GUIDELINES FOR INTEGRATED PLANNING AND CONTROL OF ENGINEER-TO-ORDER PREFABRICATION SYSTEMS

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ABSTRACT

The industrialization of construction processes is an important strategy for improving quality and productivity in construction. However, the adoption of industrialized technologies does not necessarily have a high impact in the overall performance of the production system. In fact, most papers on the implementation of Lean concepts and principles in prefabricated building systems have focused on a particular stage of the construction process, such as design, prefabrication or assembly. This paper is concerned with planning and controlling engineer-to-order (ETO) prefabricated systems, in which a single company is responsible for designing, and prefabricating components, and assembling them on site. This paper reports the preliminary results of an ongoing research project that aims to understand how the assembly process at the construction site can pull the prefabrication of components in a context with high variability. It is based on a study carried out at a steel fabricator company in which an integrated planning and control model has been developed, involving design, prefabrication and site assembly. This paper presents a set of guidelines for devising planning and control systems in such an environment.

KEYWORDS

Last Planner System, prefabrication, pull production, engineer-to-order

INTRODUCTION

There is a growing trend of using industrialized components in construction projects in some emerging economies, such as Brazil. This is mainly due to the shortage of labour, and also for the need to improve quality and productivity. However the fact that an industrialized technology is used does not mean an improvement on the overall process (Koskela 2000). In fact, a common problem that exists in those initiatives is the fact that the improvements are implemented in a specific subsystem or in a particular stage of the construction process, such as design, prefabrication or assembly. Moreover, most implementations of Lean concepts and principles on

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prefabricated systems have not explored opportunities for improving the overall system.

The focus of this paper is on planning and controlling engineer-to-order (ETO) prefabricated systems, in which a single company is responsible for designing, and prefabricating components, and assembling them on site. It is concerned with the implementation of some core Lean Production concepts and principles, such as reduction of batch-size, reduction of work-in-progress, pull production, and visual management, as well as adapting the Last Planner System™ (LPS) to this particular context. Despite the success of LPS worldwide, It has been mostly implemented in site installation (Ballard and Howell 1994; Ballard 2000, 2003). There has been a much smaller number of few cases of implementation in the design phase (e.g. Hamzeh et al. 2009; Kerosuo et al. 2012), and prefabrication (Ballard and Arbulu 2004; Ballard et al. 2002), and hardly any in engineer-to-order prefabricated systems, considering the different production stages, from design to assembly.

This paper reports the preliminary results of a research project that aims to propose a planning and control model for engineer-to-order prefabricated systems, considering the need to integrate design, prefabrication and assembly. This investigation has been developed in partnership with a Steel Fabricator Company, from Brazil. A set of guidelines for devising integrated planning and control systems for ETO prefabricated systems has been proposed in this paper

ENGINEER-TO-ORDER PRODUCTION SYSTEMS

In engineer to order production system, the decoupling point is located at the design stage, so that each customer order penetrates the design phase of a product (Gosling and Naim 2009). From one hand the further downstream the customer order decoupling point (CODP) is positioned the larger the share of value-adding activities that must be carried out under uncertainty (speculation). On the other hand, the further upstream it is positioned the larger the number of activities that can be based on order commitment (Rudberg and Wikner 2004). In that case, the competitive advantage arises from the integration of internal processes (Hicks et al. 2001).

Engineer-to-order systems can become complex production systems. Williams (1999) suggests that there are two types of complexity in project management: (a) structural complexity, which depends on the number of elements and the degree of interrelatedness between those elements; and (b) uncertainty, related to the goals and methods of the project that can be unknown.

Bertrand and Muntslag (1993) emphasize the uncertainty of product specifications. Since the product has to be engineered, at the start of the project, some decisions such as capacity, lead-time, and price have to be taken under uncertainty. This kind of uncertainty may also lead to process uncertainty, as the machines required are also unknown. Bertrand and Muntslag (1993) also point out that the mix and volume of the future demand is also a matter of concern in ETO systems. This is concerned not only with sales demand but also with the moment of customer order intake, since a project quotation is usually asked before deciding to hire the company. The same authors also argue that this quotation means that a detail analysis of the production lead times and due dates is negotiated at the very start of the project and often cannot be changed, in spite of the level of uncertainty. This kind of uncertainty is related to multiple project environments, which has not been emphasised in the literature on complex projects (Williams, 1999). Multiple project environments also tend to be affected by additional sources of uncertainty. For instance, a bottlenecks within one project may have serious effects on other projects.

