Value stream analysis of a re-engineered construction supply chain

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A case study is presented that documents the most common configuration of the supply chain for pipe supports used in power plants in the USA. This supply chain, like many others in construction, has numerous inefficiencies, many of which occur at the interfaces between processes, disciplines or organizations. Recognizing and understanding such inefficiencies, their causes and potential remedies provides a basis for process re-engineering. The study describes how today’s industry practices are changing to yield shorter supply chain lead times. To model the mechanisms that drive those changes, data are presented from industry practice in the form of value stream maps that span organizational disciplines and company boundaries. Metrics commonly used in lean construction are introduced to gauge system performance. A current state map documents how work flows throughout the design, procurement and fabrication phases of pipe supports. Analysis of this current state map highlights value-added and non-value-added times and lead times. A future state map then illustrates process improvements that can be obtained by applying various supply chain management tactics. The methodology applied in this case study could be applied to other construction supply chains equally well.

Keywords: construction performance, lean project delivery system, production management, re-engineering construction, supply chain management, value stream mapping, waste

Cette étude de cas décrit la configuration la plus courante de la chaîne d’approvisionnement en supports de tubes utilisés dans les centrales électriques américaines. À l’instar de nombreuses autres chaînes logistiques du domaine de la construction, cette chaîne présente de nombreuses lacunes en terme d’efficacité, la majorité apparaissant au niveau des interfaces entre les processus, les disciplines ou les organisations. L’identification et la compréhension de ces lacunes, ainsi que de leurs causes et de leurs remèdes potentiels, fournissent une base pour le réexamen des processus. L’étude décrit l’évolution des pratiques industrielles actuelles visant à réduire les délais de la chaîne logistique. Pour modéliser les mécanismes initiateurs de ces changements, le document expose des données issues de la pratique industrielle sous forme de graphiques de valeurs-flux portant sur l’ensemble des disciplines organisationnelles et des frontières de l’entreprise. Il présente également les règles couramment utilisées en construction rationnelle afin d’évaluer les performances du système. Un graphique sur l’état actuel décrit les différents flux de travail lors des phases de conception,
d’approvisionnement et de fabrication des supports de tubes. L’analyse de ce graphique met en évidence les temps à valeur ajoutée et sans valeur ajoutée, ainsi que les délais. Un graphique prévisionnel illustre ensuite les améliorations susceptibles d’être apportées aux processus en appliquant différentes stratégies de gestion de la chaîne logistique. La méthodologie appliquée dans ce cas d’étude peut tout aussi bien être appliquée à d’autres chaînes logistiques du domaine de la construction.

Mots clés : performance du système de construction, système logistique en construction rationnelle, gestion de production, réexamen des processus de construction, gestion de chaîne logistique, représentation des valeurs-flux, pertes

Introduction

Construction supply chains should be well thought-out networks of interrelated processes designed to satisfy end-customer needs. However, most existing construction supply chains, established for a multitude of commercial and practical reasons, have structural features that are far from optimal from a production standpoint. One problem, for example, is that individual processes in and by themselves — and also the handoffs between processes, disciplines and organizations — all are subjected to the effects of dependence and variation that cause waste in the system. Dependence and variation were already recognized many decades ago as the culprits for numerous challenges facing the architecture, engineering and construction (AEC) industry (e.g. Crichton, 1966). Even so, projects then were relatively simple, certain and slow. In contrast, today’s projects are ‘complex, uncertain, and quick’ (Shenhar and Laufer, 1995), making the effects of dependence and variation all the more pronounced. Current practices are dominated by extreme specialization within functionally stove-piped organizations and industry fragmentation, optimized to meet individual participant’s performance objectives but far from optimal from a systems’ perspective (e.g. Tommelein et al., 1999; Bashford et al., 2002). Opportunities for performance improvement at the systems’ level abound, but better understanding must be developed regarding system behaviour in order to expedite the improvement of current practices.

This paper therefore has three goals. The first is to characterize today’s traditional practices for the delivery of one type of facility component. The second is to describe means for improving systems-level performance. The third is to introduce value stream mapping (VSM) as a methodology for modeling and analysing supply chains. To achieve these goals, details and an analysis are presented of the supply chain configuration most commonly used to deliver pipe supports to power plant projects in the USA. Arbulu (2002) and Arbulu and Tommelein (2002a,b) compare and contrast alternative configurations and provide additional case study data.

