REDUCING LEAD TIME FOR ELECTRICAL SWITCHGEAR

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ABSTRACT

This paper highlights some of the key problems in reducing lead times for engineered-to-order construction products, specifically items of equipment such as electrical switchgear ("permanent plant equipment" in the jargon of the process industries). Lead time reduction has long been considered a fundamental objective in overall business improvement and is a cornerstone in lean thinking. The benefits include reduced inventories and costs, greater flexibility and responsiveness, and better satisfied customers. In construction projects, shorter lead times could significantly reduce the number of change orders and/or make projects more robust to changes.

The authors suggest that the focus on reducing engineering lead times will have a greater impact on lead time reduction than a further focus on the manufacturing stage and that the product specification stage may play a more significant role in lead time reduction. An example of a switchgear supply chain demonstrates how long lead times lead to inadequate information from various players in the product specification stage impairs the process and leads to a chain reaction further down the supply chain. As a result, numerous design iterations and change orders occur, which further propagate the long lead times. This pernicious system dynamic is further complicated by the fact that some players in the switchgear supply chain profit from (or believe they profit from) change orders.

KEY WORDS

Engineered-to-order product, lead time reduction, lean construction, order, procurement, product specification

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INTRODUCTION

Lead time reduction has long been considered as fundamental for overall business improvement (Forrester 1961) and a cornerstone for lean thinking (Ohno 1988, Shingo 1988). In manufacturing, order delivery or customer lead time is defined as the time between customer order and order fulfillment, whereas cycle time is defined as the time for an individual job to traverse a routing. Manufacturing lead time is the maximum allowable cycle time for a job. When products are made to stock based on forecasts (Handfield 1995), the customer order is filled from finished goods inventory. Therefore the lead-time is often very short though the cycle-time may be very long. In the case of engineered-to-order (ETO) products, customer orders are processed through engineering, detailing, fabrication, and delivery. This difference is driven by the different intersection of customer orders with the entire production process. Other intersections define make-to-order (MTO) and assemble-to-order (ATO) products. This paper focuses on the ETO delivery process and its lead time, which include the engineering, detailing, procurement, fabrication, and delivery times.

This inclusion of product specification and procurement processes in the lead time for ETO products is very important, as typically much more time is consumed by those processes than by manufacturing and delivery processes. We will attempt to show that significant improvements in lead time reduction for ETO products can be achieved by including the entire system.

The advantages of reducing lead times are considerable. According to Karmarkar (1983) long lead times in manufacturing:

- increase work-in-progress.
- force schedules to be frozen over long periods, thus increasing the chance of schedule changes.
- increase safety stocks due to the protection against longer lead times and the variability in forecasts errors that become greater in a longer forecast horizon.
- suboptimize improvement efforts, because increased delay between fabrication and use means a loss of information about quality and satisfaction.
- increase variability, since the task of coordination becomes more difficult by long delays.
- might erode competitiveness of a company because of long response times.

In some cases, these issues are even more significant in the construction industry because of its characteristically high uncertainty and variability (Koskela 1999). Further, 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 supplier are so long and inefficient that some quality defects continue to repeat throughout production even if the problems are identified.

Next, a brief review will be presented of earlier studies in time compression and ETO supply chains, which will be followed by a case study of the switchgear supply chain. The case study highlights some challenges with respect to time compression and evokes some discussion of the problems. Finally, the authors conclude the paper by presenting their future intention to improve the switchgear supply chain.

EARLIER STUDIES

STRATEGIES TO REDUCE LEAD-TIME

There are three main strategies to reduce lead times for ETO products: (1) some tasks can be simply eliminated (2) some tasks can be combined where they are executed simultaneously both by partially or completely overlapping, and (3) some tasks can be reduced with help of numerous improvement techniques (Figure 1). Obviously, a combination of the strategies is also possible.

