INVESTIGATION OF BUFFER DYNAMICS IN SHEET METAL DUCTWORK SUPPLY CHAINS

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ABSTRACT

The model discussed in this paper represents the interactions between design changes, site work, and fabrication shop work for make-to-order products. Being qualitative in nature, it serves as a basis for discussing how inventory and buffers are created in the Sheet Metal Ductwork Supply Chain due to changes in design and installation sequences. The authors chose to model changes in schedule and design because industry practitioners indicated that these are the main causes for variations that disrupt contractors' work flow. The authors highlight selected feedback links between activities to discuss the implications of communication, timing of demand, and product standardization vs. customization. A number of insights into the model can be abstracted to other supply chains in construction. Other supply chains in construction (e.g., electrical systems, architectural components, precast concrete) can benefit from the analysis as presented.

KEY WORDS

HVAC Ductwork, supply chain, buffers, information management.

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INTRODUCTION

Relationships between supply chain participants and intrinsic characteristics of the construction industry determine how buffers are defined, sized, and located in the HVAC sheet metal ductwork supply chain - SMDSC (Alves and Tommelein 2003). The focus of this paper is the design-fabrication-installation of sheet metal ducts and fittings for heating, ventilating and air-conditioning (HVAC) systems. Part of the waste and the problems that plague the construction industry is the result of local optimization initiatives performed by individual firms (Vrijhoef and Koskela 2000). This is aggravated by the lack of communication and transparency among supply chain participants in construction (Tommelein 1998). Therefore, any effort that aims at increasing transparency and the understanding of how supply chains work in the construction industry are welcomed (Tommelein et al. 2003). According to Tommelein (1998, p. 287-288), "(p)articipants who can 'see' the other's needs, can better plan to accommodate them."

INFORMATION SHARING AND MANAGEMENT IN SUPPLY CHAINS

Forrester (1958) demonstrated through simulation experiments the pervasive effects of delays in the sharing of information between companies (a.k.a. bullwhip effect as discussed in a paper by Lee et al. 1997) in a three-tier supply chain (e.g., factory, distributor, and retailer). In the simulations, delays in information sharing, uncertainty, and gaming about actual or potential spikes in demand caused fluctuations that spread throughout all tiers of the supply chain. These fluctuations affected the ordering and production levels in all tiers and persisted for months until the supply chain returned to its average order and production rates. Some 50 years later, Forrester's experiments and ideas have proven indispensable to successful supply chain management, yet they have not permeated supply chains in the construction industry.

Toyota has worked throughout the years with its suppliers to establish long-term relationships based on intense information sharing and a continuous improvement mentality. The change from the old way of doing business to increasing collaboration within a supply chain is not easy, however. Companies may be reluctant in sharing information with their counterparts in a supply chain because of conflicting interests amongst supply chain members (Simchi-Levi et al. 2003) and myopic control of the supply chain (Vrijhoef and Koskela 2000) to name a few. This same resistance to sharing information can be found in some mechanical contractor businesses. Even though different branches (i.e., design, fabricate, install) of the business belong to the same company, there may not be enough information sharing to allow the branches to know what the current practices are throughout the company. This results in buffers of inventory, capacity, and time that do not adequately meet the mechanical contractor's supply chain needs and contribute to the generation of waste.

MODEL ASSUMPTIONS

The model shown in figure 1 graphically represents the interactions between design changes, site work, and fabrication shop work for make-to-order products. The model is qualitative in nature and serves as a basis for discussing how inventory and buffers are created in the SMDSC due to changes in design and installation sequences.[3] The authors highlight selected feedback

[3] Industry personnel often mention that changes external to their trades, especially design and schedule changes, cause changes in their installation sequence.

links between activities to discuss the implications of communication, timing of demand, and product standardization vs. customization.

The model was developed using STROBOSCOPE (Martinez 1996) symbols but in its current form was not used to simulate the modeled system's behavior. Rectangles represent activities. Circles represent queues which hold resources used to perform activities. The solid arrows represent the transfer of resources between queues and activities whereas the dashed lines represent feedbacks. The authors chose STROBOSCOPE due to their familiarity with this system in modelling construction processes.

MODEL DESCRIPTION[4]

The starting point of the model (Design) assumes that the project design (i.e., architectural, structural, mechanical) is already available. At the starting point, the Design queue provides the input for the *Change_Orders* activity. *Change_Orders*: represents the activity that generates changes to the project. Queues that provide input to *Change_Orders* are: Ext_Changes (e.g., owner-driven changes, site conditions); Design_Comp (percentage of design complete at the time changes are requested); Coordination (degree of coordination among stakeholders in a project). Once the activity *Change_Orders* ends, it generates a number of changes that will serve as input to the *Plan* activity.

Plan represents the planning process developed by the projects' general contractor with the help of specialty contractors. This activity is triggered when all the inputs are provided by Design and Changes as well as by four other queues: Prod_Rate (production rates of the participants of the project); Sch_Tasks (number of scheduled tasks as initially planned); Time (time necessary to complete the project); Resource (resources that may be added or removed from projects).

