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LEAD TIME REDUCTION VIA PRE-POSITIONING OF INVENTORY IN AN INDUSTRIAL CONSTRUCTION SUPPLY CHAIN

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ABSTRACT

Lead time reduction is a key concern of many industrial buyers of capital facilities given current economic conditions. Supply chain initiatives in manufacturing settings have led owners to expect that dramatic reductions in lead time are possible in all phases of their business, including the delivery of capital materials. Further, narrowing product delivery windows and increasing pressure to be first-to-market create significant external pressure to reduce lead time. In this paper, a case study is presented in which an owner entered the construction supply chain to procure and position key long-lead materials. The materials were held at a position in the supply chain selected to allow some flexibility for continued customization, but dramatic reduction in the time-to-site. Simulation was used as a tool to consider time-to-site tradeoffs for multiple inventory locations so as to better match the needs of the construction effort.

1 INTRODUCTION

This paper describes a case study analyzing the capital project supply chain of a large food product manufacturing company. The company has requested anonymity, and for simplicity will be referred to as Company X. Company X maintains a large number of manufacturing facilities around the world, and operates at a very high utilization at all facilities. As a consequence, new product roll-outs or large promotions require an increase in production capacity that can only be gained by adding a new capital facility.

The key business issue that drove a change in Company X's management of construction supply chain relationships was the difficulty often experienced in completing projects by the scheduled date. The focus of this case analysis is the supply chain for constructing continuous-process production facilities for Company X (the manufacturer of the end product). Most projects involve changing and expanding existing facilities. The risk of failure to meet expected delivery times is enormous. Historically, shortages of stainless steel pipe and pipe fittings have been particularly problematic, and therefore the supply chain for pipes and pipe fittings is the focus of this case study.

The manufacturing capacity of Company X generally runs in the mid- to high- ninety percent range. There are severe market opportunity costs from a late project. In addition, considerable advertising effort for new product roll-out is coordinated with the opening of new or expanded facilities. Advertising commitments often have long lead times. There is little room for change once advertising is purchased. Because of competitive pressures and some seasonality in sales, it is not possible to extend a project delivery date once it is planned and scheduled. Prior to instituting this supply chain initiative, Company X was experiencing unpredictable availability of stainless steel pipe and fittings. This lack of availability resulted in the inability to support shorter project-to-market objectives.

The critical supply chain for completing a facility expansion project is the extended supply chain for obtaining and installing stainless steel components. This portion of the supply chain has both the longest and the most variable lead time, and comprises an important system within the final facility. Stainless steel tanks and piping are used to hold, move, and process the product. Extensive use is made of a special quality stainless steel for all parts of the production system. The length and variability of this supply chain extends to all phases: engineering, procurement, and construction.

Simulation of Company X's supply chain was performed in order to analyze the impact of inventory placement on pipe arrival time to the job site. Alternatives investigated included the following:

- All inventory held at the Mill,
- Inventory pre-positioned at a Distributor, and
- Inventory pre-positioned at the Mill, Pipe Manufacturer and Distributor (three models considered).

The objective of simulation was to better match demand patterns observed at Company X's job sites with materials delivery.

2 ORIGIN AND EVOLUTION OF SUPPLY CHAIN SIMULATION

Supply chain modeling is often traced back to the work of Jay W. Forrester as published in "Industrial Dynamics: A Major Breakthrough for Decision Makers" (1958), and his later work *Industrial Dynamics* (1961), where he further developed his theories. In his works, Forrester describes a four-tiered supply chain architecture consisting of a factory, warehouse, distributor and retailer, on which he based his simulation studies. Forrester advanced an intra-company modeling approach, focused on the interactions at the interfaces within the supply chain. These interactions occur in the form of material, manpower, capital, and information exchanges.