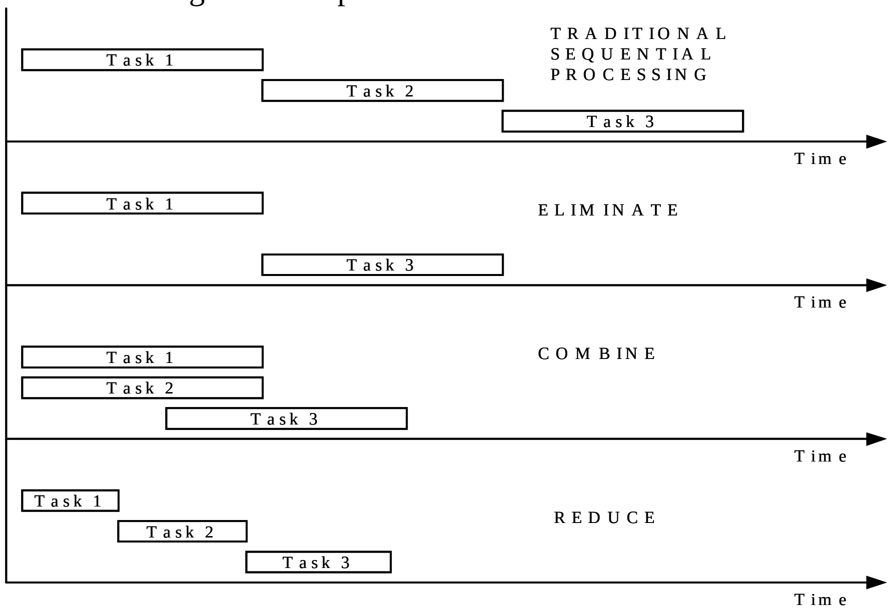

Figure 1: Strategies for reducing lead-times.

Hammond (1990) argued that processes have to be regularly reengineered because they simply get obsolete. It is not uncommon to find non-value added tasks in a process, e.g., designing components that already exist and store temporarily material. Eliminating these types of tasks can significantly impact the lead times (e.g. Shingo 1988; Handfield 1995).

Combining or overlapping tasks means that multiple tasks are worked simultaneously (Smith and Reinertsen 1998). The main idea is that the upstream task can be performed in chunks or information can be released in smaller batch sizes to the downstream activity so that the downstream activity can start before the upstream task is completed (Takeuchi and Nonaka 1986). In general, the main purpose of overlapping is to reduce the overall lead-time (Clark and Fujimoto 1991). Iansiti (1995) noted that overlapping product development tasks (concept development and implementation) also reduced uncertainty and improved the flexibility to react to market and technology changes. Overlapping requires good communication between the task members (Yazdani and Holmes 1999), therefore organizational matters must be carefully addressed. Several analytical methods have been developed to analyze the degree and benefits of overlapping (Krishnan et al. 1997; Steward 1981).

The parallel execution of tasks is the extreme form of overlapping. It requires decoupling of the tasks (Krishnan et al. 1997). In many cases, the decoupling may be difficult to apply and it may compel fundamental rethinking of processes. However, the literature recognizes examples of successful parallel execution of tasks in both engineering and manufacturing (Ullrich and Eppinger 1999; Sobek et al. 1999; Shingo 1988). In construction, it is common to decouple larger buildings to “building blocks” that are constructed relatively independent and in parallel with each other.

Multiple techniques exist to reduce task durations and lead times. These have been addressed by authors from several fields, ranging from industrial organization economy (e.g. Forrester 1961; Nishiguchi 1994; Lamming 1993), to production management (e.g. Schonberger 1996; Ohno 1988; Womack et al. 1990; Koskela 2000, Tommelein and Ballard 1997). In production management, the “Lean” doctrine can be considered as the principal philosophy of reducing lead times. Improved information and communication technologies have also simplified many tasks (e.g. Lancioni et al. 2000). However, the overall lead time actually increases if dependent tasks are improved in isolation from each other. Therefore, the efforts should be viewed from a systems approach (Shingo 1988).

