ALTERNATIVE SUPPLY-CHAIN CONFIGURATIONS FOR ENGINEERED OR CATALOGUED MADE-TO-ORDER COMPONENTS:CASE STUDY ON PIPE SUPPORTS USED IN POWER PLANTS

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ABSTRACT

Many construction inefficiencies are due to supply-chain (SC) problems that occur at the interface between processes or disciplines. This paper illustrates such problems by describing a case study on the supply of pipe supports used in power plants. Pipe supports often arrive late at the construction site because their design tends to be pushed towards the end of the power plant design process due to the interaction of supports with other power plant systems. Since power plants are typically fast-track projects, the design and construction phases overlap. Late support design therefore constrains the SC and may ultimately cause project delays.

This paper presents the five alternative SC configurations that have been identified in the case study. It addresses the need to accelerate the design, procurement, and fabrication processes of engineered or catalogued made-to-order pipe supports in order to avoid late arrivals to the site while making best use of the capabilities available in all SC participants. This paper concludes with a set of recommendations for performance improvement in the supply of pipe supports. Finally, it identifies research opportunities to achieve further improvement.

KEY WORDS

Supply-chain management, construction supply chain, interdependency, batch size, alliance, standardization, modularization, push vs. pull, pipe support, design, procurement, fabrication, power plant, process mapping.

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INTRODUCTION

Power plant construction has experienced an unexpected boom in recent years. "Between 1999 and 2001, about 83,000 MW of new capacity has come on line in the U.S., adding nearly 10% to the generation base" (ENR 2001). A total of 487 new power plant projects with more than 50MW capacity each were recently completed, or are planned or under construction in various locations around the country (ENR 2001). This unprecedented boom has placed power plant projects in the view of investors, engineering firms, contractors, material and equipment suppliers, and several others who provide a broad range of construction services.

Power plants are complex projects with thousands of components to procure, including major mechanical equipment, vessels, structural steel, pipe, pipe supports, instrumentation, valves, and fittings. Well-managed supply chains (SCs) represent a 'must' towards project success. For each power plant component, SC participants not only contribute to the effectiveness and efficiency of the SC, they also introduce a variety of inefficiencies. Inefficiencies need to be identified and eliminated to better satisfy customer needs as well as to achieve project goals, otherwise, they may directly impact project completion.

The goal of this paper is to present one SC found in power plant projects, namely that of pipe supports. Industry practitioners recommended this SC for study because pipe supports often arrive late at the construction site. We elaborate on this later in this paper. We identified alternative SC configurations for pipe supports and captured them in distinct SC maps showing engineering, fabrication, delivery, and construction. The resulting five maps reflect that different SC participants, according to their competencies and capacity, may take responsibility of the design and/or detailing of pipe supports in order to suit different project requirements. To complement the maps, we suggest a set of metrics to gauge performance in different SC phases. Analysis and evaluation of metrics provides a better picture of real SC behavior. Finally, this paper presents several considerations for SC performance improvement and it identifies research opportunities to achieve further improvement.

SUPPLY CHAINS IN CONSTRUCTION

Up until the 1980s, procurement in construction was achieved through purchasing processes based mainly on the concept of one-to-one transactions between a buyer and a seller in order to meet individual project needs. Construction companies at that time had been focusing their efforts on developing in-house resources and processes, creating internal organizational boundaries based on functional specialization. In the late 1980s, this focus changed and internal integration was adopted as a new goal. Subsequently, external integration became the new goal, and was achieved by engineering and construction firms integrating their materials management practices with their first-tier suppliers. Supply-chain management (SCM) takes such initiatives significantly further, beyond the boundaries of one or a few firms.

SCM in construction requires a structured group of companies and individuals to work collaboratively in a supply network of interrelated processes or activities designed to best satisfy end-customer needs while rewarding all members of the chain (after Tommelein et al. 2002). Therefore, SCM requires a new management philosophy based on a global-systems perspective instead of a traditional myopic and sub-optimal view of a single stakeholder. Table 1 compares and contrasts the most relevant characteristics of traditional- with SC managerial approaches

Table 1: Traditional vs. Supply-chain Managerial Approaches in Construction (after Tommelein et al. 2002)

Traditional Managerial Approaches	New Supply-chain Managerial Approaches
Project-based Management	Supply-based Management, leveraging needs for multiple projects
Separation of Design, Fabrication, Construction/Installation, and Operation Functions	Total Life-cycle Management
Uniquely Engineered Facilities and Components	Assembly of Unique Facilities from Standardized Modules and Components
Liquidated Damages	Target Costing and Problem Solving through Strategic Alliances for Key Products and Components
Competitive Bidding	Emphasis on Long-term Working Relationships
Information Hoarding	Extensive Use of Communication and Information Technology to Create Information Visibility so that the Value Chain Supports the Supply Chain
Late Payments and Retainers	Prompt Payment to Minimize Cost of Capital (Time Value of Money is an Inventory Cost)
Long and Uncertain Lead Times with Extensive Use of Expediting	Short and Reliable Cycle Times from Raw Materials to Site Installation
Early Delivery of All Materials to the Site	Phased Delivery of Materials to the Site to Match Installation Rates

SC managerial approaches focus on guiding construction companies towards meeting ever-rising customer demands and needs at a manageable cost. “A new business ethic based on profitability and value for investors must replace the outworn idea from the 1960s and 1970s that engineering is held in high esteem, and big construction projects entitle their builders to respect whether the job makes money or not” (ENR 2002).