Regarding structural complexity, Bertrand and Muntslag (1993) emphasize the structure of the goods flow, consisting of physical and non-physical stages. The non-physical stage concerns the engineering, design and process planning activities, while the physical stage concerns the component manufacturing, assembly and installation of the machines (Bertrand and Muntslag 1993). The same authors emphasize that the creative character of non-physical stages makes it difficult to be formalized in sequential and clear-cut phases as it is usually done the physical stage. Bertrand and Muntslag (1993) also point out the assembly structure of enginnering-to-order products: since products may be one-of-a-kind, specific materials often need to be purchased for a particular project. If this sort of environment products have long delivery lead times. Figure 1 depicts the components of ETO system complexity, based on concepts proposed by Williams (1999) and Bertrand and Muntslag (1993).

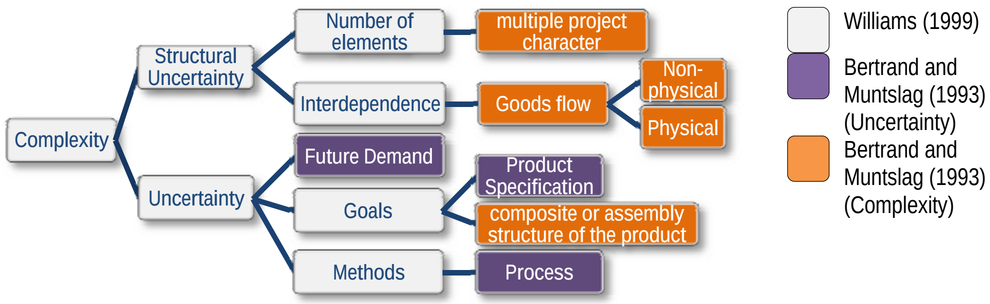


Figure 1 - What affect complexity in ETO production systems

PULL PRODUCTION

Although the idea of pull production is considered as one of the core concepts for implementing the lean philosophy (Hopp and Spearman 2000; Liker 2003; Rother and Shook 1999; Smalley 2004; Womack and Jones 2004), there are different points of view in the literature regarding the role of the client in the production system. LEI (2008) defines a pull production system when downstream activities sign their needs to the upstream processes, while a push system consists of processing of large batches of items at a maximum rate, based on a forecast demand. Each process produces either for a downstream process or for storage. By contrast, according to Hopp and Spearman (2000), the trigger for releasing the work is within the system itself, which means that the final customer is outside the process. In this perspective, a make-to-order or engineer-to-order product system can be considered as a pull system only if there is a control over the amount of work-in-progress within the system. In fact, Hopp and Spearman (2004) state that most of the benefits of pull production are the same of keeping a low WIP level. In this research work, this definition of pull system has been adopted.

Whatever the concept of pull production adopted, there are some other core ideas that are necessarily involved, such as: (i) batch size reduction or one-piece flow, in order to produce just what is needed; (ii) decentralized decision making; and (iii) lead time reduction, in order to keep throughput rate.

RESEARCH METHOD

The research approach adopted in this study is design science research, also known as constructive research. This approach is concerned with devising artefacts that serve human purposes, such as a method, a model, a set of guidelines (Van Aken 2004). Those artefacts should be assessed against criteria of value or utility (March and Smith 1995).

The research process was divided into two main phases. The first consists of identifying and understanding a practical problem in the company, while the second is concerned with devising, implementing, and evaluating a solution. At the end of the study the scope of applicability of the solution will be examined, and the connections to existing theoretical knowledge will be analysed. The implementation process has been developed with a strong participation and engagement of the managerial staff of the company, being very similar to an action-research investigation. There are learning cycles that involve five stages: diagnosing, action planning, action taking, evaluating, and reflection, as suggested by Susman and Evered (1978). A major difference with traditional action-learning research projects is that in this study there is clearly a prescriptive outcome, i.e. a production planning and control model.

A wide range of sources of evidence have been used in this study, such as semi-structured interviews, document analysis, participant observation, direct observation, and analysis of existing databases. Also, a set of four workshops involving researchers and company's representatives were carried out to discuss some key lean concepts and suggest some improvements in the system that would be evaluated in the following workshop. The aim of these events was to create discussion groups in order to provide a common understanding of concepts and practices.

