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Procedia CIRP 17 (2014) 457 – 462
www.elsevier.com/locate/procedia

Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

Synchronization of the Manufacturing Process and On-Site Installation in ETO Companies

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Abstract

Traditional Engineer-to-Order (ETO) companies are typically engaged in the production of capital goods or building projects in the construction industry. While parts or assemblies are manufactured and pre-assembled in the factory, the completion and final assembly will be concluded on-site. In usual construction supply chains, manufacturing processes are disconnected from the installation on site and scale effects of large batch production and economics of transportation charges determine the assembly sequence on site. This fact requires from ETO companies in the future a close coordination and synchronization between factory and construction site. After years of research in the field of industrialization, prefabrication and pre-assembly in ETO companies, particularly the issue of Lean Construction on site was discussed in recent years. The ambitious objective of this research is to analyze and to improve the entire value chain to enable a more sustainable production system in construction. Thus, this paper focuses on the merging of manufacturing processes and installation on-site to realize a synchronous coordinated supply chain. The research was carried out and tested in practice in collaboration with several ETO companies in the construction-related industry.

Selection and peer-review under responsibility of the International Scientific Committee of "The 47th CIRP Conference on Manufacturing Systems" in the person of the Conference Chair Professor Hoda ElMaraghy"

Keywords: Engineer-to-Order (ETO), Lean Construction, Just in Time (JIT)

1. Introduction

Industrial production can be classified according to different market interaction strategies [1]: (1) Make-to-Stock, (2) Assemble-to-Order, 3) Make-to-Order and (4) Engineer-to-Order. Lean implementations are no longer limited to high-volume production and are becoming increasingly common at low-volume, high-variety non-repetitive companies, such as Make-to-order or Engineer-to-Order productions [2]. Companies in the Engineer-to-Order (ETO) sector are characterized by their complexity and customer specificity as well as by the uniqueness of their products [3, 4]. These ETO components are produced by fabrication shops, which sit squarely at the intersection of manufacturing and construction [5]. One of the major issues still needed to be tackled is unfolding the full potential of Lean principles in non-repetitive manufacturing environment [6]. While in the automotive or aerospace industry the application of Lean Manufacturing methods is common nowadays, the ETO environment is lagging behind these developments [7]. Recently also some research has been done in a high-mix small-lot size environment [8, 9]. The Egan Report [10] argued that Lean principles, such as standardization, Just in Time (JIT) and long term partnerships with suppliers should be adopted. In recent years especially the principles of industrialization and prefabrication of factory-finished elements have gained more and more acceptance in the construction sector [11]. Prefabrication of modular elements increased and led to a higher impact of work in the manufacturing hall of ETO companies [12]. In traditional ETO supply chains,

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doi:10.1016/j.procir.2014.01.058

manufacturing processes are disconnected from the installation on site. This is emphasized by considering tier one suppliers which produce and deliver their products to the site for assembly. Due to an unreliable on-site execution planning and an insufficient communication of on-site installation and off-site manufacturing, these two worlds often cannot be aligned in an optimal way. Therefore a JIT delivery of ETO components from production to the construction site is not possible. However, the JIT concept is one of the principles of Lean Production and nowadays also of Lean Construction.

This paper describes a concept, which was elaborated and implemented within an industrial case study. The case study treats the expansion project of the central hospital of Bolzano in North Italy. The concept focuses on aligning the manufacturing and construction process for ETO components.

2. State of the art in off-site production and on-site installation in the construction industry

Manufacturing provides the elements from which buildings, bridges, façades and houses are constructed. These Make-to-Order products are produced by fabrication shops [5]. Several concepts emerging from the manufacturing industry have in later years been successfully adapted in the construction industry. In the following sections the state of the art of those concepts in ETO companies and on the construction site will be shown.

2.1. Industrialization in ETO and Lean Construction

In the construction sector one of the areas of industrialization that holds potential is the prefabrication of systems and components. This includes building panels and modules that can be undertaken in manufacturing plants under controlled environments and then transported to various sites for quicker assembly. On-site factories, automation and robotization of various tasks represent other avenues of development. The vision is to combine advanced manufacturing in factories and on construction sites trough an Industrialized Construction [13]. An Industrialized Construction would increase the value-adding activities during production and, to a large extent, eliminate the non-value-adding activities such as waiting times, transports or controls. The construction industry is also in the process of adopting this approach to industrialization [14].