To apply these approaches, SCs need to be characterized and understood in terms of their structure, function, and behavior. Construction SCs are converging, temporary, and made-to-order chains (Vrijhoef and Koskela 2000). ‘Converging’ refers to all materials being directed to the construction site where elements are assembled from incoming materials. ‘Temporary’ refers to SCs typically producing one-off construction projects through repeated reconfiguration of project organizations. ‘Made-to-order’ refers to new products and components being made to suit each project’s specific needs.

SUPPLY CHAIN OF PIPE SUPPORTS: CASE STUDY BACKGROUND

Power plants are complex facilities, configured as a combination of fuel storage and combustion systems; a foundation system; a structural system; a power-generation-, power-conversion-, and transmission system; and various piping systems. Power plants include piping systems for high- and low-pressure steam, feed-water, hot and cold reheat, and other systems such as condensate and heat recovery steam generator systems (HRSG). These systems include pipe but also pipe supports, valves, in-line instrumentation, etc.

A pipe support is an assembly of components that attaches to the pipe and transfers the pipe's load to the building structure in a manner that will ensure adequate restraint under static and dynamic conditions during plant startup, operation, and shutdown. Therefore, pipe supports represent the interface between the building structural system and the piping systems, which interact with the location of equipment and vessels in the plant. Examples of pipe supports are constants (labeled 'A' in Figure 1) and variable springs (B), dynamic supports (or snubbers) (D), slide bearings (F), isolated supports (G, H), and pipe shoes (pieces of pipe that transfer gravity loads to a structure underneath the pipe).

Three main parts can be distinguished in a pipe support: the device which itself is called a pipe support, the steel attachments (labeled 'E' in Figure 1) used to connect the pipe support device with the building structural system, and the complementary hardware ('C'=pipe clamps and ancillary equipment; 'I'= turnbuckle) that connects the pipe support device with the steel attachment. The combination of these components represents a pipe support as described in this paper.

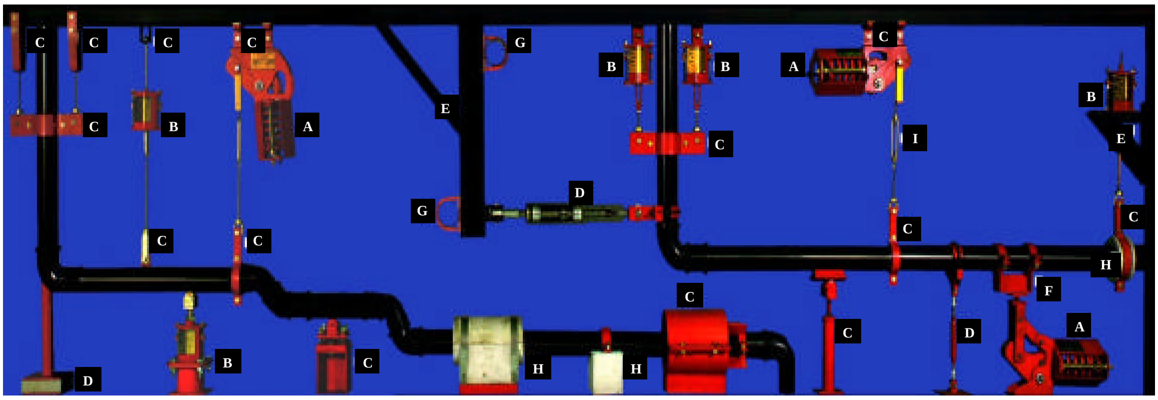

Figure 1: Example Pipe Supports (modified from Pipe Supports Limited Inc. http://www.pipesupports.com visited on 02/26/02)

IMPORTANCE OF PIPE SUPPORTS IN POWER-PLANT SUPPLY CHAINS

Relatively speaking, most pipe support systems are inexpensive and require straightforward engineering when compared to the cost and engineering going into the other power plant systems. Nevertheless, problems in supplying pipe supports can compromise the success of the overall project. The reality is that a piping system is not complete and ready for start-up testing unless all pipe supports are in place.