After the *Plan* activity ends, a group of tasks is generated based mostly on what is defined in the schedule (Sch_Tasks) and not so much in the system status (i.e., push schedule). These tasks go through the Make_Ready activity, which ideally screens for constraints on their execution, and actions are taken to assure that tasks can be developed as planned. However, the way the Make_Ready activity is often carried out in construction sites does not allow contractors to adequately remove constraints. An alternative to the traditional way of planning is proposed by Ballard (2000), i.e., The Last Planner System of Production Control.

The *Make_Ready* activity releases information (Demand) to subsequent activities (*Fabricate*, *Ship*, and *Install)* about the tasks that should be executed and, at the same time, orders the resources necessary for the execution of tasks. Installation crews (Site_Workers) install inserts, hangers, and set up the area to receive the ductwork.

Fabricate represents the fabrication activity performed by the fabrication shop. It receives the Demand and dispatches orders to be fabricated by *Shop_Workers*. The fabricated ductwork is stored in the shop yard (Fittings). According to the Demand and potential changes in the installation schedule (*Change_Install*) generated by *Plan*, the *Ship* activity withdraws ductwork from Fittings and ships it to the project site. The ductwork is stored on site (Site_Fittings) and waits for installation according to the input from Demand and Change_Install. Once Installation ends, it generates a group of installed ductwork that is sent to Duct_System, closing the cycles depicted by the model.

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[4] Queue names are underlined and activity names are shown in italics.

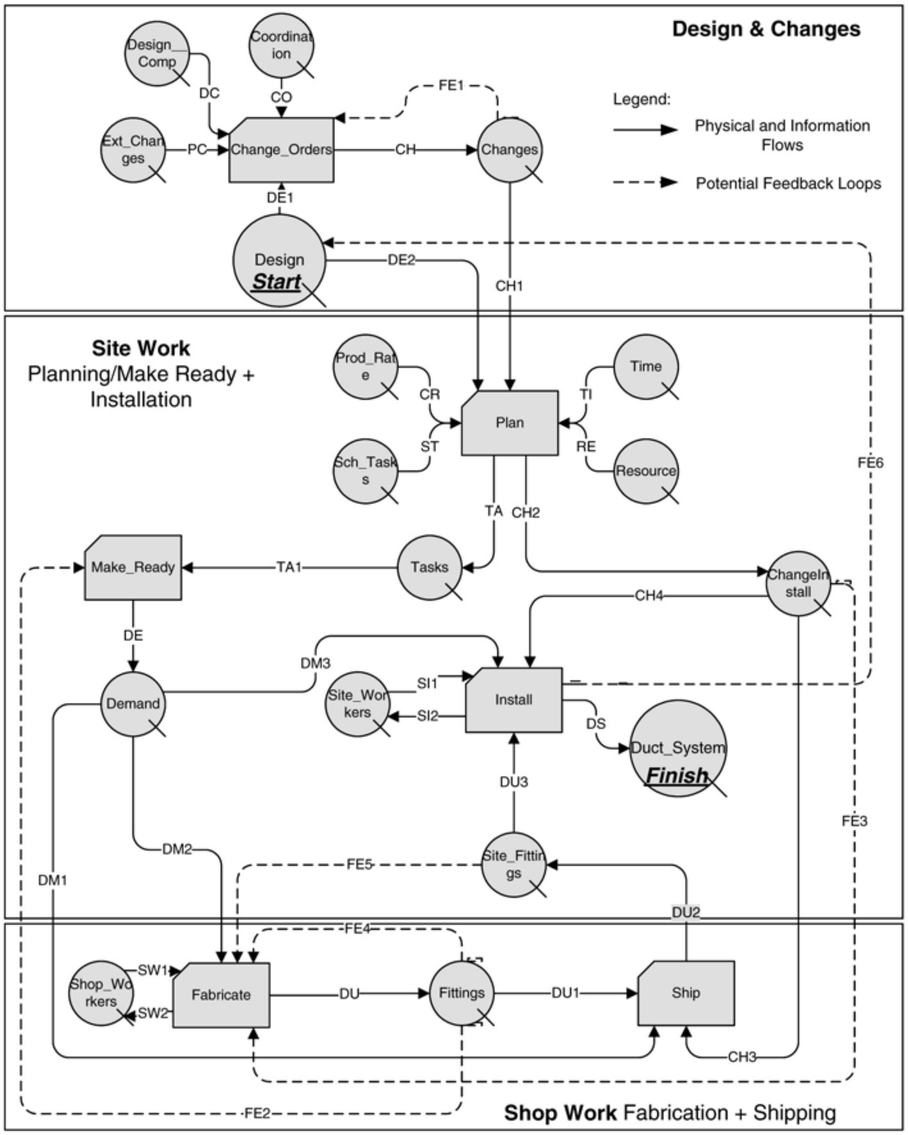

Figure 1: Dynamics of inventory creation, buffers, and batches

ANALYSIS OF SELECTED FEEDBACKS

Figure 1 shows some feedback links that would bring performance benefits to the system modeled. The authors focused on feedbacks that are related to the impact changes have in buffers due to their relevance for this paper. Next is a discussion about each feedback (i.e., FE) in figure 1 and the consequences that result from their absence in the system.