Processes may also be simplified by standardizing product planning, components and products, which may be interpreted as a combination of the other strategies. This will significantly cut uncertainty and reduce the number of design iterations and/or speed up the iteration process (Loch and Terwiesch 1998), since the set of solutions is reduced and predefined before the process starts. These strategies are important to consider in the ETO supply chains as well.

TIME COMPRESSION AND SUPPLY CHAIN MANAGEMENT

Several authors have studied time compression in supply chains (e.g. Forrester 1961, Burbidge 1989, Stalk and Hout 1990). Handfield (1995) identified two types of lead time reduction in supply chains: (1) reducing the mean lead time and (2) reducing lead time variation. He also identified several means to compress time for make-to-order products such as system simplifications and component standardization. Clark and Fujimoto (1991) have found overlapping of activities as an effective time compression strategy for new product development, which is a form of the ETO process. Many opportunities to reduce project duration rely on understanding the interface of engineering and fabrication (Sobek et al. 1999).

Van der Vaart et al. (1996) among others have studied the complexity and prevailing uncertainty in MTO supply chains. According to Wegelius-Lehtonen and Pahkala (1998), poor information flow is the main problem in MTO construction products and typically the problems are located in boundaries of different organizations. Gil et al. (2000) found several opportunities how early involvement of specialty contractors would improve the MTO process, but noted restrictions as well. Tommelein and Weissenberger (1999) studied the supply of structural steel and found that buffer sizes and locations are not rationally planned throughout the supply chain and that lean practices are poorly understood across organizational boundaries. Many other ETO products, such as HVAC ductworks (Holzemer et al. 2000), concrete elements and facades (Vrijhoef and Koskela 2000), and switchgear (Barker 1994), have also been studied from a supply chain approach. Many studies have identified possible improvements, but rarely have those improvements actually been implemented and achieved.

CAUSE OF LONG LEAD-TIMES FOR ETO PRODUCTS: CASE FROM SWITCHGEAR

SWITCHGEAR AND MEMBERS OF SWITCHGEAR DELIVERY PROCESS

Switchgear is a general term covering switching and interrupting devices and their combination with associated control, metering, protective, and regulating devices, as well as assemblies of these devices with associated interconnections, accessories, enclosers, and supporting structures. It is used primarily in the generation, transmission, distribution, and conversion of electric power (ANSI/ IEEE 1992). Switchgear connects and transforms the incoming power from the utility grid to a secondary distribution network that provides power to end appliances such as lighting and receptacles. In commercial buildings, switchgear alone is around 10% of an electrical contractors' total material cost.

The main members of the switchgear delivery process are switchgear manufacturer, switchgear sales representative, electrical engineer, mechanical engineer, architect, local utility company, electrical contractor, electrical distributor, and a variety of regulators and standard setting bodies.

CURRENT STATE OF SWITCHGEAR DELIVERY PROCESS

Switchgear is a critical procurement item, since the ability to deliver it on time and within a predetermined cost may determine whether or not an electrical contractor gets awarded a contract. In current practice, cost minimization is mainly achieved through careful customization of each switchgear, where the switchgear components are chosen based on lowest component cost. This attempt to minimize 'cost-to-purchase' neglects other critical components in 'cost-to-use' such as engineering and procurement cost or the cost of potential changes. The way customization is currently performed requires much back-and-forth communication among several parties, which partly explains the long delivery lead time.

Current state map

The simplified current state map shown in Figure 2 is based in part on interviews that were conducted with a mid-size electrical contractor and a large switchgear manufacturer during Fall, 2001. It represents the engineering of switchgear for a 400,000 square foot, 21 floor high-rise office building, in downtown Oakland, California. The electrical contractor had both design and construction responsibilities (Design-Build). The procurement, fabrication, and delivery process steps of the map do not represent a specific project, but rather "typical" industry practice, as indicated in interviews with various industry practitioners. Although, the description of the current state represent only a spot of the whole industry, the authors are curious to learn to what extent the findings can be generalized to the industry.