The problem starts in the design phase. Pipe support design requires input regarding the design of the structural steel system; the location of mechanical equipment, vessels, and instrumentation; as well as the physical (e.g., diameter, material, routing) and system characteristics (e.g., operating temperature and pressure) of the pipe that connects them. Current practice, therefore, is to define these inputs first and to push pipe support design towards the end of the power plant design process. Since power plants nowadays are managed as fast-track projects, support design gets done in a rush and at the last minute, thereby potentially constraining the downstream SC. Failing to allow sufficient time for design, procurement, and fabrication of pipe supports can make it necessary for field workers to use temporary supports so that they can make progress on pipe installation (though this also increases rework in the field) and circumvent erection delays.

CURRENT SUPPLY-CHAIN PRACTICES FOR PIPE SUPPORTS

CHARACTERIZATION OF CURRENT SUPPLY-CHAIN PRACTICES

To characterize this SC, five alternative configurations have been captured in distinct cross-functional maps showing various roles played by the SC participants. The main participants in the SC for pipe supports are (1) engineering firms, (2) pipe support suppliers (who detail and fabricate the supports), and (3) contractors. Pipe fabricators may play a role in this SC but they are not necessarily directly involved. Engineering (1) and contracting (3) may lie within the scope of work of a single engineer-procure-construct (EPC) firm. Delivery to site and construction are mentioned but have not been detailed in this case study. The five alternatives require more-or-less the same activities to design and fabricate the supports, but different SC participants perform them at different times. Figures 2 through 6 show short versions and Arbulu (2002) presents more detail on the following configurations:

Configuration 1 (Figure 2): Engineering firm designs the pipe supports. Supplier details, fabricates, and supplies the supports. Contractor installs. This model describes, by far, the most common practice in the industry.

Configuration 2 (Figure 3): Engineering firm routes pipes and performs pipe stress analysis. Supplier designs, details, fabricates, and supplies the supports. Contractor installs.

Configuration 3 (Figure 4): Supplier fully designs pipe supports. Contractor installs.

Configuration 4 (Figure 5)**:** Contractor takes responsibility for pipe-support design and fabrication, though likely will subcontract this work out, and then installs.

Configuration 5 (Figure 6)**:** Pipe Fabricator takes responsibility for pipe-support design and fabrication. Contractor installs.

DESCRIPTION AND ANALYSIS OF ALTERNATIVE CONFIGURATIONS

Configuration 1 is most commonly used today for pipe support delivery.

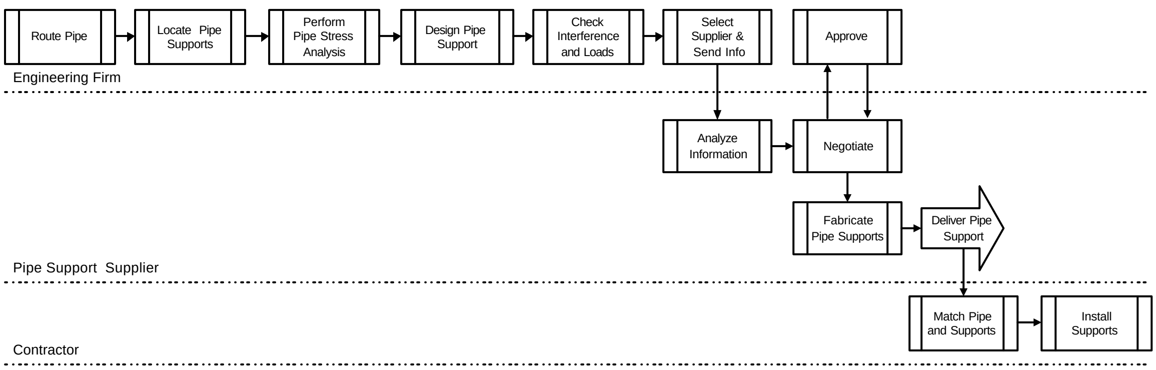

Figure 2: Configuration 1 – Engineering Firm Designs and Supplier Details, Fabricates, and Supplies Pipe Supports used in Power Plants