The following section describes the motivation for case study selection and the research methodology. The subsequent section includes a review of concepts from lean construction (Ballard et al., 2002; Koskela et al., 2002), business process re-engineering and supply chain management that underlie the reasoning applied in this study. Value stream analysis (VSA) is then introduced as the basis for analysing the current state map of the supply chain for pipe supports. VSA adopts a flow perspective rather than an activity-based perspective on how work gets done. It includes metrics to gauge certain types of waste in the supply chain. Using data from the VSA and considering supply chain management tactics currently being implemented by leading firms in the industry, opportunities for re-engineering industry practices across organizational boundaries are highlighted on a future state map. The methodology used is not limited in application to the case study described here, but could be applied to other construction supply chains equally well.

Case study development

Selection of a supply chain for the case study

In recent years, an increasing number of practitioners in the power plant industry have been observing that ‘pipe supports often arrive late on site’. Recognizing this problem, they have sought means to improve delivery processes in order to reduce lead times in the pipe support supply chain. Because of a general interest in the delivery of engineered-to-order facility components – pipe supports representing but one example – members on the Construction Industry Institute’s Project Team 172 ‘Improving Construction Supply Chain Performance’ commissioned several case studies including the present one from the authors to document best practices for reducing lead times in capital projects supply chains (Tommelein et al., 2002).

Admittedly, pipe supports are minor components relative to others that comprise a power plant. Most pipe supports are inexpensive and straightforward to engineer when compared with the cost and extent of engineering devoted to other power plant systems. Up to about 20% of the total number of supports in a power plant are customized. Nevertheless, problems in supplying pipe supports of any kind can compromise the success of the overall project: a piping system is not complete and ready for start-up testing and turnover unless all pipe supports are in place.

In certain circumstances, pipe supports become critical for timely project completion; one such circumstance is detailed in the section entitled ‘Lead time: one metric to gauge system performance’. The problem develops early on in the delivery process. Pipe support design requires input about plant requirements and load conditions; the design of the structural steel system; the location of mechanical equipment, vessels
and instrumentation; as well as physical (e.g. diameter, material, routing) and system characteristics (e.g. operating temperature, pressure) of the pipe to be supported. Current practice usually is to define these inputs first and to push pipe support design towards the end of the power plant design process. Since power plants often are managed as fast-track projects, design and construction overlap. When supports are designed in a rush and at the last minute, the downstream supply chain may become strained. For example, failure to allow sufficient lead time to fabricate and supply pipe supports to the site, or failure to coordinate the delivery of supports with the delivery of pipe and other system components, can necessitate field workers using temporary supports. This enables progress on pipe installation and circumvents erection delay. While possibly boosting productivity rates early on in the project, such practices more often than not create out of sequence work and rework in the field, affect overall on-site piping productivity and may ultimately result in project delays and budget overruns.

Case study methodology

Data about industry practices at large were collected over 2 years by conducting in-depth interviews with more than 25 practitioners working for various engineering–construct–design (EPC) firms (including piping engineers, pipe support designers, structural engineers, materials managers and expediters), pipe support suppliers (upper management as well as project managers and shop production managers) and developers of software for piping design and pipe support detailing. Interviews included an initial workshop and other face-to-face meetings, numerous telephone interviews with follow-up calls and e-mail exchanges. Discussions were structured around specific project data when available, but invariably also included anecdotal, historical evidence. The researchers visited a supplier’s job shop on two different occasions to gain a better understanding of pipe support fabrication. To augment the data collected through interviews, the researchers also reviewed the technical and trade literature for information available on the World Wide Web.

Cross-functional maps, value stream maps and computer simulations were used to capture and analyse project data, and to develop understanding of the causality of more complex supply chain behaviours (Arbulu and Tommelein, 2002a,b; Arbulu et al., 2002). To validate the research findings, the case report was reviewed by members on Project Team 172 as well as by others who previously had provided substantial input.

The data presented in this paper were obtained from various firms and pieced together as needed to describe the case study’s supply chain, which spans organizational boundaries. Meredith (1998 p. 443) therefore would call this a ‘multiple case study’. The researchers found that data from one organization was hard to match up with data from another organization because different organizations need different details and they represent their data differently. Moreover, supply chain participants usually are assigned to several projects at the same time and thus have to multitask, so that performance on one project is affected by performance on another. This makes it difficult to collect supply chain data on a single project. The research findings therefore do not represent any one specific project, but are indicative of current and emerging supply chain practices in the power plant construction industry.