Description of the main process steps

The process consists of engineering, procurement, fabrication, and delivery. Figure 2 represents the main steps and the sequence of the steps.

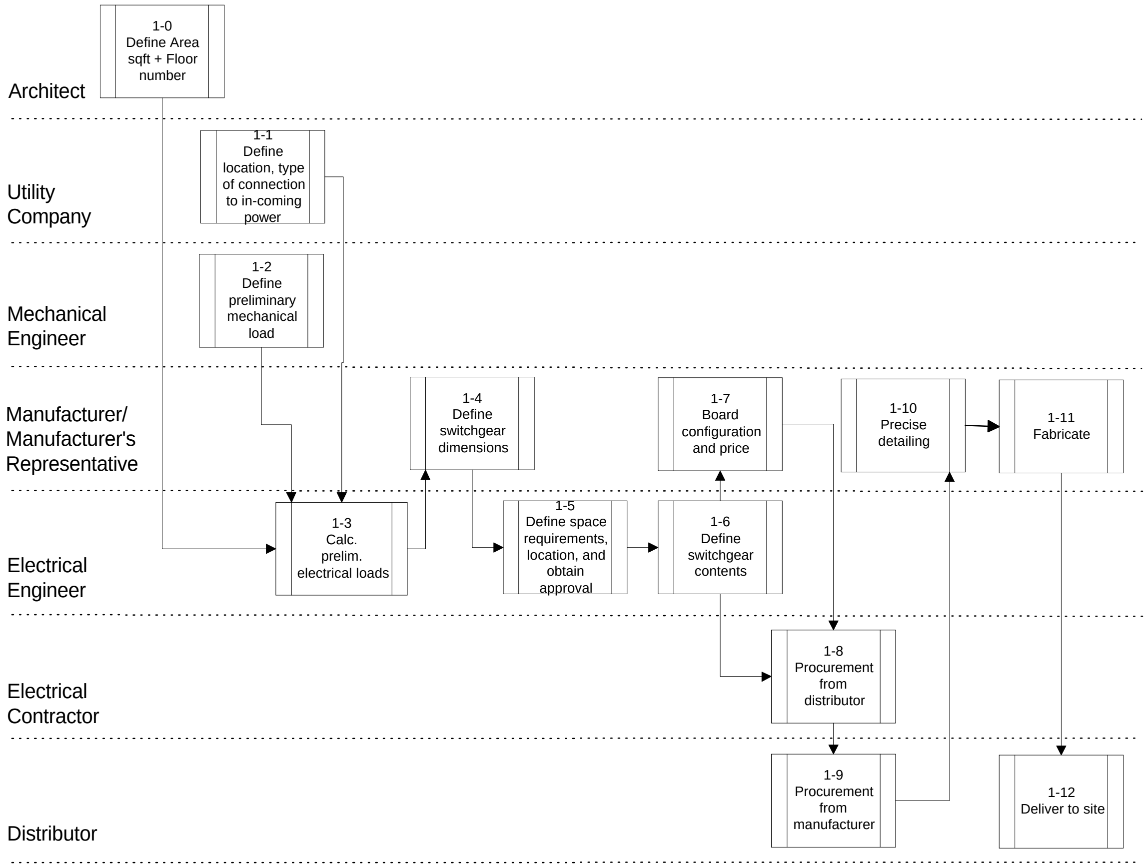

Figure 2: Current State Map for Switchgear

Engineering

The engineering task includes calculation of preliminary loads (1-3), definition of the switchgear dimension (1-4), definition and approval of location (1-5), definition of switchgear content (1-6), configuration of the boards (1-7), and precise detailing of the switchgear (1-10). Accordingly, the engineering lead time is the time between steps 1-3 and 1-10 less the procurement steps (1-8, 1-9). Note the information processing and flow required before an order takes place (1-8). The engineering time consumed about two thirds of the total six month lead time. The electrical engineer needs input information from the architect, mechanical engineer, local utility company, and the manufacturer in order to specify the switchgear. But in many cases other parties have to be considered as well, such as the electrical contractor, regulatory and standard setting bodies, and other trades on site. The communication is mostly conducted through phone, fax, and meetings, and several iterations are common. A major cause for the iteration is because the input from the architect and the mechanical engineer has to be submitted in an early stage of the project and is prone to changes. Another complicating factor is customization. Although switchgear is mostly assembled from standard components, standard products or switchgear are uncommon.