Angerhofer and Angelides (2000) follow the evolution of supply chain simulation since Forrester's work. They provide an excellent synopsis of research and development performed through the 1980's and 1990's. Recent work in supply chain simulation focuses on the development of simulation frameworks and programmatic models, and their application to case studies. Case studies in the literature can be broadly classified according to one or more of the following problem types: inventory management, process improvement, or forecasting/demand management. Inventory management case studies are prevalent in manufacturing-type industries and focus on optimizing service level and process time. Process improvement case studies are prevalent in the construction industry, and often have a more internal operations focus, with little or no emphasis on management of the supply chain interfaces that Forrester espoused. Forecasting and demand management simulation is done either to anticipate or to mitigate risk due to consumer behavior, and is rarely if ever used in construction applications.

Supply chain consideration in the construction industry has tended to focus on the interactions between contractors and subcontractors in the construction process, or on the project-related supply problems. Tommelein (1998) showed the importance of coordination and communication and its relation to site inventory reduction. Tommelein, et al. (1999) demonstrated that variable production levels between subsequent trades can be more deleterious than the variability in a single step. The present paper is focused instead on the location of inventory in the supply chain and its implications for the arrival of that material on site. Each of these cases demonstrates interest in the interface between the supply chain and the construction site (Vrijhoef and Koskela 1997), with the present work carrying this interest all the way upstream to raw material processing at the mill.

Most simulation case studies in the manufacturing environment rely on highly customized proprietary simulation environments. Examples include custom applications developed for entities such as IBM, GM, Sandia National Laboratory (Archibald et al. 1999, Bhaskaran 1998, Trone et al. 2000). However, there is significant effort underway to develop general-purpose object-oriented simulation environments. Examples include ProModel, Supply Chain Guru and SIMUL8. Construction supply chain simulations, perhaps because of their very origins in construction, tend to rely upon discrete-event simulation tools commonly used in construction process simulation. For example, Tommelein et al. (1999) used the CYCLONE derivative STROBOSCOPE.

3 THE SUPPLY CHAIN

The supply chain for the stainless steel pipe and pipe fittings is depicted on Figure 1. The symbols used are based on Damelio (1996), with the legend presented in Table 1. In 1995, Company X recognized the pernicious effects of the length and variability of this supply chain, and decided to intervene in the supply chain in order to buffer the lead times directly. Further, they realized that other stakeholders (e.g. the network of contractors, subcontractors, and suppliers involved in a construction project) were unable to make the necessary capital investment because they were not assured of continuing sales in the marketplace. Company X made the decision to enter their construction supply chain as a holder of inventory directly for this purpose.

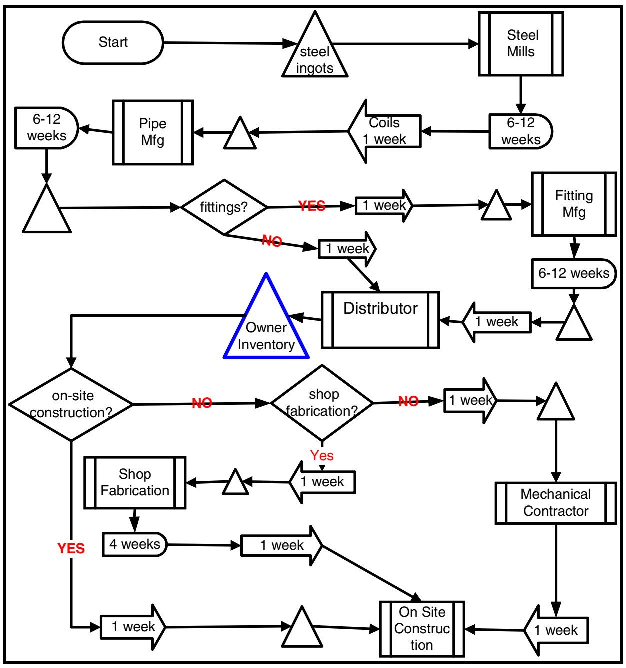

Figure 1: Supply Chain Map for Stainless Steel Pipe and Pipe Fittings

Table 1: Description of Supply Chain Map Symbols

Symbol	Description
Triangle	Inventory holding location
Single line arrow	Transfer of Material
Block arrow	Transportation
Rectangle	Processing Step
Diamond	Decision or Branch
Large “D”	Delay