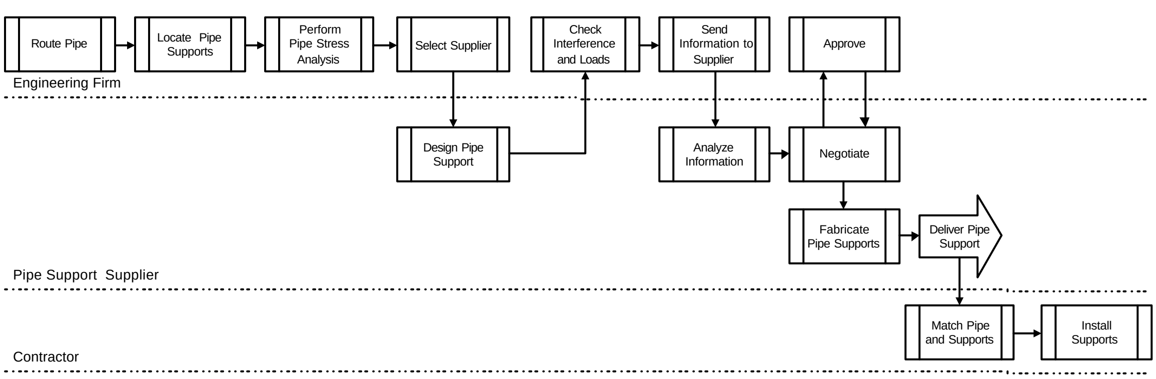

Figure 3: Configuration 2 – Engineering Firm Routes Pipes and Performs Pipe Stress Analysis. Supplier Designs, Details, Fabricates, and Supplies the Supports

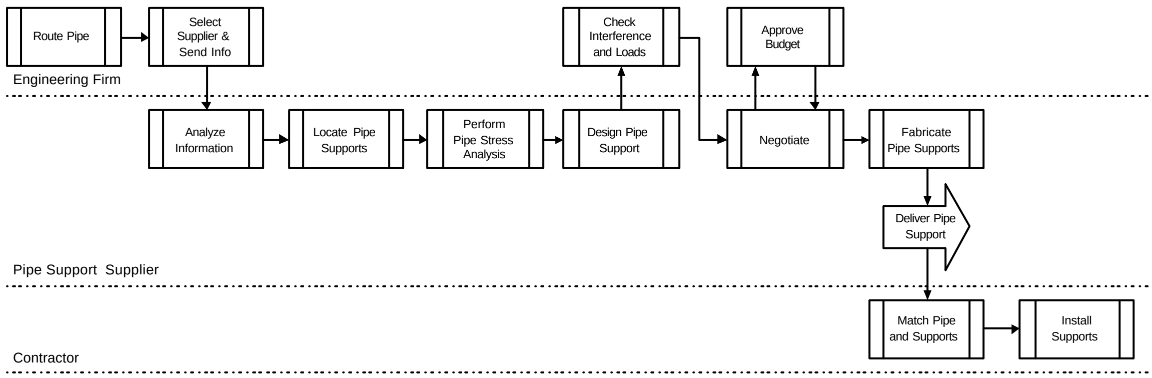

Figure 4: Configuration 3 – Supplier Fully Designs Pipe Supports

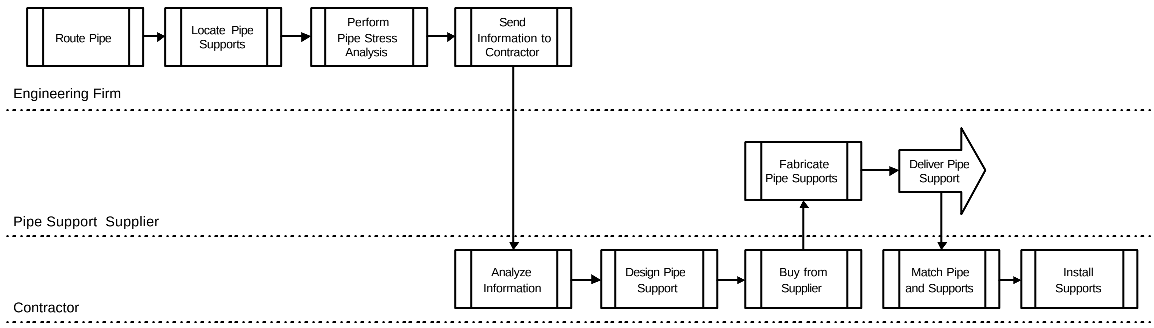

Figure 5: Configuration 4 – Contractor Takes Responsibility for Pipe-support Design and Fabrication

This is a ‘cascading’ configuration with more-or-less sequential handoffs between organizations. The cascading effect is an important characteristic because it allows the information to flow from one to the next SC activity with a low level of interdependency. Less interdependency between participants typically means better flow of information, but also less iteration (which could have a positive or negative impact on performance), though the flow may be stretched out and otherwise impeded.