Order Fulfillment

Procurement of switchgear is commonly conducted through a distributor. The distributor is often able to get a better price from the manufacturer than the electrical contractor, because of distributors' larger procurement volumes. The manufacturer produces the precise detailing (1-10) and acquires material first after a purchase order is placed (1-9). Nevertheless, the initial purchase order gets updated throughout the delivery process. The manufacturer is aware of the iterative nature of the product specification and the multiple change orders. The manufacturer hedges against that uncertainty by reserving significant time for load leveling or by reserving excess capacity. This means that the owner pays either directly for the change orders (e.g. redesign, manufacturing setups, unused material, etc) or indirectly (the increase in lead time increases the probability of further change orders). The manufacturing lead time may be a few months but it is common that the manufacturer reserves capacity for rush orders which can be filled in a few days or in some case in a day. The manufacturer's lead time depends on his supplier lead times and his own available capacity.

Even if the distributor quotes for the contractor and handles product related issues after the order is placed, the distributor's role is very restricted, since switchgear requires much more technical knowledge than the distributor is normally able to provide. The technical issues are actually solved between the manufacturer's representative or sales engineer and the electrical engineer. Interestingly, sometimes the manufacturer's representative quotes a price too, and this price may be more competitive than the distributor's.

Characteristics of the Delivery Process

It is relevant to distinguish between information and material flows. Normally, the equipment goes directly from the manufacturer to the site, but the shipping may require several loadings and off loadings depending on the distance between site and manufacturing facility and the urgency of the delivery. However, the information flow is not a straightforward process and it can be characterized as fragmented, complex, and uncertain.

Fragmentation. Even though a few switchgear manufacturers dominate the U.S. market, the switchgear supply chain is fragmented. There are tens of thousands of distributors and contractors. The supply chain players are highly specialized in their own niche and have close relations to the immediately adjacent tiers but there is little transparency of the overall supply chain. In addition, there has been little effort among the distributors or contractors to standardize their interactions. Doing so would help manufacturers better standardize their products, which would significantly simplify product specification and thus reduce overall process complexity and uncertainty.

Complexity. The switchgear supply chain gets very complex because so many players have to contribute information. The more players and the longer the lead times, the more probable it is that a change occurs. A delay or a change from any of the players often causes a chain reaction where many other players need to re-verify their requirements and needs. This phenomenon is explicitly discussed by Gil (2001).

Uncertainty. Uncertainty means the lack of knowledge of a state, a value or a condition. At the time when the electrical engineer has to start to specify the switchgear, the information that the architect and the mechanical engineer provide is often incomplete or prone to changes. Uncertainty is not only by the need to specify switchgear early, but also the result of the customized nature of the switchgear. Therefore, uncertainty may prevail in numerous ways.

Product variety. A case in point is Cutler-Hammer's standard catalog Magnum DS switchgear that has 25 different lay-out alternatives just for the main, tie, feeder, and instrumentation sections, 30 different dimensions (width and depth) for each main section, 17 different breaker types, nine alternative buses (ratings), three alternative trip units, not to mention the various analog meters such as ammeters, voltmeters, watt hour, power factor or electronic power metering. Then there is a long list of specific and optional features ranges manually or electrically operated breakers to breaker lifters (Cutler-Hammer 1999). Accordingly "standard" low voltage switchgear turns out to have hundreds of varieties. Nevertheless, there has been some effort from the manufacturer and owner side to further standardize products.

