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ROLE OF LOADING PLANS IN THE CONTROL OF WORK IN PROGRESS FOR ENGINEER-TO-ORDER PREFABRICATED BUILDING SYSTEMS

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ABSTRACT

The benefits of pull production systems are well reported in the literature. Some authors argue that those benefits can be achieved through the control of work-in-progress (WIP) levels. However, when the construction project uses Engineered-To-Order (ETO) building systems, each production phase (namely design, fabrication, and site installation) may require a different batch size. The task of reducing batch size become more complex, since the production system needs a systemic view of the project flow. The paper discusses the concept of a pull system, based on the idea of controlling WIP, in a less repetitive environment. Design Science research was the methodological approach adopted in this investigation, in which an empirical study was carried out in partnership with a Steel Fabricator. Several sources of evidence have been used, such as participant observation, semi-structured interviews, document analysis, direct observation, and analysis of existing databases. The study revealed that the definition of the minimum batch in this context must consider both how the assembly process is carried out on site, and also how components are transported. The implementation of a method to control WIP in the plant contributed for reducing lead-times and inventory levels, and made project delivery more reliable

KEYWORDS

Engineer-to-order, work-in progress control, prefabricated building systems.

INTRODUCTION

Different degrees of customization exist for prefabricated components in the construction industry, from nails and bolts that are typically produced by make-to-stock production systems, to complex and highly customized components that are customer-driven manufactured (Elfving et al., 2004). In an engineered-to-order (ETO) product, the customization point is located at the design phase, which means that the design is not started until a client order arrives (Kachru, 2009).

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Due to this close interaction with the client, the ETO production systems results in a dynamic, uncertain and complex environment (Bertrand and Muntslag, 1993). Understanding the peculiarities of this kind of production system is important to conceive planning and control systems that are capable to cope with the high level of complexity involved. Logistics management is a critcal factor in companies that deliver ETO prefabricated components, because it usually requires controling different project phases, such as design, fabrication and assembly, in a multiple project environment. The delivery of each project often affects the others due to the need of sharing resources, while requiring distincts information and raw materials, and demanding different levels of interaction with the client. In the construction industry, ETO prefabricated building systems have an extra difficulty: the final assembly needs to be carried out in a constuction site. This often means that there is a complex interaction between building subsystems, delivered by separate companies. Moreover, each project has its own requirements for loading and must be delivered in different location and in different site conditions.

In some ETO suppliers for the construction industry, planning and control are normally carried out by each production phase (design, manufacturing, logistics and assembly) as isolated and disconnected processes, increasing the project lead time (Elfving et al., 2004). The fragmentation and suboptimization of each production phase tend to affect the downstream flow, making the assembly less reliable due to delays in the delivery of components, and also to the need solve problems related to the poor integration of components (Tommelein, 1998). It is common to have the construction sequence being defined by the fabrication process with the aim of freight optimization, resulting in large production batches (Matt et al., 2014). Process transparency is necessary between manufacturing and assembly processes, in order to make the former understand the needs of the different projects and plan better its production based on a confirmed demand (Čuš-Babič et al., 2014).

Logistics management plays a key role in this environment (Hicks et al., 2001). A delay on delivering components on the site causes an increase on the assembly time and can result in contract penalties, while the early expedition of deliveries increase the storage cost, and handling components efforts on site, affecting company profits (Čuš-Babič et al., 2014).

This investigation is part of a broader research project on logistics management, developed in partnership with a company that designs, fabricates and assembles steel building systems on site. Steel building systems typically involve a large number of components, and some of them need to be preassembled on site. Each batch required a wide variety of heavy components to be fabricated, or bought and delivered at the same time to the construction site.

Ronen (1992) claims for a complete kit of products to start the production, without which there will be different problems such as an increase on work-in-progress (WIP) levels, on lead time, problems of quality and rework. In ETO environments, it must be considered that there are different project stages (design, fabrication, logistics and assembly) and the focus should be on producing complete kits in all those stages, considering the requirements of the downstream process. In order to adopt a pull production strategy for fabricating or designing according to the site needs, there is a need to consider those factors. The adaptation of the pull-system for non-repetitive and complex production environments should be based on the WIP control. For Hopp and Spearman (2004), controlling a low-level of WIP brings most of the benefits of a pull-system. The aim of this paper is to presents the preliminary results of an investigation which aims to devise a method for controlling work-in-progress in ETO prefabricated building systems, through the discussion of the loading plans role in controlling WIP.

RESEARCH METHOD

Design Science Research was the methodological approach adopted in this investigation. This approach is concerned with devising artefacts that serve human purposes, such as methods, models, and guidelines (Van Aken, 2004). The design science is understood as a model of knowledge production, and the action research as one of the possible ways to achieve this type of knowledge production. Cole et al. (Cole et al., 2005) highlight the synergies between both approaches and argue that design science research benefit from the mature body of evaluation and other criteria of performing action research.