By contrast, configuration 2 shows greater reciprocal dependence between the engineering firm and the support supplier who is in charge of all pipe support design. This allows for greater concurrency and less rework but requires greater collaboration to be

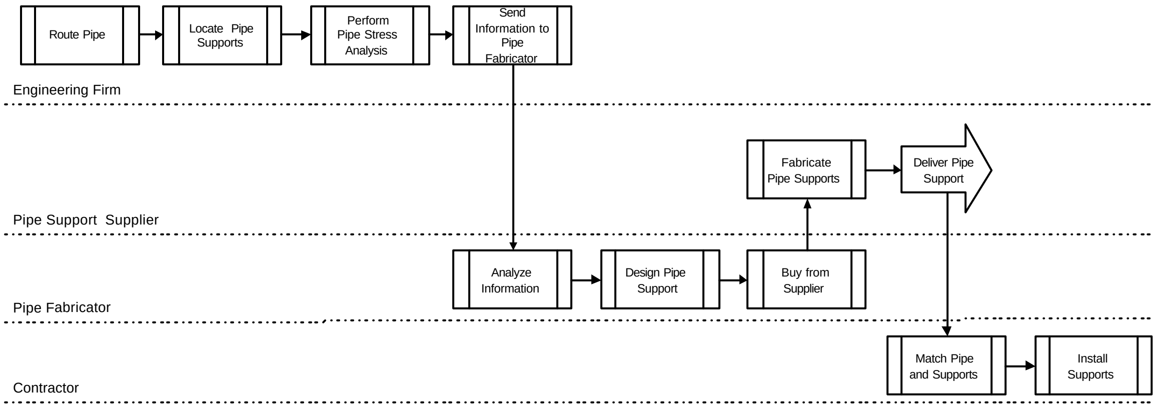

Figure 6: Configuration 5 – Pipe Fabricator Takes Responsibility for Pipe-support Design and Fabrication

successful. Sometimes, engineering firms do not have sufficient in-house capacity to engage in support design and therefore hire the supplier to provide this service.

Similarly, configuration 3 shows reciprocal dependence between the engineering firm and the supplier, but here, the information exchange is even greater than it is in configuration 2, because pipe stress analysis is more involved. Pipe stress analysis is a service offered by some support suppliers, but engineering firms appear to favor doing this work in-house for a variety of reasons.

Configurations 4 and 5 also 'cascade,' but the contractor or the pipe fabricator, respectively, rather than the support supplier, receives the handoff from the engineering firm. These configurations have been used to date for small supports where no significant engineering is required, because it has been assumed that contractors or pipe fabricators do not have the skills necessary to design and fabricate supports.

A sixth configuration that reflects vertical integration between the engineering firm, the pipe support supplier, and the pipe fabricator has been identified but not studied in detail yet. The Shaw Group, known for fabrication of pipe as well as fabrication of hangers and supports, represents this new configuration thanks to its recent acquisition of Stone and Webster Engineering in 2000. This vertical integration across so many tiers of the SC to yield a single company enables Shaw to compete heads-on with many of its own customers. Shaw is "changing the status quo of running EPC businesses by conceding that engineering is a commodity and that engineering services must be sold with a value-added component" (ENR 2002).

SELECTION OF SUPPLY-CHAIN CONFIGURATIONS

The selection of a SC configuration to best suit any one project must take into account numerous factors, including the capabilities (e.g., core and non-core competencies), capacity, and strategic corporate goals of each of the companies involved, as well as industry trends and the current and forecast market situation. In practice, engineering firms may use more than one SC configuration to balance the needs of several, concurrent and prospective projects. For example, on one project the engineering firm may select a supplier early and collaborate with them in configuration 2 for the engineered-to-order supports (these may be 20% or fewer of the supports on that project), then involve that supplier in configuration 1 for all remaining supports, which simply can be selected from that supplier's catalog and made to order.

The selection of a SC configuration for pipe supports is governed by the decisions the power plant owner makes. In part due to the unexpected growth of the power plant industry during the last few years and, accordingly, the number of projects individual owners wanted to initiate within a short time span, some owners have established direct alliances or long-term agreements with pipe fabricators and with pipe support suppliers. Doing so corresponds to one of the new SC managerial approaches shown on Table 1.

EPC firms have also focused on establishing alliances with support suppliers. For example, Electronic Data Interchange (EDI) initiatives have been implemented in order to ease and expedite the interfacing between processes. EDI initiatives provide a foundation to support increasing levels of standardization of products and processes as well as power plant modularization initiatives.

To achieve the best results in terms of value (including cost, quality, and lead time), the owner makes decisions about whether or not its supplier alliance or an EPC firm's alliance is to represent the best solution for each power plant project in particular.

SCOPE OF SUPPLY-CHAIN MANAGEMENT PRACTICES

Vrijhoef and Koskela (2000) distinguished four scope ranges for the implementation of SCM (they called them 'roles of SCM') in construction, depending on whether the focus is on the supply to the site, the construction site, or both. The following description of each scope range paraphrases Vrijhoef and Koskela (2000) and it is based on Figure 7. These scope ranges can be implemented simultaneously at all levels in order to leverage improvements in overall SC performance.