Change orders. The following statement from a manufacturer's plant manager illustrates well the extent of change orders:

> *I do not recall a single time, when I have been Plant Manager, that an order has gone through without a single change order by our customer after he has placed an order. Small orders [<$10,000] have maybe 2, and large orders 10-15 change orders.*

Long lead times. Typically, post engineering lead time for switchgear is between 4-8 weeks, but the engineering time is at least 8-16 weeks. The pure engineering in itself (value-adding) does not take that long. Most of the engineering time is waiting where either the worker waits for input values or the input values wait for the worker. Work waiting on worker is what adds to lead time. Worker waiting on work reduces productivity or prompts multitasking, which later typically leads back again to work waiting on worker.

CHALLENGE

One of the fundamentals in systems thinking is that the whole is more than the sum of its parts. However, the fragmentation and the narrow specialization of the members of the switchgear supply chain indicate that the switchgear delivery process is lacking a systems view. The process can be characterized by "protectionism", where each stakeholder is more interested in its own niche (e.g., specifying, procuring, fabricating the switchgear) than in the system, switchgear delivery process, as a whole. The behavior is not uncommon in supply chains and can be identified in other settings as well. The supply chain "protectionism" is comparable to the construction "site protectionism", where it is common that each trade "optimizes" merely in its own interest without considering the system impact or other trades. However, the site production has a coordination mechanism that may empower systems thinking even if the organization may not always be aware of how to proceed with systems optimization.

The switchgear supply chain is lacking an overall coordination mechanism, which makes the overall system inefficient and generates lots of unnecessary work. A case in point is the engineer-contractor-manufacturer relationship. The steps between 1-2 and 1-6 in Figure 2 are never correct at the first trial and they may include multiple iterations, hence the duration of the steps are highly unpredictable. However, the manufacturer's production is set up for a stable environment that requires early commitment and complete information release from the customer. The manufacturer does not carry out any production preparations before receiving a purchase order (step 1-10). This has led to extended lead times (and cost)[4], where the manufacturer reserves notably more time for fabrication than is actually needed (steps 1-10 and 1-11). The relation between manufacturer's lead times and cycle times are in most cases more than 10:1. Since the manufacturer "freezes" a large time interval from the total delivery process, where after he charges for every change, it significantly reduces the flexibility of other stakeholders in the supply chain. The owner, architect, electrical engineer, and even the manufacturer's sales and marketing departments lose valuable time to explore and compare alternative solutions, and to react to other systems (e.g. mechanical, structural) and trades' needs. The construction site ends up solving some product related problems (e.g. wiring) though these problems would have been much more convenient to solve on the manufacturer's shop floor.

This is a vicious circle where longer manufacturing lead times cause more engineering uncertainty and more engineering uncertainty leads to longer lead times (Figure 3).

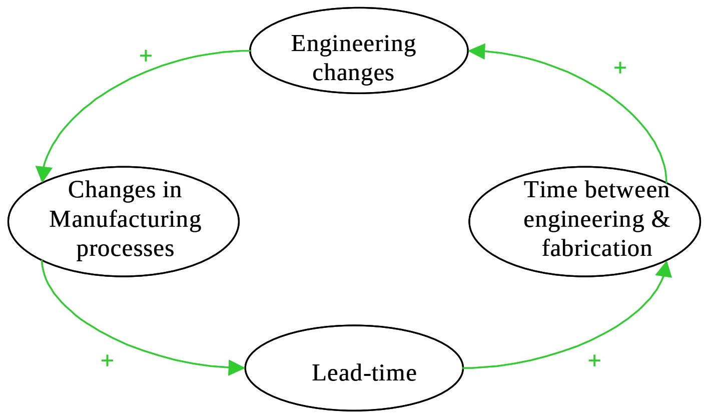

Figure 3: Vicious Circle in the Delivery Process

The vicious circle is further complicated by the fact that some players in the switchgear supply chain rely on change orders for their profitability. The process and organizational structures have been settled and unchanged for a long time. In this type of static environment where everyone has about the same, fixed production system and replaceable products, the competition is often restricted to cost. However, in the switchgear case, the cost is not based on systems cost, it is based on minimum component cost. The process and organizational structures are overlooked, and long lead times and change orders are the consequence.