The triangles shown in Figure 1 represent possible locations considered for storage of Company X’s inventory. The large triangle in the middle of the map labeled Owner Inventory shows the location chosen in 1995 as part of their Inventory Acquisition Program. Internal approval for a holding project for “Construction Materials” was obtained from management. The buffering was accomplished by creating an inventory of standard stainless steel pipe and pipe fittings owned by Company X. A single independent distributor was selected for the purposes of storage of this material, inventory control, and material handling. Individual projects could then be planned, scheduled, and completed in a shorter and more reliable time frame. Risk of extensive upstream lead times from mills and pipe manufacturers were buffered or eliminated.

In addition, the distributor was also able to provide extensive information and tracking of pipe, fittings and flanges for Company X. This information had not previously been available from any member of the supply chain. This information has allowed improved planning and scheduling and provided the knowledge needed to evaluate the program. Costs incurred by Company X for carrying this inventory have been more than offset by price savings achieved through bulk purchases and through savings relative to continuing inflation in stainless steel prices. In addition, the total capital invested in supply chain inventories has been reduced because individual distributors no longer carry inventories of the pipe and fittings.

In spite of these advantages, it should not be taken that this decision was easy to accomplish or was made without political difficulty. Predictably, Purchasing management within Company X recognized that there was significant capital associated with maintaining a large inventory of pipe and pipe fittings not related to a specific building project. In order to reduce the potential for suboptimization in response to the resulting internal pressure, subsequent inventory replenishment was accomplished via a virtual “project.” Expenditures for this purpose were drawn against this virtual project, which was then reimbursed by the next actual project, leading to a new draw.

The map depicted in Figure 1 was developed via a series of interviews with Company X personnel within the purchasing and capital facilities development departments. In addition, upstream supply chain member input was sought via interviews with personnel from the distributor and the pipe manufacturer. The interviews were conducted by faculty researchers, and were augmented by an intern on a ten-week assignment within Company X assist in detailing this process. This intern was able to provide the data needed to estimate the delay times shown on Figure 1.

4 RESULTS

The capability of interest is the availability of the piping to be installed at the desired time following release of a specific facility expansion project. Although earlier release of projects has an obviating influence on this capability, the focus of the case is on reduction of the cumulative leadtime and on management of excessive or uncertain lead times through well-chosen buffer locations. Since adoption of the 1995 Inventory Acquisition Program, a number of advantages have been experienced.

Holding inventory of finished pipe and fittings at a distributor warehouse has been very effective in buffering against long scheduling lead times from the mill and pipe manufacturing processes. Specifically, typical lead times times from mills and provide greater flexibility related to pipe size.

Strong positive relationships with the distributor warehouse, pipe and fittings manufacturers, and fabricators have led to delivery of excellent quality parts, components, and modules on a timely basis. Holding inventory buffers further up the supply chain allows more flexibility in response to changing needs, but increases the need for reduced lead times in manufacturing and capacity scheduling in the remaining downstream operations.

5 SIMULATION OF THE SUPPLY CHAIN

The delivery of material to the construction site earlier and more reliably was a significant motivator for the development of the supply chain intervention previously described. It has been noted that the results of the 1995 Inventory Acquisition Program were considered successful for several reasons, not the least of which was the dramatic reduction in the actual arrival time at the job site. Nonetheless, it seemed clear to the researchers that this solution likely provided earlier arrivals than actually necessary, and hence, probably was more expensive than needed.

To address other potential approaches to the buffering problem, the supply chain was simulated using a discrete event simulation engine. The simulation experiment was conducted using the Simphony system (AbouRizk et al. 1999). Simphony was selected because it allows development of special purpose templates for a focused area of application (Hajjar and AbouRizk 1999).

The CYCLONE model network is presented in Figure 2. As the details of the processing required at the higher locations in the supply chain were neither well known to the researchers nor particularly important to the result, they were combined into individual processing steps, and the delay time was taken as part of the processing time. This simplification should not be taken to indicate the lack of possible process improvements within these individual processes, but rather to indicate that it is difficult for the manufacturer to exert influence over those processes at any level of detail.

