 p. 379) not only lead to underestimated procurement times but also created numerous problems for the project participants downstream in the supply chain. For example, in Novo’s case, the procurement was scheduled to be completed February 7th but the actual contract was signed June 11th, nearly four months later than anticipated. Therefore major part of the slack in the manufacturing and installation phases was swallowed up by the procurement phase, which meant that more resources (labor hours and overtime) were needed to keep up with the production schedule.

CAUSES OF LONG LEAD TIME

A wide array of causes contributed to the long delivery lead time. However, a major reason why causes had not been addressed earlier was that stakeholders were not aware of the delivery process as a whole; they lacked a systems view of the process. Therefore, improvements to date had been local, focused on a certain functional unit, rather than on global process improvements.

Current improvement efforts, except for product standardization in the US, have concentrated on transformation of inputs to outputs, e.g., automating the shop drawing phase. Though some of the changes have brought notable improvements for the particular stakeholder who introduced the change, the overall delivery process has not benefited by the same magnitude. Also, the danger of applying only the transformation concept is that it may fuel the “vicious circle” of increased delivery lead time and increased probability of changes, where as the time between design and manufacturing increases the probability of design changes increases, which increases the probability of manufacturing changes, which pushes the delivery lead time (Elfving et al. 2002).

In general, the flow and value concepts of production were not properly applied or not applied at all. Examples are large and non-sequenced document and material batches, fierce competitive bidding, and early commitment. Competitive bidding was one of the main

reasons that upstream players had to commit early to design solutions and to pursue large design batches. Hence, it created waste not only in procurement but in other phases of the delivery process as well. Another major cause of waste in the form of waiting and rework was due to changes. Bay Street had 337, Novo 330, and Paradise Pier 200 changes or add-ons only in the pieces of PDE. For example in Novo the changes increased the value of the original contract by 30% and delayed the scheduled site installation by several months. Also, other issues such as industrial organization and types of standards also impacted the delivery time (Elfving 2003). Table 2 summarizes the main causes of long lead time.

Finally, owners and architects consider the project environment to be dynamic. They find it evident and normal to constantly revise the project, and design iterations and changes are part of this process. However, the delivery process of PDE is poorly structured for their dynamic needs. Specifically the approval of drawings and specifications is very slow and embedded with waste.

Table 2: Summary of causes that pushed the delivery lead time

Phase	Cause	Bay Street	Novo	Paradise Pier
Design	Changes due to early commitment and lack of knowledge	X	X	X
	Changes due to design errors	X	X	X
	Coupling PDE design to other systems design	X	X	X
	Outdated practice of auxiliary design and approvals	X		
	Owner(s) and tenant(s) delayed design input	X	X	X
	Low level of design standardization		X	
	Tedious collection of design input (and poor reliability of input)	X	X	X
	Non-sequenced "push" driven design	X	X	X
	Complexity-Large number of specialists			X
Procurement	Serial competitive bidding	X	X	X
	Exclusion of product flexibility	X	X	X
	Large document batches	X	X	X
	Improper document sequence			X
	Commercial relationships	X		X
	Changes in product specifications	X	X	X
	Sequential and bureaucratic document flow	X	X	X
	Gaming	X	X	X
	Misunderstandings in scope of task			X
Cumbersome and tedious shop drawing approval process	X	X	X	
Manufacturing	Component lead time	X	X	X

	Capacity	X	X	X
	Sequential and bureaucratic document flow	X		X
	Production method		X	
	Data entry into software		X	
	Changes		X	X
	Non-sequenced equipment delivery	X		

MAJOR OPPORTUNITIES

The value-added times in the delivery processes were only a few percentages of the total delivery lead time. In all three cases, significant opportunities to reduce the delivery lead times were identified (Table 3) and most of the changes (Table 4) do not even require financial investments. Education and training are often the only cost. In fact, the industry partners proposed the improvement suggestions in Table 4 during the workshops after reviewing the current state map and playing the airplane game⁵. Airplane game is a production simulation game, where players assemble “Lego” planes based on different sets of production polices. As players move from a push-based production environment to a pulled-based production environment they experience e.g., significant improvements in cycle time and throughput, while work-in-process is reduced.