DESCRIPTION OF THE COMPANY

The company is the largest steel fabricator in Brazil: it has more than 2000 workers, three manufacturing plants, and around 200 simultaneous contracts. It is divided into three macro processes (Table 1) and 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. In 2006, the company has started a program for implementing Lean concepts and tools in their operations. The implementation process started in one of the manufacturing plants. Initially, there were changes in the plant layout in order to create one direction general flow, although jobs are allowed to visit subset of work centers, enabling a certain degree of customization.

Table 1 – roles of the main departments

Main departments	Responsibilities
Design and engineering	Develop the conceptual design of buildings, and the detail design of components
Plant	Manufacture components
Logistics	Store and ship components
Assembly	Assemble on site

Another important change was the batch size reduction, by dividing projects into stages, as shown in Figure 2. Each stage is also broken into sub-stages, which contains a set of specific products that can be assembled independently from the other ones. Design and production control is mostly based on those sub-stages, after the conceptual design is approved by the client, including the logistics and assembly. The company has also implemented the Last Planner System ™ first at the assembly process and that at the design processes. Besides improving planning reliability, this implementation pointed out problems in the assembly process caused by upstream flows, such as in the fabrication or delivery of components.

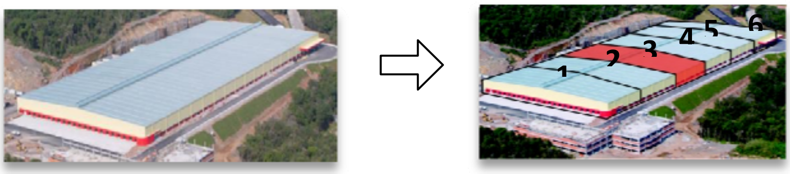


Figure 2 - Reduction of batch size by dividing the building into stages

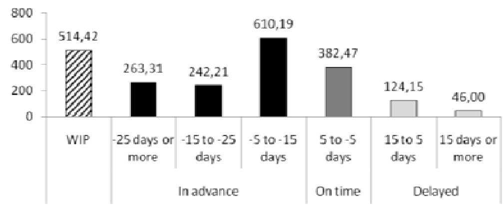
EXISTING PLANNING SYSTEM

There is a planning department in the company that is in charge of producing long-term project plans, from design to the delivery of components on site. One of the main roles of this department is to define the monthly target for design, manufacturing, and assembly. A distinct department is responsible for planning and controlling the assembly process. There is also another department responsible for monitoring what is produced, sending invoices to clients. At the medium and short term planning level, planning tends to be decentralized.

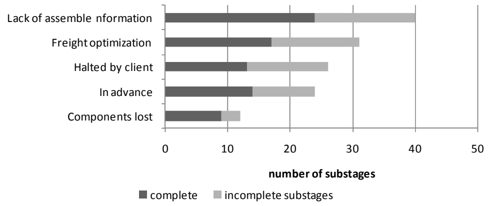
As mentioned above, the Last Planner System™ has been partially implemented in both design and assembly, and a similar planning and control system is in place at the manufacturing plant. However, there is a lack of integration between all those planning and control instances (design, manufacturing and assembly), and between them and the departments involved in long term planning. As a result, despite the high uncertainty in the assembly process, the main source for planning the design and manufacturing activities is the project master plan. Therefore, the existing planning approach is top-down and the production system is predominantly pushed.

Despite the decision of reducing the batch sizes at all stages, several metrics were still defined in terms of steel tonnages. This is mostly due to the fact that the monthly targets for design, manufacturing, and assembly were all defined by using this type of metric, as well as the turn-over of the company. This approach has traditionally made all company departments to be more concerned about the amount of tonnage has to be produced than the specific type of material that is needed. Before the implementation of the stage and sub-stage units of planning, heavy weight components, such as columns and beams, would be sent to construction sites without the small components that connect structural components. The company has decided to create a lock in the system to avoid this kind of problem: components could not be shipped if all the components of the respective sub-stage have not been produced.