The research process was divided in three main parts. The first consists of understanding the existing situation of the company, which has been involved in research projects with the Federal University since 2011. The second part refers to the implementation process, in which different cycles for devising, implementing, and evaluating a solution took place. The third part refers to the development of the final method, which is out of the scope of this paper.

The implementation process lasted 8 months, when the main researcher made weekly visits to the company. A wide range of sources of evidence have been used during this period, such as semi-structured interviews, document analysis, participant observation, direct observation, and analysis of existing databases. The implementation process was made possible thanks to the participation of the manager of the logistics department, who were willing to make some structural changes in the company processes. For this reason, the implementation process was based on action-research, to collaboratively develop the solutions.

The analysed company is the largest steel fabricator in Brazil: it had more than 2000 workers, three manufacturing plants, around 200 simultaneous contracts, and an annual revenue around $300 million dollars. It is divided into three different business units: (a) light steel structural systems for warehouse and industrial buildings; (b) high rise buildings; and (c) heavy structures for bridges and off-shore platforms. This study is focused on the operations of the first one. The main production processes under the scope of the company are the design and engineering of components, fabrication, and site assembly of steel building systems.

RESULTS

EXISTING SITUATION

Since 2006, the main director of the first business unit has started to lead a program for implementing lean production concepts and methods throughout the company. One of the most important changes made in the company as a result of that program was the reduction of batch size, by dividing a project into stages. Each stage is also broken into sub-stages, which contains a set of specific products that can be assembled independently. The aim was to control design and fabrication based on those sub-stages, after the conceptual design is approved by the client. The manufacturing plant has a lower level of control, which was called packing-list (PL). PL is a set of similar materials that can be put in sequence in a machine to be produced – it is a subdivision of sub-stages for fabrication reasons. As the sub-stage is a batch configured for assembly needs, it will be called as assembly batch.

One important characteristic of the contracts, which affects the planning and control system, is the payment conditions. In general, when a project is sold, a deposit of around 7% is required. The second payment, is made when the materials are shipped to the construction site summing up 75% of the project, paid according to the amount of materials delivered. The remaining 25% is paid as long as the stages are assembled in the construction site. This contractual rule creates an incentive for the company to increase work-in-progress, by producing the heavier components first, although it is the final building that is sold to the client. While the division in stages and the establishment of an assembly batch for all production phases were important steps toward a focus on the final product, the production phases were still encouraged to produce in volume.

Despite the decision of dividing project into stages, the most important metrics currently used for different production phases were based on the weight of components designed, produced, transported and assembled, leading to a strong focus on the utilization of capacity. However, the nature of each production phase requires a different batch for production (Figure 3), which means that each phase would improve weight metrics differently. The establishment of an assembly batch was an attempt to standardize those differences, making the company as a whole to consider the demands of the final production phase. The assembly batch should work as a transfer batch, with the aim of reducing work in progress.

The output of the design development phase was the project as a whole, except in the case of large projects in which drawings could be delivered as a package for each building. The detail design refers to the detailing of each steel component, so each team used to work in a specific set of products of the project, such as structural elements, roofs, and closing elements, including all the components required for the assembly of those products.

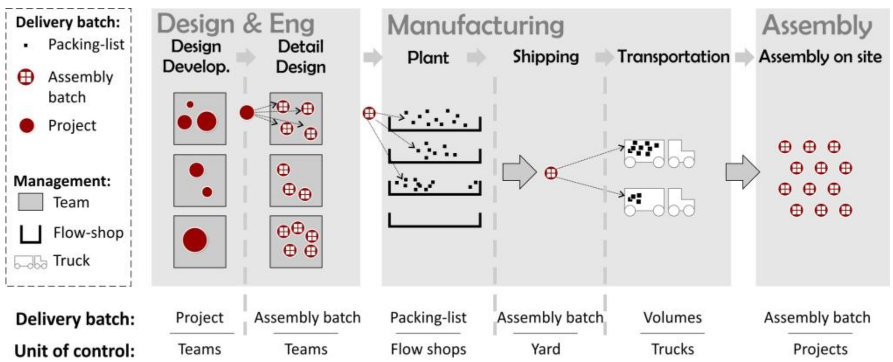

Figure 3. Different batching processes

The fabrication plant, in turn, was divided in flow shops specialized in one or a small set of product types. For that reason, each batch was divided into packing lists. Different packing lists from the same assembly batch should be produced by different flow shops. The production planning and control system of the plant used to be based on the maximum utilization of capacity. Therefore, the plant manager would rather put similar PLs from different projects in sequence, instead of sequencing different PLs from the same project in order to finish it earlier.