The model shown in Figure 2 was used to consider a number of scenarios for possible inventory holding locations. An early refinement exercise was used to determine that there was no significant change in the statistical parameters describing arrival times (mean and standard deviation) after 100 iterations, so 100 iterations were run for all scenarios. Counter elements were inserted into the model at locations where the arrival time history was de-

on the order of 40 to 50 weeks have been reduced to the order of 8 to 10 weeks for delivery of 100% of the pipe to the site. Consolidation of buffers at a single distributor has enabled Company X to reap the benefits of risk pooling. Inventory buffers of stainless steel coils located in front of the pipe manufacturer buffer against long and variable lead sired (typically the site). The first use of this model was to simulate both the original supply chain (in which the stainless steel begins its journey to the site at the mill) and the 1995 revised supply chain (with the stainless steel kept in a buffer at the distributor). Batching concerns were not modeled directly except at the distributor itself, as the evidence from interviews indicated that the batching delays were already built into the delay values used for processing times. The processing times for each stage in the supply chain were allowed to vary within a uniform distribution, again based on the interview results.

The simulated arrival times for these two cases are shown in Figure 3. The figure shows the average result for 100 iterations of the model (solid line) along with the range (dashed lines) for each case. The results show reasonable agreement with actual arrival times noted by capital facility development personnel at Company X. It is interesting to note that both curves are quite steep, showing relatively high delivery intensity throughout the time period during which materials arrive at the site. This rapid delivery reveals an “old-school” construction management mentality, and is designed to support construction management desires to have significant amounts of pipe “on-the-ground” before pipe erection begins, in order to maximize crew assignment flexibility during erection. This desire is in keeping with observations by others (Howell and Ballard 1996, although we should note that these authors were generally critical of the practice). Still, data from construction show a much shallower demand curve (Figure 4).

Figure 4 shows clearly that the monthly demand is fairly steady for all of the relevant pipe materials throughout the construction process. Using either the unbuffered supply chain or the owner intervention case, it is clear that the arrival of material will occur over a much shorter time period than required for installation as indicated by Figure 4. As a consequence, the project will require on-site inventory storage space for a very significant fraction of the pipe delivered. The advantages rendered by this early delivery to the craft assignment flexibility will likely be offset to some degree by a lack of flexibility to revise the actual pipe material in response to changes after arrival and some damage/loss of pipe while stored on site.

To address those concerns, additional simulation experiments were conducted to consider alternative placements for inventory in the supply chain. The objective was to develop inventory placement locations that would result in a less steeply sloped arrival pattern than those depicted in Figure 3 that better matched the demand curves shown in Figure 4. To that end, the quantity of pipe required for