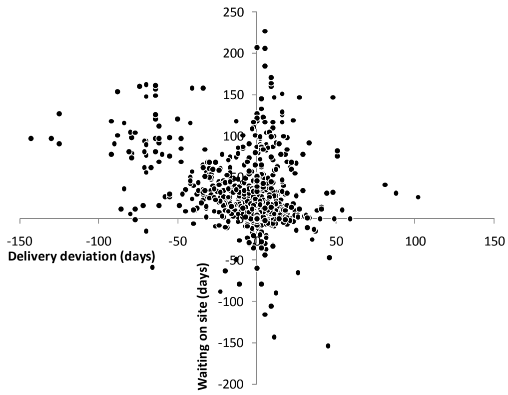
During the diagnosis stage of the research study, the amount of inventory at the plant yard was monitored during a month period. There were 2.500 tons of materials waiting to be shipped to construction sites. Figure 3 shows that the majority of the components stored were produced in advance, and that the lack of information from the assembly process was a major cause for the high level of inventory. This analysis refers to the components that were in the yard for more than 20 days.



(a) How long in advance



(b) Causes for the anticipation



(c) Impact on construction site

Figure 3 – analysis of the work-in-progress of components

Since the client usually pays for the components that are delivered on site, there is much pressure to ship them in advance, if necessary, even if there is not enough space on site. As shown in Figure 3(c), 60 % of the sub-stages delivered on site waited for more than 10 days before being assembled.

PRELIMINAR RESULTS OF THE IMPLEMENTATION

The main focus of the first implementation cycles was to devise and implement a level of integrated multi-project planning that could establish a formal and systematic connection between different project stages. At the same time, the company defined planning and control models strongly based on the Last Planner System™ for the design and assembly processes. There was also an effort in terms of improving the performance measurement system in terms of using batch completion, rather than tonnages, as the main metric for assessing the achievement of targets, as well as making the metrics from different project stages more comparable. A set of guidelines was established for guiding this implementation process. These are presented bellow.

IMPLEMENTING COLLABORATIVE AND DECENTRALIZED PLANNING AND CONTROL

Due to the high level of uncertainty, it was important to avoid centralized decision making, so that each department had both short and medium term planning and control processes. This was a mean to have more participation from the operational level, and also to understand problems that were hindering production. These are requirements for pulling production in an environment of much variability from demand. In this sense, it is important to emphasize that in this environment it is not enough to control the amount of work-in-progress. There is a need to confirm the need for execution at several control points along the product development process.

By adopting the Last Planner System™, it is possible to create basic stability, and establish short term learning cycles, at different project stages: design and engineering, prefabrication plant, logistics and assembly. It was necessary to make an adaptation in the Last Planner System for this engineer-to-order multi-project environment. Uncertainties about product specification would hinder design and manufacturing plant departments to make a correct analysis of constraints. In some cases it was decided to make the look-ahead in a weekly basis.

ESTABLISH INTEGRATED PLANNING AND CONTROL MEETINGS

The aim of these meetings was to provide up-to-date information from both downstream and upstream processes so that monthly targets for different project stages could be adjusted. This could be considered as confirmation points of the orders placed at the master schedule, in which projects halted or waiting for decisions from the client would be taken out of the monthly target. By contrast, some construction sites that had available resources earlier could be expedited in relation to the master schedule. The aim is to adjust plans so that the manufacturing plant can fulfils the actual demand of the assembly process in different construction sites, in order to reduce work-in-progress, both at the plant yard and at the construction sites.

MAKE USE OF THE INFORMATION FROM ASSEMBLY IN A SYSTEMATIC WAY

The introduction of an integrated planning and control instance would be useless if there was no reliable information from the assembly process in construction sites. As assembly is the very last process in the chain, and some of them are far away from the headquarters, it is important to have effective initiatives for improving the flow of information from assembly to manufacturing and design.

A regular meeting, named prioritization meeting was redesigned in terms of scope of decisions and information demanded. This meeting started to be held twice a month. Aggregate information from all construction sites should be brought in order to provide an overview of the changes in demand. This effort involves the planning department and the project managers, who should provide up-to-date information about the status of the sites. The most important source was the status stressed in Table 2.

Table 2 – Defining assembly status

Status	Meaning
Should be anticipated	Construction site is full of resources and is able to receive and to assemble the components before the predetermined dates.
Can be anticipated	Meaning that there were available resources, such as teams and yard to store material, but the due dates of the assembly process are not going to be anticipated.
Respect schedule	The assemble process is going to respect the due dates and has no room to store material produced in advance.
Do not produce	there are some contract issue with the client and the materials should not be produced

This categorization changed the way in which targets were established. The decision was made to have a status “can be anticipated”, with the aim of increasing the level of utilization of the plant. Those parts are then produced in advance by ensuring, and, if possible, delivered to the site so that the client could be billed. However, it also provided opportunities to expedite the conclusion of some projects, by reducing the total the lead-time.