FE1: Changes and *Change_Orders*. The absence of this feedback, as a limiting factor to the number of changes represents the freedom owners have to adjust the project to meet their needs and the need contractors and other stakeholders have to account for design mistakes, omissions, coordination problems, etc. Therefore, the project's design may change, even when the product is under construction.

FE2: buffer at fabrication shop (Fittings) and the make ready process (*Make_Ready*). Regardless of how much inventory exists in the fabrication shop buffer, the make ready process keeps on releasing orders for fabrication because the products in the inventory buffer are not interchangeable.

FE3: changes in the installation schedule (Change_Install) and Fabrication (*Fabricate*). When change orders happen, the installation sequence often changes and new plans are generated (Change_Install). Installation personnel may (or may not) be informed about the changes but may choose not to inform the fabrication shop (*Fabricate*) about the changes. Therefore, the feedback FE3 may not exist. Field foremen prefer to have the ductwork ready to be installed (workable backlog) because they do not have to wait for it to be fabricated and work on alternative plans.

FE4: shop inventory (Fittings) and Fabrication (*Fabricate*). The problem observed in the feedback FE2 also happens in FE4. Even though there is a buffer of ductwork at the fabrication shop yard (Fittings), the fabrication shop (*Fabricate*) continues to fabricate what is demanded because most products are made-to-order.

FE5: site inventory (Site_Fittings) and Fabrication (*Fabricate*). Mechanical contractors like to say that "the fabrication shop is there to serve the field and not the other way around". Therefore, the fabrication shop (*Fabricate*) works according to the Demand defined by the *Make_Ready* activity, carried out by project managers, superintendents, and field foremen. As observed in the feedbacks FE2 and FE4, ductwork is fabricated regardless of the ductwork buffer already stored on the field (Site_Fittings).

FE6: feedback between installation (*Install*) and Design. The feedback FE6 would allow designers and detailers to learn from field installation. Communication between designers and detailers and field installation may not happen very often. Incentives for such interaction between design/detail and installation may be lacking.

MODELING INSIGHTS AND CONCLUSIONS

A number of insights into the model as presented can be abstracted and applied to other supply chains in construction. Other supply chains in construction (e.g., electrical systems, architectural components, precast concrete) may have similar characteristics to the SMDSC and can benefit from the following analysis.

Demand definition: fixed vs. variable demand

In construction, the total demand is usually known upfront, the timing of demand is variable. In other industries (e.g., automobiles, appliances, clothing) the total demand as well as its timing are variable. The main questions for the definition of demand in the construction industry are: When will the known (fixed) demand materialize?; and How to deal with change orders which will cause variation in product and schedule (timing) during the construction phase?

In order to adequately define activity and supply chain buffers, one has to understand the fixed (Sch_Tasks) and variable (Changes) components of the demand placed on each part of the supply chain. The authors propose that companies keep track of the root causes of the problems and make them available to be discussed with other stakeholders in the supply chain.

This would increase the transparency of information in the supply chain and it would likely reduce the occurrence of spikes in demand caused by the lack of information sharing and gaming (e.g., Bullwhip effect).

Time to fabricate ductwork early vs. late

The implementation of push-pull interfaces is one way to match the time when products have to be fabricated and the time they are required by the next activity in the supply chain. Another way to match fabrication and installation times is to establish a feedback (e.g., FE3) between the changes in schedule (Change_Install) and the fabrication shop (*Fabricate*). The feedback FE3 would assure that the capacity buffer in the fabrication shop is used for producing ductwork that is actually needed. The implementation of push-pull interfaces at the same time as standardization or modularization of ductwork parts (discussed in the next section) would allow the fabrication of ductwork closer to the installation time.

Standardization

The standardization of parts across projects can reduce inventory levels, capacity and time buffers due to risk pooling effects. Work in process and finished product buffers can be reduced as parts can be interchanged between projects. The feedback FE2, FE4, and FE5 can be put in place and parts already in stock would not be ordered from the fabrication shop (*Fabricate*).

Standardization can also help increase flexibility of site crews in terms of the backlog of tasks ready to be performed when changes happen. Due to risk pooling across projects, the workable backlog (i.e., the buffer of ductwork ready) would be much larger for any given project, as parts would be stored at the fabrication shop. By keeping an inventory of interchangeable parts to deal with demand variation across projects, the fabrication shop would not need to carry an inventory with multiple types of parts for each project.

Variation in times due to customization and not to randomness

The model presented does not show the durations of activities. However, the authors want to note that, intuitively, they think that part of the variation present in the system comes from the customization of parts rather than internal or external variability. The model shows that even when there is a large buffer of finished products in the fabrication shop (Fittings) and on the project site (Site_Fittings), *Fabricate* continues to produce custom products as specified by design and demanded by field installation. Therefore, the need to customize a large number of ductwork for different projects results in variable times and batch sizes for fabrication, installation, and shipping, as well as makes the definition of buffers more difficult. In this case, buffers have to be constantly redefined to match the load on production systems.

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