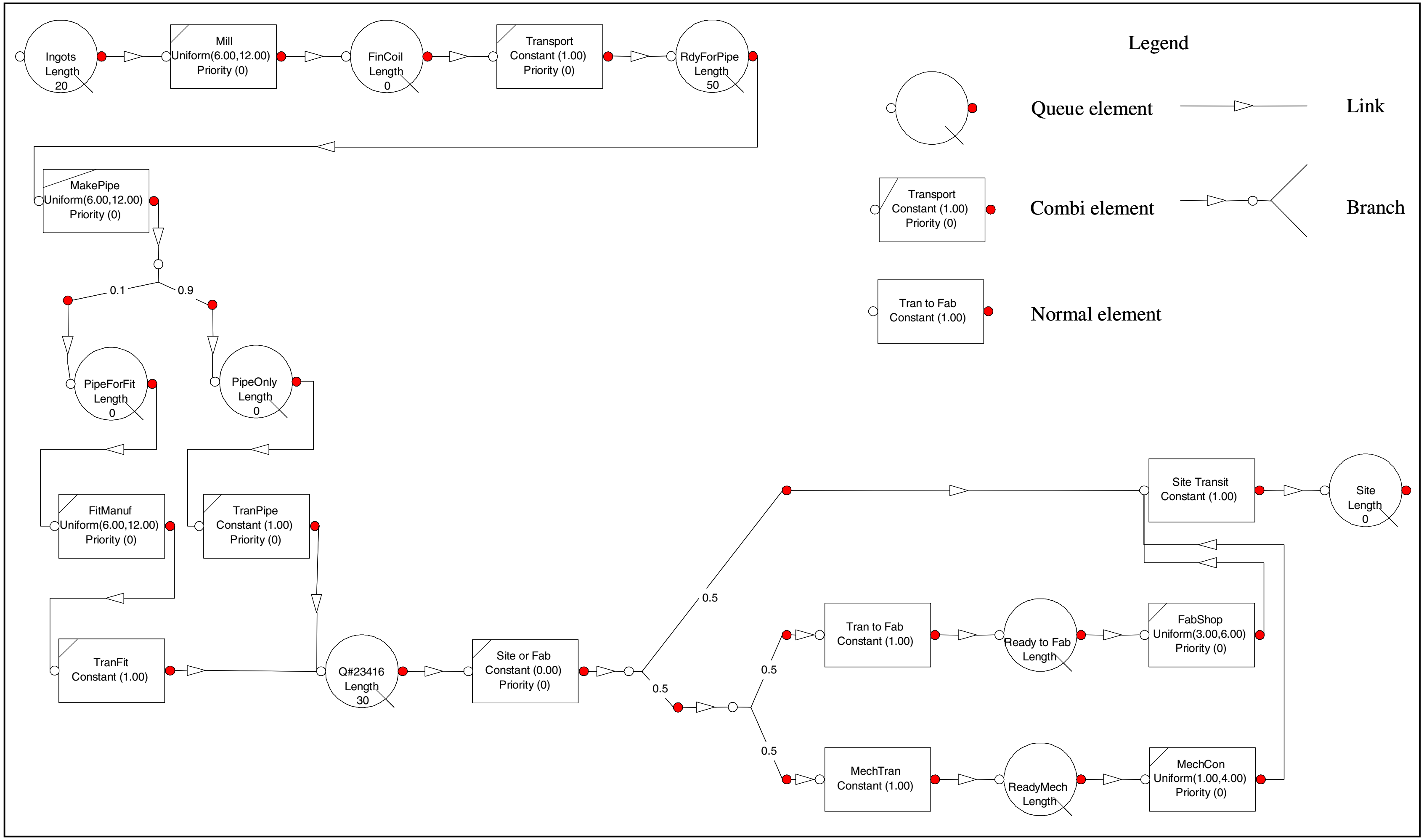

Figure 2: CYCLONE Model of Stainless Steel Supply Chain

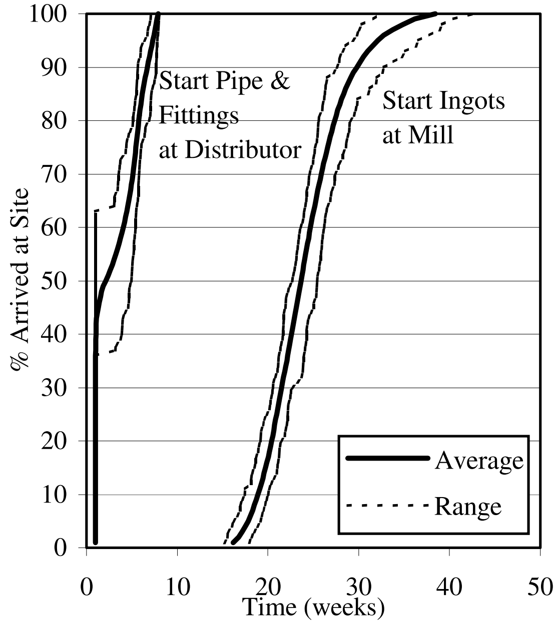

Figure 3: Simulation Results for Pipe Materials Beginning at the Mill and Distributor