DISCUSSION

The vicious circle phenomenon suggests that when reducing lead times for ETO products, we have to consider the engineering processes as well, not only manufacturing processes. In fact, the reduction of engineering lead time will probably have a larger impact on the whole process than reduction of manufacturing lead time. This is also supported by Hopp and Spearman's law of variability placement (1996, p. 305). The law states that efforts to

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[4] Cost is not part of this study but it is likely that there is a significant hidden cost considering already the lengthy process, 2-6 months (all the labor hours: architect, electrical engineer, manufacturer's sales and customer service, contractor's procurement etc. that are needed before fabrication is significant. Multiplying these hours with the salaries of each participant ends up to a considerable sum).

reduce variability in the front end of a system would likely have the greatest impact on the whole system. In the delivery of ETO products, the front end is the engineering stage. Accordingly, reducing variability and uncertainty in the engineering stage should be the primary focus on improving the entire process. That is also where opportunity to apply time compression strategies should be revealed. This means we should eliminate, combine, and reduce various tasks to not only reduce the total product delivery lead time but also reduce variability and uncertainty, in the engineering stage. Several techniques to reduce uncertainty and variability already exist, such as team problem solving, reduced batch size, last commitment, and set based design but who is in the best position in the fragmented switchgear delivery process to take the initiative?

Some of the time compression strategies are hard to apply to the current process and organizational structures, which are sequential with strong “territorial” protectionism. For example, combining activities by overlapping engineering and manufacturing activities is not possible without radically changing the process and/or organizational structure. Similarly, eliminating some time consuming activities, such as waiting for approvals, may not be possible without other changes occurring in stakeholder processes or in the relationship among stakeholders.

To what extent lead time reduction and other improvements can be achieved of ETO supply chains is a matter for empirical exploration and experiment. Based on earlier findings on the proportion of value added time in a delivery process (e.g., Womack and Jones 1996, Tommelein and Arbulu 2002) the authors believe the lead time could be reduced up to 50%.

CONCLUSIONS

Reducing lead time for electrical switchgear is challenging but may carry significant benefits throughout the ETO delivery process. The main challenge is to change the organizational and process structures in order to avoid the kind of systems behavior that spins the vicious circle. In the vicious circle the longer lead times cause more uncertainty, which cause more waste, which then cause longer lead times. Consequently, reducing lead times would also reduce uncertainty and waste thus making the process more predictable. However, it is not possible to break the vicious circle if the various players in the process continue to locally optimize and “protect” their tasks without considering the systems impact. Some players may profit from the vicious, which further complicates the problem. This indicates that there is a limited understanding about the interaction between engineering and subsequent process steps, especially with respect to lead time. Currently, the engineering stage of the switchgear delivery process is overlooked even if it is the most uncertain and time consuming stage of the entire process.

This lack of a systems view and knowledge about dependencies is a hindrance for significant improvement. Preliminary investigation indicates that there is plenty of room for improvement throughout the process. However, currently, there are no “convincing” facts or numbers that would persuade the switchgear stakeholders to change their practice in order to achieve radically shorter lead times. Currently, the manufacturer requires all the detailed product data far before the fabrication even starts. A starting point could be to overlap the engineering and fabrication stages by processing information in smaller chunks or batch sizes, and the most uncertain batch of information should be postponed until the very late part of the process This could already significantly improve the whole process. The upstream players including the owner and the engineers would have more time to compare alternatives and react to changes in their environment, and so provide better opportunities for the downstream players to deliver what "really is needed". As a result, waste in the form of rework and unnecessary processing could be saved in the engineering, procurement, and fabrication stages. The cumulative savings can be significant considering the lengthy and complex delivery process for switchgear.

The authors intend to study the switchgear delivery process to gain further understanding of the opportunities to reduce the overall lead time and opportunities to reduce variability and uncertainty. Once opportunities are identified, experiments will be performed with industry partners to test and refine altered processes.

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