Process literature

Research studies have shown that waste is omnipresent in construction supply chains (e.g. Luhtala et al., 1994; Vrijhoef and Koskela, 2000). It often occurs at the interface between processes, disciplines or organizations. Eliminating waste, then, must be a target for those aiming to improve system performance, but ‘What to look for when analysing a process?’ and once waste has been identified: ‘What to do about it?’ Several schools of thought, including lean construction, process re-engineering and supply chain management, describe process features that must be articulated and suggest tactics to remove waste.

Lean construction: transformation, flow and value (TFV) view of production

In the field of lean production, Ohno (1988) identified seven sources of waste:

- Defects in products
- Overproduction of goods
- Excess inventories
- Unnecessary processing
- Unnecessary movement of people
- Unnecessary transport of goods
- Waiting time

Womack and Jones (1996) later recognized as an additional source of waste:

- Design of goods and services that fail to meet the user’s needs

After tracing the history of various schools of thought in production management and while searching for a theory of construction, Koskela (1992, 2000) forwarded an integrated view of production, the so-called transformation, flow and value (TFV) theory.

The crucial contribution of the TFV theory of production lies in calling attention to modeling, structuring, controlling, and improving production from these three points of view combined.

(Koskela et al., 2002)
This TFV theory includes the goal of eliminating waste in the six flow principles (Koskela, 2000 p. 56):

- Reduce the share of non-value-adding activities (waste)
- Reduce lead time
- Reduce variability
- Simplify by minimizing the number of steps, parts and linkages
- Increase flexibility
- Increase transparency

Simply put, waste refers to all efforts that do not add value to the final product from the point of view of the customer. It is possible to attack directly the most visible waste just by flow-charting the process, then pinpointing and measuring non-value-added activities (Koskela, 1992 p. 18). Reducing the share of non-value-adding activities is a tenet in process improvement.

Re-engineering construction supply chains

The term ‘process re-engineering’ was popularized in the early 1990s by Hammer (1990) and Hammer and Champy (1993), who presented the following guidelines:

- Organize around outcomes not tasks
- Have those who use the output of the process perform the process
- Subsume information-processing work into the real work that produces the information
- Treat geographically dispersed resources as though they were centralized
- Link parallel activities instead of integrating their results
- Put the decision point where the work is performed
- Capture information once and at the source

While these authors attracted a significant number of followers, the results of process re-engineering have been mixed. Although the guidelines advocated radical change, at times they resulted in radical failure (e.g. Shrage, 1998). Recently, Hammer (1996, 2001) described how various organizations adopted the process focus and successfully reinvented themselves, but his descriptions appear to lack an underlying theoretical framework. Champy (2002 p. 3) recognizes that while process focus within an organization may yield benefits, true leverage requires the involvement of multiple organizations. He thus defines the term ‘X-engineering’ as:

the art and science of using technology-enabled processes to connect businesses with other businesses and companies with their customers to achieve dramatic improvements in efficiency and create value for everyone involved.

In this paper, the term ‘re-engineering’ is used in a broad sense, not specifically referring to Hammer and Champy’s ideas.

Supply chain management

In contrast to process re-engineering, which has gone through ups and downs, supply chain management has emerged as a new field (the term was coined by Houlihan in 1983) by building on advances in other fields including logistics, operations and purchasing, and by leveraging the use of information technology. Though its theoretical development has not yet come to an end, and its application to the delivery of capital projects is still in its infancy (Tommelein et al., 2002), a number of tactics are widely recognized which result in performance improvement. Several such tactics are elaborated below and applied to explain process improvements in the delivery of pipe supports.

Manufacturer’s early efforts at identifying waste and its causes focused on achieving in-plant process performance improvements. To reap even greater benefits, they then shifted from an in-plant view to a view outside into their supply chains, including not only first-tier, but also higher-tier suppliers and customers up and down the chain. Despite best efforts, today’s practices of supply chain management in many industries are still restricted to achieving more optimal performance across only a few tiers of their supply chains and few efforts – if any – span the entire length of any one supply chain. Nevertheless, a more global view of supply chains is gradually being adopted in different economic sectors including the construction industry.