The plant yard used to receive the ready components, which could be organized in individually or in a package of components, depending on the size. At that moment, the products were organized in the yard according to the product type to wait the completion of the assembly batch. After the assembly batch is manufactured, the shipment process is able to start. However, in most cases, it is not possible to ship a complete assembly batch in one truck. For that reason, in the loading process, components are organized according to the package made after production. Lastly, at the construction site each truck load should wait for the completion of the batch delivery before starting the assembly process. Deliveries and measurements at this phase are based on the assembly batch completion.

All those different batches, associated with the incentive on weight metrics were causing high levels of inventories at the plant yard and at the construction sites. The shipment department manager would struggle to send any fabricated component, regardless if it was from a complete batch or not. This practice was leading to material handling challenges, making it hard for the site manager to know if everything required for the assembly process was already there. Therefore, the company’s director implemented a rule in the ERP system that would avoid shipping components from a not fully fabricated assembly batch. This rule could only be broken with the permission of the company’s director.

The use of a metric based on tonnages produced encouraged managers to focus on maximum utilization of capacity. This was true for the design and engineering process, the fabrication process, and even for the transportation process. Simple components were detailed first; heavier components were fabricated and shipped first. However, the construction site could not benefit from this as they received incomplete batches for the assembly process. This maximum utilization strategy led to high levels of work-in-progress (WIP) – open batches from different projects under production, as shown by the inventories in the plant yard (Figure 4), in terms of number of batches. The level of inventories also shows that some of the complete batches were not ready to ship, because of some bureaucratic reason.

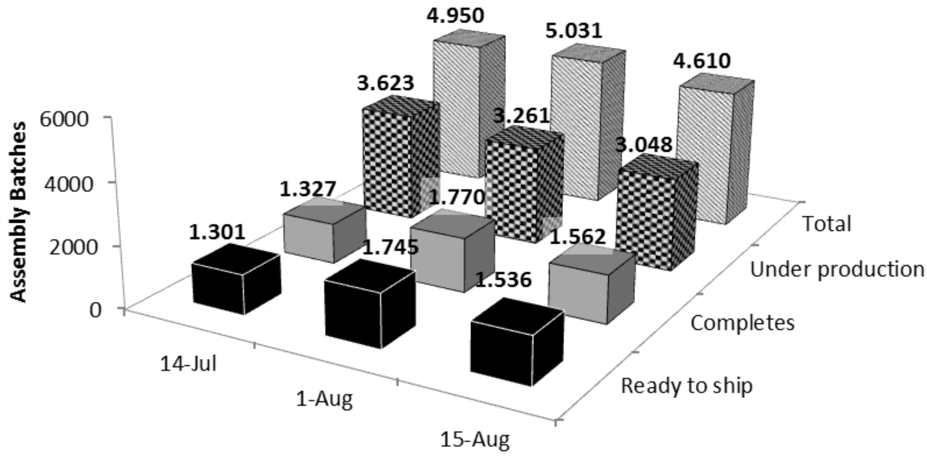

Figure 4. Inventories in the plant yard

IMPLEMENTATION PHASE

The existing scenario revealed the need for a different understanding of the assembly batch. It emerged as a minimum batch for the assembly, as it encompasses the minimum number of column axes to build a section of the building that can be fully assembled. However, this basic rule was still broad, causing difficulties in the fabrication, packaging and shipping processes. An important aspect to manage production and controlling WIP in ETO systems is to understand how to manage nonstandard products. Caron and Fiore (1995) argue that the benefits of the problem of the traditional scheduling techniques can be overcome by using assembly kits for promoting a better logistics flow and controlling the level of WIP in the production units.

The development of the loading plans was the first step for understanding the assembly kits as a way to develop a method to control WIP in ETO prefabricated systems. The initial analysis was made in structural elements which were heavy components with different dimension sizes. This kind of load was hard to organize and were often the least optimized freights. Each load should contain the right amount of components to start the assembly process on site. This means that each assembly batch was divided into a sequence of truckloads. The first of them should containing all the auxiliary pieces from that batch, such as bolts, flanges, etc. The site manager should be able to start assembly without waiting for the second load.

The loading plans worked as an integrative tool, joining three sorts of information: the component dimensions and weight; the assembly sequence; and the shipping constraints. First, each structural component was sequenced according to the assembly requirements. Then, the loading plans were developed using plan views of the components, showing the position of the elements on each layer of the truck. In parallel with the drawings, a spreadsheet was fulfilled showing the key information for the components (name, site axis, size, place in the truck, and weight). Those spreadsheets were important both for the Logistics Department for planning the loads and for the defining the loading plan to ensure that each layer was lighter than the bellow one.