MAKE USE OF SHORT-TERM PLANNING INFORMATION AS A CONFIRMATION POINT

There was also a need to create confirmations points in order to provide a link between the monthly targets and the actual production short-term goals. The previous step established a strategic confirmation of the master plan to the definition of the monthly target. However, this was not enough for really shielding production, since the monthly look-ahead plan of each department was not effective, and there were difficulties in terms of adhering to the target. So the decision was made to have a short-term integrated control meeting, to check if each department was producing what is needed for the following period. One representative of each department (engineering, plant, logistics and assembly) is supposed to participate in this meeting, held weekly, in order to discuss what have been their focus and what should it be.

USE VISUAL MANAGEMENT TOOLS

The use of visual management board helped to develop this level of control, by providing an overall view of existing orders, and their status. The demand to use visual management tools emerged from a group of managers themselves, who wanted to the existing problems to appear for everyone. Figure 4 presents a set of visual tools that have been used in each department, and the integrated control board that gathers information from each department.

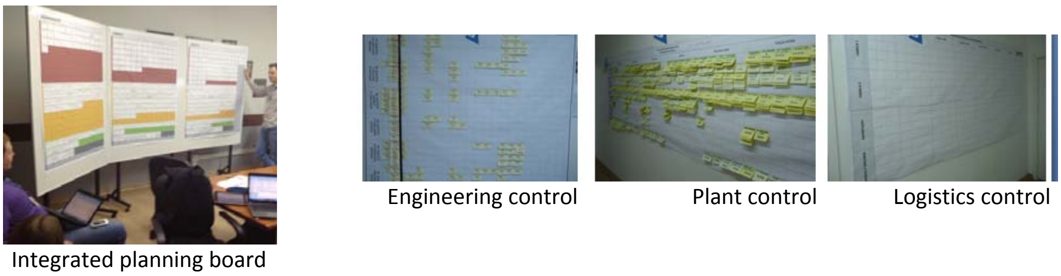


Figure 4 – Visual management boards and the integrated instance

The integrated control board contains four important information for each department: (a) urgent sub-stages, including batches that are late or that should be produced earlier than scheduled; (b) feasible goals that are established in the monthly target (master schedule); (c) batches that can be produced, consisting of a backlog of products based on the position given by project managers about the construction site status; and (d) the ones that should not be produced regardless the master schedule. This became an important source for look-ahead planning at each department, focusing on downstream information from assembly. The board was updated once a month according to monthly targets, twice a month with the information from the prioritization meeting, and weekly with information from the short-term integrated control meeting.

DEVELOP PEOPLE CAPABILITIES

The last guideline is concerned with making people capable to understand the concepts behind routine procedures. Even after a standard procedure is changed or created, if people involved do not understand the concepts underlying it, they are will not be able to adopt is correctly. For that reason, workshops and training courses were carried out in this research project for people involved in the implementation process. In some of them, some core production management concepts and principles were emphasized. It was also important to discuss their application in daily activities to ensure that the contents had been learned and were useful for the company. Although some changes have not been easy to introduce, due to the complexity and scale of operations, the discussions and the decisions made by the company indicate that such effort has been effective.

CONCLUSIONS

The aim of this paper is to establish some guidelines for enabling pull production in a complex engineer-to-order environment. The implementation process was the basis for the discussion of the guidelines since they emerged from this process. There were some important contributions regarding the different ways last planner can be implemented. Even though its underlying ideas were used, there was a need to adapt the system to provide a different look-ahead and another instance between the look-ahead and the master plan in order to be suitable for this context. While the look-ahead in each department with the learning cycles, it was not enough to make sure each department was producing what is needed at the end of the line.

Regarding the pull production, it will only be achieved in this production system with more reliable information about the construction site, here called the assembly process, and with a more rigid control over their work-in-progress. This paper is part of an ongoing research and the latter topic is a matter of further development. The guidelines suggested here were a useful starting point for enabling more reliable information of the construction site. The different confirmation points defined were important means to deal with the uncertainty that affects even what is really needed by the construction site.

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