While the benefits of consideration of the entire supply chain are intuitively obvious, development of theoretical underpinnings for multitier supply chains evaluation is still ongoing (e.g. Choi et al., 2002). The literature consists primarily of detailed treatments of the two-tier or dyadic relationship. Extension even to the triadic relationship is conceptually and theoretically complex due to the potential for suboptimization. The case study presented herein considers only the dyad of the engineering design firm and the pipe support supplier.

Lead time: one metric to gauge system performance

Supply chain lead times are determined by several factors such as:

- Processing time
- Set-up time
- Move time
- Queue or wait time (e.g. Hopp and Spearman, 2000 p. 327)

In service industries, which include engineering and construction, a significant component of wait time is decision-making
time (Arbulu, 2002), such as the time needed to issue a permit or grant approval. Decision-making time may be critical, especially when several participants interact, playing different roles for different organizations. Owing to reluctant decision-making from any one of those participants, information may await processing for days or even weeks – a wait time often significantly longer than the processing time required to perform transformation tasks. Therefore, identifying and eliminating, or at least significantly reducing, this component of wait time is essential to compressing lead time.

The lead time of a single component’s supply chain is important relative to the lead time of other supply chains, because it is the combination of supply chains that defines a project delivery process. If all parallel supply chains in a project have a short lead time, then that project will complete early. To cope with project complexity, project managers often rely on the 80/20 rule-of-thumb: focus on the 20% of the items that contribute to 80% of the cost, delays or other problems. Using this rule, however, pipe supports seldom make it to their list of priorities. Pipe supports are not typically ‘critical’ or ‘pacing’ items in a schedule in the way that turbine generators or transformers are. According to this kind of thinking, which is also reflected by Vorster et al. (1998), having the design and fabrication of pipe supports on the critical path would be a scheduling anomaly.

Now consider the 80/20 rule after it has been successfully applied. The 20% has been managed so as to be no longer a problem. On complex, uncertain and quick projects, the criticality therefore shifts to one or several items that previously were on the 80% list. Management must therefore be flexible and willing to redirect its attention during project execution in order to recognize and deal with these shifts. This may present a situation in which pipe supports become critical. In CPM scheduling, a similar phenomenon is well known. As a schedule is increasingly compressed, more parallel paths in the network become critical. Project managers on fast-track projects therefore have a greater challenge on hand than managers on more slowly paced projects.

A reduction in lead time of a single supply chain, in and by itself, is also important. A short lead time has the following advantages over a long lead time for that supply chain (Koskela, 2000 p. 60):

- Faster delivery of the product or service to the customer
- Reduced need to forecast future demand accurately
- Less opportunity for disruption in the supply chain due to (design) changes
- Greater possibility that participants will interact in a timely fashion with other supply chain participants
- Easier synchronization of one supply chain with others (e.g. merging supply chains at the site)
- Less opportunity for products to become obsolete

**Value stream analysis (VSA)**

After determining what value a product or service has for a customer (not an easy task) the transformation of an organization’s current practices to become more lean will include restructuring and eliminating waste from the system of interdependent tasks that are executed to bring that product or service to market. This set of tasks and associated information make up the value stream. A value stream perspective should look across individual functions, activities, departments and organizations and focus on overall system performance, rather than suboptimize any one of these.

Value streams are mapped and analysed using value stream mapping (VSM), a technique created by practitioners at Toyota to ‘make sustainable progress in the war against [waste]’ (Rother and Shook, 1998). VSM includes creating a map of the flow of material through production and the flow of information from the customer back to each production process. A current state map of in-plant value streams then serves as the basis for developing future state maps that leave out wasted steps and interfaces while pulling resources through the system and smoothing flow. The difference between the current state and potential future states provides a road map to start the implementation of performance improvements.

To map a value stream, Rother and Shook’s approach (1998) is to choose a product family and then mapped its current state before analysing production data and metrics. In contrast, the maps presented herein pertain to pipe supports in general, not to any single product family. Future research might refine the maps for specific product families (e.g. variable springs as opposed to dynamic supports), a concept that is waiting to be recognized by AEC practitioners.

Many VSMs pertain to work within the boundaries of a single organization. Recent efforts (e.g. Jones and Womack, 2002) have applied VSM on a macro scale, considering the supply chain upstream and downstream of a specific organization. Adopting such a view is most appropriate and in fact unavoidable because of the highly fragmented nature of the AEC industry.