The development of each loading plan required a close interaction between the research team and the logistics team. This was important for creating learning cycles, in which the main decisions and conclusions were tested. The acknowledgement of the product constraints played a key role in planning well-defined batches. Figure 5 summarizes the main decisions taken during the development of the loading plans. It shows the main dimension and weight constraints of the components for the shipping process. This analysis was the first step to standardize the process for developing the loading plans. The singularities of each assembly batch were also identified but these are not discussed in this paper, due to limitations of space.

The loading plans were first implemented for a set of three sites. The site managers from those sites highlighted gains in transparency, which made it easier the identification and control of components, reduction in the demands for transportation equipment. In order to confirm the reported benefits, the company measured the impact of applying the loading plans in one site. In this case, there was a productivity improvement of 20% in the assembly process, comparing to the best productivity reported in historical data.

Although there was a clear positive impact on the assembly phase, the shipment process did not report similar benefits. There was an increase of 50% on the time required for loading a truck. One of the main causes identified for this problem was the fabrication sequence. As described earlier, the plant used to optimize production by focusing on reducing setup times instead of finishing assembly batches. The amount of components resulting from that strategy made it unfeasible for the logistics team to organize the yard by project. Therefore, each load requires components from different parts of the yard, which were difficult to find and demanded long distances of transportation. The amount of components a forklift transports was less than 5% of a truck capacity, which means that it would be necessary, at least, twenty displacements inside the yard to complete one loading.

Dimension		**Weight**	
Constraint	**Justification**	**Constraint**	**Justification**
The longest pieces must stay in the inferior part of the truck	A longer piece over a small could destabilize the loading causing serious safety risks	The weight of each layer must be considered (heavier pieces in the inferior level)	The center of gravity closer to the ground, increasing the charge stability
Avoid cantilever in pieces	A cantilever could cause shear failure	Centralizing weight inside the layer must be considered	The center of gravity close to the center helps prevent tipping
The arrangement of beams and columns must be done before the secondary parts	The secondary parts will be used to clamp the main pieces, which are heavier		
Beams and columns with the same height should be in the same level	Increasing the stability for the superior level decreases the time needed to adapt the wood supports and allows better distribution of the load on the truck		

Figure 5. Constraints for the loading plan development

When the loading was made without a loading plan, the logistics team used to take all the components they could find from the planned assembly batch, as there was no instruction on how to break it into a set of trucks. The problem to find components would only appear in the last load of a batch. Although the shipment was faster in this scenario, it causes different sorts of inefficiencies at the construction site such as difficulty to find the right components, increase on equipment costs, losses of components and, most of all, increase on assembly time.

DISCUSSION

The definition of the minimum number of components to start the assembly together with the site manager, revealed the possibility to reduce the batch size a little more. It is worth noting that it is not easy to define a minimum batch in this kind of production system, since the client needs to receive the complete building. Although it can be delivered in smaller sections, which were the stages of the project, and further detailed into assembly batches, the amount of work to be performed in one day of execution is even smaller than those divisions.

As highlighted by Laufer (1997), this kind of batching can be regarded as the overlapping of successive phases. The same author states that the key to the success of this overlapping process is to define a batch so that the subsequent and interconnected batches do not need to be redone. For this reason, the connection between the amount of work to be performed and the amount of components that fit a truck load is what define the minimum batch in this study. It is a matter of understanding the product and the load of work provided by a truck.

The problems highlighted in the use of the loading plans in the first phase, revealed that the plant scheduling process should incorporate this analysis, in order to avoid the need to spread the components along the yard and re-join them to attend a loading plan. Although each production phase may develop their own metrics based on their production nature, the establishment of a unified batch, adapted to the assembly process, is an important step toward the integration of the phases, WIP control and lead time reduction. If the transfer occurs through different combinations of components, it will cause a different ways to optimize the production that can lead to a negative impact in the overall process. By contrast, a unique batch encourages the synchronization within the production units and the communication between one another.

CONCLUSION

This investigation aimed to discuss the role of loading plans in the control of work in progress for ETO prefabricated building systems. In this phase of the research, it was possible to obtain a better understanding of the batch size, its impacts for the different production phases in this type of production system. It was observed that most of the losses and inventories could be avoided if there was a better coordination between the outputs from fabrication plant and the deliveries made by the logistics department. The following steps of this research project are related to changes in the fabrication sequence in order to attend site needs. This integration between the fabrication and the construction site plays a key role for making WIP control effective. The use of the same loading plans developed for the construction site to control the end of the flow shop is part of this challenge.

Nevertheless, the use of the proposed guidelines for loading plans in one of the company's products revealed some benefits for the assembly process on site, avoided the shipment of inadequate loads for site demands, and enforced the need for producing what is required by the site even if leading to a certain degree of inefficiency in the plant yard.

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