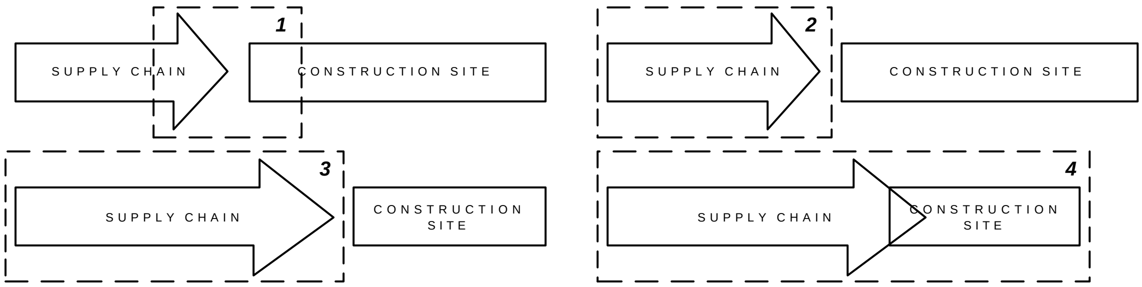

Figure 7: Four Ranges in Scope of Application of SCM in Construction (after Fig. 2 in Vrijhoef and Koskela 2000)

- SCM focuses on the impact of the SC on construction site activities and aims to reduce the cost and duration of those activities. The primary concern therefore is to establish a reliable flow of materials and labor to the site.
- SCM focuses on the SC itself and aims to reduce costs, especially those related to logistics, lead time, and inventory.
- SCM focuses on transferring activities from the site to earlier stages in the SC.
- SCM focuses on the integrated management and improvement of the SC and site production, that is, site production is subsumed by SCM.

Using this categorization, the SC configurations presented in this paper match scope ranges 2 and 3. Scope range 2 may be distinguished when engineering firms use in-house capabilities as well as supplier capabilities to reduce support design lead times and costs. This also contributes to balancing the engineering firm's design capacity in order to achieve project goals. Scope range 3 is exemplified through power plant modularization initiatives where pipe and pipe supports as well as other power plant components such as structural steel, are fabricated early and preassembled, then shipped to the site in pipe rack. While pipe rack frames are being put together, crews assemble the final pipe supports from the parts previously delivered by the pipe support supplier. Then, pipe installation can take place as soon as the steel is erected, eliminating the usual lead time required for pipe support installation (Burke and Miller 1998). Clearly, in this case activities are transferred from the site to earlier stages in the SC.

Since "power plants are somewhat like snowflakes. There are no two alike. (Schimmoller 1998)", designers have traditionally been inclined to customize pipe supports. Power plant modularization represents an incentive to minimize the amount of time and effort devoted to the customization of individual power plant elements like pipe supports. Initially conceived as "a reaction to the highly competitive, low-margin, short lead-time nature of today`s power plant design and construction market (Schimmoller 1998)", power plant modularization will lead to a greater level of standardization of plant components. Gotlieb et al. (2001) calculated that the cost of solid-fuel fired plants can be reduced on the order of $170/kW by making modularization an integral component of design from the start.

SUPPLY-CHAIN METRICS

SC performance can be measured through different types of metrics applied to the SC at large or to any of its different phases. Examples are, in terms of lead times, the time to approve detailed drawings prior to the start of fabrication, the time to fabricate the supports, the time to deliver the support to the site, and staging time on site (arrival of supports prior to their installation). Note that with alliance suppliers, using standardized detailed drawings and CAD systems, the detailed-drawing approval process can be significantly shortened from the time it traditionally took.

In terms of value, one metric is the actual work time vs. the total time in system, also known as value added time vs. lead time. A detailed analysis of value-added and non-value-added times in the SC of pipe supports is presented in Arbulu and Tommelein (2002). That analysis concluded that an average of 4% of the total SC lead time adds value to the final product: a pipe support.

In terms of how information is released from one activity to another, the analysis of batch sizes as units of handoff from one SC participant to the next is extremely helpful. Tommelein and Arbulu (2002) further analyze the impact of batch sizing on SC performance. Arbulu (2002) presents different computer simulation models based on the SC of pipe supports that illustrate the effect of batching, multitasking, and variability as contributors to lead time.

Besides time, value, and quality, cost is an important metric. However, cost data is more sensitive to obtain and we did not insist on doing so. Other considerations in comparing different SC configurations may include the distance or directness of control and communication between the various SC participants and the number of process steps in the SC (length of the SC).

The amount of process iteration during the design phase may be investigated using a design-structure matrix that provides a clear representation of a complex system capturing interactions/interdependencies/interfaces between elements in the system. The system in this case would be the pipe supports, intertwined with other systems.

The metrics for SC performance, proposed here, are only a guide for future work. The Supply-Chain Council (2002) presents a detailed list of metrics and the Supply Chain Operation-Reference (SCOR) model that was conceived for various manufacturing industries, but can be modified to suit construction. Note also that some data for metrics is readily available whereas other data is more difficult to obtain.