**Current state value stream for pipe supports**

**Value stream map**

A high-level map of the supply chain for pipe supports for US power plants is shown in Figure 1. This map includes the work of the engineering firm and the supplier. In this configuration, the engineering firm is in charge of designing pipe supports and the supplier is in charge of detailing and fabricating them.

Figure 2 shows the value stream each single pipe support follows from design to delivery to the site. It shows a series of linked task boxes with triangles in between. In terms of duration, task boxes represent the time a pipe support will be in
process in a conversion task. This time is an upper-bound estimate of value-added time. The triangles represent the time a pipe support waits until it is processed by the next task. In and by themselves, triangles are holding places and they do not have any specific duration. Instead, the VSM shows total durations between tasks or lead times (arrows above tasks, spanning from one triangle to another one). Accordingly, the difference between the total time in the system (sum of lead times shown above arrows) and the processing time (sum of times shown under each task box)

Figure 1 Supply chain of pipe supports

Figure 2 Current state value stream map
represents a lower-bound estimate of the total non-value-added time or waste.

The unit of value-added time used for Figure 2 is the man-hour. Since more than one person may contribute to the completion of each task, the real time needed to perform that task may differ from the value-added time shown. The total time in the system is the time a pipe support takes to go from initial design to completion of fabrication. The unit of time in the system is a week, considering that each week corresponds to 40 hours of work per person.

The value-added times and lead times shown in Figure 2 were determined using two sources of information. As mentioned, the researchers interviewed practitioners in engineering firms and supplier organizations. The data presented here are approximate durations, obtained and validated by several industry practitioners, for each supply chain task. The researchers also obtained data from a recently completed power plant project. It proved very difficult to obtain similar data on other projects, in part because the VSM includes tasks performed by the engineering firm and other tasks performed by the supplier, and these organizations are functionally stove-piped. The data will generally reside in disparate databases and would have to be extracted and then matched.

**Analysis results**
The VSA shows that a pipe support takes from 28 to 37 weeks to flow through the system. One reason for this range of values for duration is the diversity and complexity of supports covered by the design, detailing and fabrication phases shown in Figure 2. The analysis also shows that the about 3.6% of the total time a pipe support needs to flow through the system represents value-added time. The remaining 96.4% of the time reflects non-value-added time, or waste.

**Future state value stream map and analysis**

**Supply chain tactics**
Industry leaders, early adopters of supply chain management practices, have been able to save about 6–7 weeks off the lead time traditionally required to deliver pipe supports. The supply chain tactics used to obtain such a major process improvement include the following:

1. Buddy with a supplier and involve that supplier early in the design phase of pipe supports, which assumes that some alliance or other pre-project agreement is in place so that no time is wasted on selecting a supplier during project execution

2. Standardize products (pipe supports) and processes

3. Use electronic data interchange (EDI)

These tactics are elaborated on below.

**Value stream map and analysis results**
The lead time compression achieved by applying (1) is easy to visualize using the VSM: the activity ‘Select Supplier and Send Info’ (crossed-out activity in Figure 3) can be totally eliminated, thereby reducing direct work time by 1–2 man-hours but – more importantly – also reducing the total lead time by 1 week.

The lead time compression achieved by applying (2) and (3) is more difficult to show. Practitioners estimate that it is realistic to assume a 50% reduction in the total duration of each task that takes advantage of these suggestions for improvement (circled tasks in Figure 3). Correspondingly, Figure 4 shows the future state VSM for pipe supports. The new lead time ranges from 25 to 29 weeks, roughly 25% less than the current state lead time of 28–37 weeks. The new value-added time is about 4.2%, slightly higher than what it was previously. Given that this value of this ratio still is low, it should be possible to reduce the lead time and increase the value-added time further. This can be done, for instance, by reducing batch sizes and the degree of multitasking, especially during design and in other phases. The following sections provide more detail on these and other supply chain tactics, and Tommelein and Arbulu (2002) expand on them even further.

**Considerations for supply chain performance improvement**

**Buddy with suppliers**
Pipe support suppliers offer a large product variety, ranging from catalogued supports to custom designs. Supplier job shops can fabricate more or less anything the customer wants, especially if the business deal is right. Despite the fact that companies know which of their products can substitute for a competitor’s, no industry-wide standard for pipe supports exists. Given this situation, engineers typically work with one supplier’s catalogue as a reference during design, even though that supplier has not yet been selected to do the work. When the supplier finally is selected, the design may need to be converted or replaced altogether with a better solution, e.g. value engineered by the supplier. This is a clear example of a design–bid–redesign–build process. Practitioners estimate that redesign may account for up to 20% of the work performed by pipe support suppliers. By involving a supplier early on in design, no later conversion will be needed and wasteful rework may be avoided.