Table 3: Lead time and number of activities in current and estimated future state

Performance measure	Bay Street		Novo		Paradise Pier	
	Current State	Future State	Current State	Future State	Current State	Future State
Lead time [week]	79	35	86	41	133	65
Number of activities	49	38	62	51	66	47

The authors estimated that the proposed changes could reduce the process lead time by 20-40% of total delivery time. Also, at least 15-20% of labor hours may be saved throughout the process. The estimates mainly stem from eliminating non value-added activities from the process, particularly from the time-consuming procurement phase, and reduced cycle time of all the phases due to smaller batch sizes.

A central point in improving the delivery processes is to recognize that design, procurement, and manufacturing have significant interdependencies. Therefore, it is necessary to analyze them in an integrated manner, rather than as separated disciplines as is so common in the construction industry.

⁵ In Bay Street, where no workshops were hosted, the improvements suggestions were proposed during the interviews with industry partners.

Table 4: Improvement suggestions that industry partners shared⁶

Phase	Improvement suggestion	Bay Street	Novo	Paradise Pier
Design	Reduce document batch	X	X	X
	Standardization of detailed engineering		X	
	Pulled-based design	X	X	X
	Application of manufacturer's configuration software	X		X
	Downstream players in upstream decisions	X	X	X
	Postponement of detailed engineering	X	X	X
Procurement	Alternative procurement methods	X	X	X
	Re-structuring organizational relations	X		X
	Smaller document batches	X	X	X
Manufacturing	Changes in manufacturing logic		X	
	Sharing software with customers	X		X

In addition, the TFV theory provides a new approach to traditional transformation-based thinking. It contributes to better understanding of the process behavior and identification of improvement opportunities. Particularly, the flow concept turned out to be helpful. For example, 90% of the waiting time for shop drawing approvals could have been eliminated if the batch size had been reduced to one piece of equipment instead of all the equipment in the project. However, there is a set-up time (to pull the right documents, to become familiar with requirements, etc.) to review the shop drawing. Therefore, a more realistic batch size to review may be one floor or building section at a time instead of one piece of equipment. In paradise Pier, which has 19 buildings, if the batch size of shop drawing approvals had been one building instead of 19, the waiting time would have reduced to 1/19 or with 95%. In Novo, which has 10 floors, if the batch size of shop drawing approvals had been one floor, the waiting would have reduced to 1/10 or by 90%. Also, the separation of systems design and detailed engineering and then the postponement of detailed engineering were considered as viable alternatives to current practice. Their pursuit will require close collaboration among project stakeholders. The systems level design defines main principles of power distribution in a building and they have to be considered in an early design phase so that the various building systems, such as structural, mechanical, and electrical match together. The detailed engineering refers to the configuration of components, such as switchboards and MCCs in the power distribution system. The inputs that are needed for the detailed level engineering are known in a much later stage of the project than the systems level input. Therefore, integrating systems design and detailed engineering forces the latter one to early commitment, which makes detailed engineering unreliable.

Another major opportunity lies in streamlining the current procurement practice and exploring alternatives to the current form of competitive bidding. Competitive bidding based

⁶ For detailed description of the improvement suggestions see Elfving (2003).

on nominally complete plans and specifications does not seem to be an efficient way to procure customized products. Among other things, it led to confusion among the stakeholders, reinforced conflicting project goals, consumed large amounts of resources and time, caused gaming behaviors, and created long and slow document flows.

Finally, the workshops proved to be a valuable method to enhance the collaboration among process stakeholders and to validate the research findings.