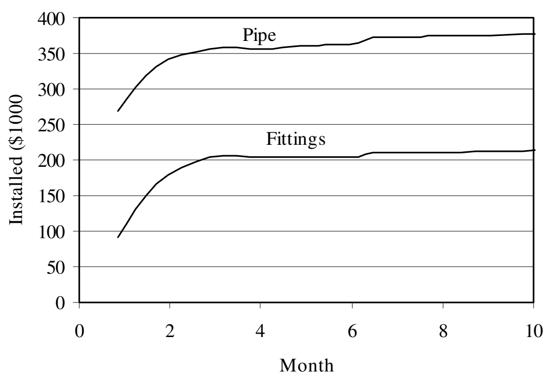

Figure 4: Schematic Pipe Demand Patterns During Facility Construction (Based on 1 Project)

the project was divided among several locations, as indicated in Table 2. The resulting arrival times at the site are shown on Figure 5 for Plan 1.

Figure 5 demonstrates that pre-positioned inventory at various stages in the supply chain can be used to develop an arrival pattern much more in keeping with the observed demand patterns for pipe in construction. The other two models exhibited slightly different slopes, but overall gave very similar behavior and are not depicted in Figure 5. It must be recognized that so far, this analysis has assumed pipe deliveries to be more or less interchangeable in the construction process. This assumption is probably not entirely accurate, as in general particular pieces must be installed at particular locations. This means that communication and coordination systems must be designed so as to support delivery of the appropriate pieces at the right time

Table 2: Alternative Inventory Location Models

Inventory Distribution For Different Models			
Starting Locations	1	2	3
Mill	20%	30%	40%
Pipe Mfg	50%	50%	40%
Distributor	30%	20%	20%

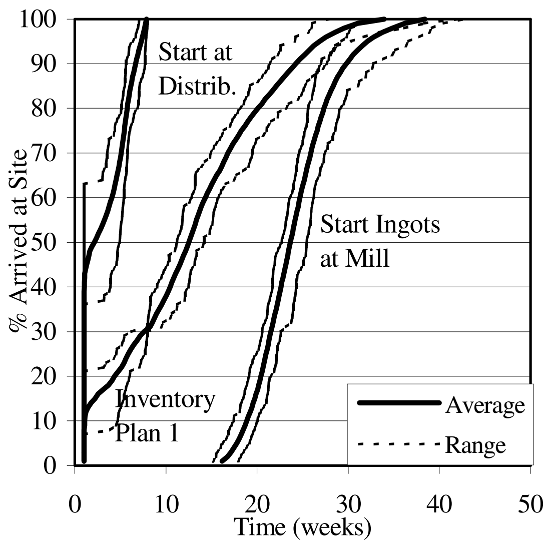

Figure 5: Arrival times of Pipe to the Job Site Using Scattered Inventory Locations

(the "matching problem" of Tommelein et al. 1999). This communication and coordination problem is likely to be equally complicated.

6 SUMMARY AND CONCLUSIONS

The simulation of supply chains is a relatively new field of inquiry in construction engineering research, as for that matter is the application of supply chain management itself. Supply chain modeling is relatively common in other industries, notably in manufacturing environments. These simulations tend to have a more directly cost- or profit-based focus, and most commonly are interested in forecasting of demand or management of inventory. Construction simulation has tended to focus on the improvement of processes within a single supply chain participant, with a few notable exceptions.

In this paper, a case study of a supply chain simulation application in construction was presented. The particular interest in this case was on the location of owner-held inventory of long-lead material (particularly stainless steel). Company X, a product manufacturer, was interested in the reduction of lead time for construction of new facilities, and used an inventory of stainless steel pipe material to shorten pipe delivery lead time.

Completion of a simulation experiment using the discrete event simulation environment SIMPHONY resulted in a reasonable match to the expected performance based on observed lead times. Additional experiments were then performed to evaluate potential placement of inventory in multiple locations in the supply chain as a means of controlling delivery time to match the construction process. An advantage of this alternative is that it provides increased flexibility, as more product is located higher in the supply chain is more suitable for modification to suit changes in requirements during design or construction. However, the longer period for delivery to the site does tend to reduce crew assignment flexibility and to increase the need for coordination and communication in the supply chain immediately upstream of the site.

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