From a supply chain performance perspective, a wealth of product variety is a mixed blessing. Engineering firms value being able to design what they consider to be the best solution given the project requirements and then procure what they design, but focusing on product design alone does not result in a good delivery process. If each product supplied to a project is unique, then managing the system is significantly more complex than it would be if products were more standardized and supplied in multiples (e.g. Tommelein, 1998). Custom engineering may be a ‘penny wise and pound foolish’ proposition when the supply chain is not designed to accommodate
‘Mass customization’ aims to trade-off such product against process performance choices.

The advantages of involving the supplier in design are:

- Engineers can identify pipe support catalogues early on
- Suppliers may advise engineers so they can jointly optimize the design process
- Suppliers have direct understanding of the fabrication process and their own upstream suppliers, and therefore can tailor catalogue designs to best meet design requirements, whereas engineers may choose to make do with catalogued supports because they cannot gauge the cost implication of more custom design
- Suppliers who gain insight into the project requirements early on can manage their own supply chain better, e.g. at an opportune time they can buy materials needed to make supports
- Engineers and supplier(s) can integrate and speed up their communication and transactions using EDI
- Engineers and supplier(s) can quickly resolve requests for information

Alliances or multiproject long-term agreements are becoming increasingly common in the power plant industry. One of their main purposes is to establish clearly defined process protocols and have all involved work together towards a shared set of objectives. Such pre-project agreements establish the fundamentals of team collaboration so that no time is wasted during start-up of the project(s) where they are invoked. Nevertheless, owners who have formed such agreements with support suppliers and make engineering firms use them may find they are not automatically serving their projects in the best way. Supplier performance depends not only on the products provided (and the degree to which these can be standardized across projects to ease operation and maintenance of the facility), but also on the supplier’s capacity at the time a project comes through, and on the ability of all involved to work together to meet the project needs. An owner-selected supplier must work with the engineering firm and construction contractor in order to hand off information and pipe supports effectively. Current practices show that some owners procure supports but have engineering firms review the supplier’s fabrication drawings. For contractual reasons, these drawings may have to pass through the owner and they can thereby miss getting a timely review by the engineering firm. Owners who ask engineering firms late in the process to review fabrication drawings may find that this task does not fit on the engineering firm’s schedule. In general,
engineering firms appear to prefer to manage the drawing review process themselves.

In the late 1980s and early 1990s, owners increasingly outsourced construction functions as they did not think it was a core competence needed to conduct their business. Experienced facilities operations and maintenance personnel therefore joined the construction side of the business. The tide appears to have reversed; not all owners have found their position to be tenable. In the last 5–10 years, power plant owner personnel has learned their lessons on recently completed projects. This learning represents a new awareness for owners who try to avoid waste embedded in received traditions and who strive to create high-performance supply chains, for instance by developing supplier alliances. Champy (2002 p. 38) calls this alternative to the traditional ‘make-or-buy’ the ‘build-buy-or-buddy’ decision.

**Standardize products and processes**

Standardization of products and processes helps to reduce variability in the supply chain, but much remains to be done in this regard. As mentioned, pipe supports have not yet been standardized in the power plant industry. This means that detailing cannot be done in full by the engineering firm until a specific supplier has been chosen. Standardizing supports is advantageous in terms of design as well as for ease of sourcing. For instance, it would help designers avoid late changes that may affect the project delivery date.

To standardize, a limited number of configurations must be defined; too many standard products defeat the purpose of standardization. Industry practitioners suggested that the number should not exceed 100–150 configurations. A smaller number of configurations may further reduce engineering time, though it may also result in over dimensioning and inferior performance. Besides reducing system complexity, standardization would ease the training required of new engineers entering the field. This is a concern because fewer engineers are entering the market and today’s engineers learn how to design pipe supports by experience in practice; it is not a subject commonly taught in schools.

Standardization also pertains to processes. Today, each supply chain participant uses their own procedures for each supply chain phase to deliver supports. Champy (2002 p. 26) calls this alternative to the traditional ‘make-or-buy’ the ‘build-buy-or-buddy’ decision.