To illustrate the use of some of these metrics, we have analyzed real data related to SC lead times, namely data on 680 pipe hangers and supports from a power plant project currently under construction. In this case, the SC of pipe supports followed the structure of SC configuration 1 (engineering firm designs pipe supports). Figure 8 depicts several lead times for different SC activities and handoffs, starting with the date at which the first purchase order was issued and ending with the actual shipment date to the site. For example, the handoff between design and fabrication is represented by the number of calendar days since the engineering firm issued the drawings to the supplier ('Issued') until the support supplier sent detail drawings for approval ('SA'). This handoff took more than 8 weeks on average (61 days = 8.7 weeks), whereas the fabrication process itself took no more than 6 weeks (27 days + 13 days). This data demonstrates that SC handoffs can be highly inefficient. This particular handoff took so long because of the interdependency between participants in the SC, and the high degree of analysis and verification required after each handoff, in part due to lack of product and process standardization.

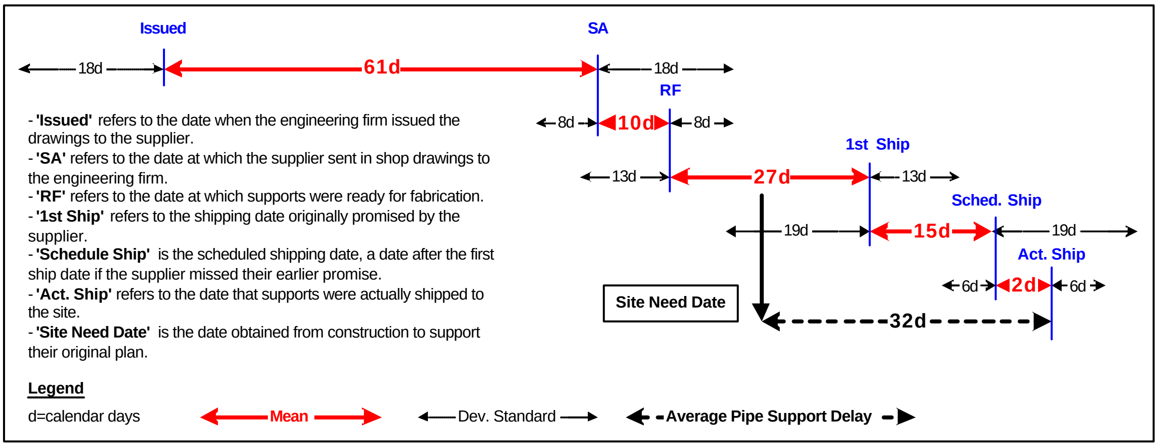

Figure 8: Lead Times in Pipe Support Detailing, Fabrication, and Delivery

TOWARDS FURTHER SUPPLY-CHAIN IMPROVEMENT

To achieve further performance improvement, not only in terms of product and process design, but also in overall SC configuration design, several suggestions are pertinent to this case study. In the power plant industry, pipe supports are not standardized on an industry-wide basis, so that designers are forced to use supplier-specific catalogs and custom-designed supports for different projects. Lack of standardization in pipe supports means that detailing cannot be done in full by the engineering firm until a specific supplier has been chosen. Some engineering firms complete the design anyway and then ask the supplier to re-engineer the design so that their product can be incorporated in the final analysis. This kind of 'value engineering' is misguided as it creates a lot of waste in the process. Industry-wide standardization of pipe supports would help designers avoid late changes that may affect the project delivery date. Making supports into commodities has its advantages in terms of where you can buy them from (if they are 100% substitutable), and it also has an impact on who does the design and how, who can fabricate, and how long does fabrication takes. Substitutability is an outcome of standardization.

To standardize, a limited number of configurations must be defined. If the number of standardized products is too large, that will defeat the purpose of standardization. Industry practitioners have suggested to us that the number of standard supports should not exceed 100 to at most 150 configurations. Fewer configurations may further reduce engineering time though it could come at a cost of over-dimensioning or other inferiority.

Since many SC inefficiencies are located in the handoffs between processes, disciplines, or organizations, selecting a supplier earlier in the SC has several advantages. For example, suppliers have direct understanding of the fabrication process and therefore can more easily tailor catalog designs to best meet design requirements. Suppliers may act as as an advisor to the owner or engineering firm to optimise the design process. Also, an early identification of pipe support catalogs will avoid later conversions from one supplier's standards to another one's. Suppliers that gain insight into project requirements early are able to better manage their own SC, e.g., procure materials needed to make supports earlier on. Early involvement of suppliers in the SC also may contribute to better integration and acceleration of transactions using EDI, which are essential to supporting standardized products and processes as well as power plant modularization initiatives. The approval process of shop drawings (pre-approved drawings for fabrication) may also be accelerated, and during the fabrication phase, RFIs may be resolved more quickly.