BARRIERS

Although the industry partners came up with a number of improvement suggestions (Table 4), there are barriers to overcome. Some of the main barriers to redesigning the current delivery process, which emerged when implementation requirements were discussed with the stakeholders, include inertia against change, the lack of cross-organizational collaboration, and the lack of resources to implement the changes. The cases demonstrated that there are some well established, local, “received traditions” among the stakeholders regarding procurement of PDE, which may be hard to change. A case in point is competitive bidding. Improving the delivery process from a systems approach requires cross-organizational collaboration. However, applying competitive bidding as the procurement method made the participants in all three cases reluctant to have cross-organizational collaboration. The current competitive bidding does not seem to provide incentives for long range process development, because there is a high probability that the stakeholders will be changed after every project. Competitive bidding mainly aims to cut costs and not necessarily to increase value. Most stakeholders recognized this; however, there was little experience and hence also lack of confidence that the equipment could be acquired by other means. Accordingly, it may be very difficult to change such a deep-rooted tradition. Also, people particularly those with a low degree of commitment to the delivery process, may not be aware of their impact on the process and thus ignore any improvement effort.

The workshops confirmed that the most radical improvements, such as owner furnished and negotiated contracts, reduced document batch sizes, discarding shop drawing approvals, and pull based delivery, require close cross-organizational cooperation and can be successfully executed only if all the major process stakeholders are committed. A single stakeholder can only improve the delivery process in limited ways.

Finally, people involved in the delivery processes were often overloaded with their work, which provided them little time for rethinking and development. Successful change will require dedicated people with adequate knowledge and time.

CONCLUSIONS

ETO products have traditionally been less studied from the product delivery point of view (design, procurement, manufacturing) because of the belief that they are “one-of-a-kind”. Due to poor replicability and other challenges, there has been a presumption that there is little value in studying them. Nevertheless, this study demonstrated that the product may be very different but the delivery process is still largely the same. Our findings show that there is a major opportunity to redesign the PDE delivery process. We expect that many of the findings such as large document batch sizes, long gaps between design and site installation, and high

number of changes applies to other ETO products. Other findings such as differences between standard types may not have so significant role in other ETO products. Nevertheless, instead of speculating on these issue we leave them to be explored in future studies. Some evidence of comparable findings from other ETO products already exists (e.g., Luhtala et al. 1994, Hong-Minh 2002, Arbulu 2002, Tommelein et al. 2003), and valuable future research topics include:

- To what extent can the findings of this study be generalized to other ETO products and whether the findings are comparable with other industries where ETO products are manufactured, e.g. electronics?
- What kinds of methods are needed to implement future state maps in a cross-organizational environment?
- What type of incentives and performance measures are needed in the implementation phase and after it?
- With regard to changes in the product delivery process, who pays and who gains?

Finally, the impact of change orders on construction projects has been widely studied (e.g., Hester et al. 1991, Zeitoun and Oberlander 1993, Cox et al. 1999), however, these studies have mainly focused on the direct cost (changes in contract value based on material, labor, and overhead) and rarely on indirect cost (productivity loss of various stakeholders, cost of administration, cost of legal disputes, etc.). Especially with respect to ETO products, the whole delivery process including the work done by designers and manufacturers should be included. Currently, it seems that the cost of design iteration, change orders, and add-ons are generally underestimated because the estimates only consider the direct cost. The direct cost of change orders and add-ons was between 8-30% of the contract prices in the cases studied. The indirect costs, such as the cost of managing the change order process and the loss in productivity, were not measured, but the order of magnitude was estimated to be at least the same as the direct cost. Other scholars have argued that the indirect cost is significantly higher than the direct cost of change orders (e.g., Burati et al. 1992, Love 2002). The exclusion of the indirect cost of changes may be one reason why there was not a stronger effort to improve and reduce the change order-approval cycle in the cases being studied. Hence, it would be interesting and valuable to see more complete studies in this area.

ACKNOWLEDGMENTS

This research was part of a four-year study on construction supply chains. It was funded in partly by the Electrical Contracting Foundation, and scholarships and grants awarded to Mr. Jan Elfving from Tekes-National Technology Agency of Finland, Academy of Finland, Association of Finnish Civil Engineers, Svenska tekniska vetenskapsakademien i Finland, Foundation of Technology in Finland, Confederation of Finnish Construction Industries (RT), Skanska Oy, and SRV Viitaset Oy. All support is gratefully acknowledged. Thanks are due to all people interviewed in course of the case studies, for the time and knowledge, and enthusiasm they shared with us.

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