**Figure 4** Future state value stream map

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**Foster communication and coordination**

Fostering communication and coordination between supply chain participants helps to increase flexibility and transparency, which are needed to balance and synchronize flows in the supply chain (Rother and Harris, 2001). Yet, the design of pipe supports conventionally occurs in a system with func-
tional stove-piping into disciplines such as structural engineering, piping design, mechanical engineering and process design. The barriers to improved supply chain performance within a functionally organized company may be as large – if not larger – than those between the company and its suppliers or customers. Industry practitioners mentioned that about 15% of engineering designs have ‘mistakes’. These may be related to the deficiency (in terms of timeliness and detail) of information released to suppliers.

To expedite tasks and avoid mistakes, the industry is developing new tools. The introduction of computer software for sizing pipe supports is one example, but software available in the market today does not yet fully design all possible types of pipe supports. Many firms provide a table of catalogued items with pictorial references, but such software is not necessarily integrated with computer-aided design (CAD) software. The tables may provide list prices as well as materials required to build each supplier-standardized support. In addition, users may have a graphical representation of the supports. Some programs are more sophisticated and include detailed designs of standard or engineered supports using two- or three-dimensional modelling. Clearly, a lot more work lies ahead in improving EDIs in this area.

**Minimize batch sizes**

Batching is an important consideration in supply chain performance assessment because bigger batch sizes cause longer wait times and therefore longer lead times. Arbulu (2002) identified several types of batches with different sizes along the pipe support supply chain, and Arbulu et al. (2002) analysed the impact of batch sizing on supply chain lead time.

A lean perspective on production systems suggests that in the best of circumstances the batch size should be one, so that the flow of resources through the value stream is continuous and incurs the least delay. In practice, this ideal situation is hampered by considerations pertaining to the economics of means and methods being used (including set-up times), which force the ‘optimal’ batch (economic lot size) in any one process to be greater than one. The goal of production system design, then, is to maintain batch sizes as small as is reasonable, while changing means and methods so that smaller batches become affordable and while improving communication between participants in the supply chain in order to achieve more synchronized flow.

**Dedicate resources**

Lead times are extended as the result of multitasking. In industry, piping engineers and suppliers multitask between two or more tasks that may belong to one or more (power plant) projects. They do so because not all information or other resources needed to complete a task are available when they have the time to work on that task. Multitasking reduces their idle time. The caveat is that it does not necessarily increase their productivity because each switch of tasks comes at a set-up cost. In order to obtain more reliable throughput, resources must be dedicated to particular tasks and have some excess capacity to buffer the anticipated variability in work load.

**Conclusions**

This paper has presented a case study on industry-wide practices regarding the delivery of pipe supports used in US power plants. It has illustrated some of the complexity, including dependence and variation, that is so characteristic of construction supply chains. Data obtained from industry to support the case study illustrated that more than 96% of the time in this supply chain is non-value-added time, which highlights that there is a significant opportunity to reduce order-to-delivery lead time for this engineered-to-order product. The study described various tactics that industry leaders in supply chain management are implementing to improve overall supply chain performance.

Mapping and VSA were valuable tools to help document how pipe-support supply chains are being re-engineered. Practitioners in the construction industry may find these tools can help them recognize opportunities for supply chain improvement.

Improving the performance of supply chains is not an easy task because of the fragmented nature of the industry and functional stove-piping within organizations. Supply chain participants who want to reduce lead times through the elimination of waste should consider:

- Selecting suppliers early and involving them in engineering design
- Communicating unambiguously using standardized processes and restricting design alternatives to a limited set of standardized pipe supports
- Integrating computer tools that are needed to automate the pipe support design process and product specification

While this paper focused on the supply chain of a specific engineered-to-order product, namely pipe supports, the methodology used applies to supply chains of other AEC products equally well. In fact, an order of magnitude of 5% for value-added time over lead time may prove to be the rule rather than the exception in the delivery of engineered-to-order products in the AEC industry today, so opportunities for process improvement abound.

The authors challenge individual companies and their supply chain partners to use the data, analysis and conclusions from this paper as a basis for conducting their own research, using their own process and project data. Companies should not be surprised to find the same orders of magnitude when applying the metrics. This will enable them to develop an appreciation for the research findings and supply chain opportunities presented here. Major efforts in process definition and supply chain management are undertaken by leading firms in the industry. Companies not engaging in supply chain management may find themselves falling rapidly behind in performance relative to their supply chain-conscious competitors.
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References