Anecdotal evidence collected during this case study revealed that about 15% of pipe support designs have engineering 'mistakes.' To avoid mistakes, the industry has started using new tools (especially computer software) to improve design. Many firms provide software incorporating a table of catalogued supports and hardware with pictorial references. These packages create a bill of materials (BOM) and price for each support based on a catalog of standard supports. Other versions integrate with AutoCAD or 3D CAD programs. Unfortunately, the products available on the market today, do not yet allow users to completely design all kinds of pipe support.

Lack of coordination and communication in order to achieve a synchronized flow or materials between the participants often hamper performance. There appears to be relatively little, real-time coordination between pipe support fabrication and pipe fabrication; the two processes are de-coupled and take place concurrently. The respective fabrication schedules get defined in the design process based on input from construction regarding site needs. This kind of schedule push is reflected in priority lists. It is not clear how suppliers are kept abreast of changes in construction during execution, and, therefore, of changes in component due dates.

CONCLUSIONS

Construction SCs are intrinsically complex and varied. This paper has illustrated this by presenting five different alternative SC configurations for pipe supports used in power plants. Engineering firms or power plant owners usually select and manage these configurations. A benefit of having several SC configurations is that one can balance the abilities and constraints of SC participants in order to achieve project goals.

The presented case study has demonstrated that SC interfaces can create waste in the system. This, complemented with inefficiencies in SC activities, contributes to long lead times. Therefore, the probability increases for supports to arrive late to the site. Certainly, problems with pipe supports start in the support design phase but the solution for these problems may be found even before this point in time. The level of interaction between pipe and pipe supports makes us conclude that good pipe support design starts with good piping design and layout (e.g., Nayyar 2000).

Three future research proposals stand out as the result of this case study. First, additional research needs to be done to investigate opportunities for improving the synchronization of parallel SCs such as those of pipe, pipe supports, and instrumentation, including delivery and matching at the site (e.g., Tommelein 1998). Second, additional research is needed to relate modularization efforts to improved SC performance. Finally, a study is needed of the effect of 'commoditization' of engineering services as a contributor to SC performance improvement (also see ENR 2002).

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REFERENCES

Arbulu, R.J. (2002). *Improving Construction Supply Chain Performance: Case Study on Pipe Supports used in Power Plants.* Master of Engineering Thesis, Constr. Engrg. and Mgmt. Program, U.C. Berkeley, Berkeley, CA, May.

Arbulu, R.J. and Tommelein, I.D. (2002). "Value Stream Analysis of Construction Supply Chains: Case Study on Pipe Support Used in Power Plants." Companion paper to appear in *Proc. IGLC-10*.

Burke, G.P. and Miller, R.C. (1998). "Modularization Speeds Construction" *Power Engineering Magazine*. Available at http://pe.pennnet.com visited on 03/30/02.

ENR (2001). "Power Plant Construction." *A Special Report by Engineering News-Record and Power Magazines.* December, 128 pp.

ENR (2002). "The Shaw Group Branches Out." Cover story of 1 April issue, *Engineering News-Record*, www.enr.con/new/coverstry_040102.asp, visited on 04/05/02

Gotlieb, J., Stringfellow, T., and Rice, R. (2001). "Power Plant Design Taking Full Advantage of Modularization." *Power Engrg. Mag.*, http://pe.pennnet.com, 03/30/02.

Nayyar, M.L. (2000). *Piping Handbook*. 7th ed., McGraw-Hill, New York.

Schimmoller, B.K. (1998). "Power Plants Go Modular". *Power Engineering Magazine,* January. Available at http://pe.pennnet.com visited on 03/30/02.

Supply Chain Council (2002). http://www.supply-chain.org visited on 03/30/02.

Tommelein, I.D. (1998). "Pull-driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique." ASCE, *J. Constr. Engrg. & Mgmt.*, 124 (4) 279-288.

Tommelein, I.D. and Arbulu, R.J. (2002 forthcoming). *Assessment of Supply Chain Performance for Engineered and Catalogued Made-To-Order Components: Case Study on Pipe Supports used in Power Plants*. Research Report, Constr. Engrg. and Mgmt. Program, U.C. Berkeley, Berkeley, CA.

Tommelein, I.D., Walsh, K.D., Hershauer, J.C. (2002). *Construction Supply Chain Management Primer*. Work document (not a CII publication) developed by Project Team 172 on "Improving Construction Supply Chain Performance" for the Construction Industry Institute, available from Tommelein, I.D., Constr. Engrg. and Mgmt. Program, Civil and Envir. Engrg. Dept., U.C. Berkeley, CA, January version.

Vrijhoef, R. and Koskela, L. (2000). "The Four Roles of Supply Chain Management in Construction." *European J. of Purchasing & Supply Chain Management,* 6, 169-178.