Three main principles underpinned the industrialization of construction: standardization, prefabrication and systems building. Standardization of building components was a perquisite for their production under factory conditions (prefabrication) which – together with dimensional coordination – enabled the growth of systems building [15].

The approach of Industrialized Construction requires total synchronization on construction, manufacturing and design processes. It needs emphasis on rationalization, standardization, repetition, collaboration, supply chain partnering and more effective planning and project management [16].

In recent years, in addition to Industrialization the concept of Lean Construction has increasingly gained in importance. The most important core element of Lean Construction is waste reduction [17, 18, 19, 20]. A related aspect, crucial for waste reduction in Lean Construction, is efficient transportation and stockholding of material, often termed JIT delivery [19, 21, 22]. Another central aspect of waste reduction is off-site manufacturing of components and units [23].

Approaching production management through a focus on processes and flow of processes is a core element of Lean Construction [20]. The Last Planner System is a key aspect that enhances efficient production planning and control [22, 24, 25]. Last planners prepare weekly work plans to control the workflow, and if assignments are not completed on time, they must determine the root cause and develop an action plan to prevent future failures [26].

Cooperative relationships among the supply chain actors are an important element of Lean Construction [22, 23] facilitating the integration of different actors’ competences and efforts in joint problem-solving. Due to changing customer-supplier relationships, the requirements of the involved crafts are unknown among the participants. This often causes high coordination costs in construction projects [27].

2.2. Capacity regulation in manufacturing

In manufacturing a control loop steers the performance of a working process. According to the Value Stream Engineering approach (VSE) the flexible use of human resources is of primary importance [28]. At the consuming process the quantity of needed components is measured and then visualized at the producing process (controlled variable). The control loop can adjust the work capacity (correcting variable) in a certain range.

Push systems are those where production jobs are scheduled, whereas Pull systems are those where the start of one job is triggered by the completion of another. In Push systems, like material requirements planning (MRP), an error in demand forecasts causes bullwhip effects. However in JIT ordering systems, amplifications are avoided because the actual demand is used instead of the demand forecast [29].

Two types of JIT ordering systems are generally used for supply chain management.

The KANBAN system was developed by the Japanese automobile manufacturer Toyota [30]. Pull production controlled by Kanbans requires a steady part flow. However production in high volumes contradicts the fundamental principle and JIT performance objective of Work in Process(WIP) minimization [31]. In the construction industry production lines which produce many different parts face serious practical problems adapting a KANBAN system. There simply isn´t enough room to have a standard container of each part number present, and even if there were WIP levels would be higher than necessary [32].

A system that could solve the previous mentioned problems is called CONWIP (CONstant Work in Process). This system possesses the benefits of a Pull system and can be used in a wide variety of manufacturing environments. The so called backlog allows explicit control over which parts are produced and in which sequence, and WIP is not maintained for each part number. A CONWIP production line sets the WIP levels and measures throughput [32]. WIP is directly observable while capacity which is needed to appropriately release work in a push system must be estimated. In a CONWIP system, the cards pass through a circuit that includes the entire production line. A card is attached to a standard container of parts at the beginning of the line. When the container is used at the end of the line, the card is used and sent back to the beginning where it waits in a card queue (backlog) to eventually be attached to another container of parts. The card priority used in the backlog is "first in system first served" (FSFS). The only exception is rework which is given the highest priority [32].

3. Synchronization of manufacturing processes and on-site installation

The construction industry is generally considered as being someway behind those sectors where effective supply chain management is regarded as key to gaining competitive advantage and dealing with the need to constantly improve operations to satisfy the increasingly sophisticated demands of end users [33]. Such views are reinforced by Arbulu et al. [34] and Fearne and Fowler [21] who found that most existing construction supply chains have structural features that are far from optimal from a production standpoint due to the essential discontinuous and transient supply relationships that exist in this sector. Moreover, the construction sector is characterized by a lot of unpredictable (non-plannable) events more than other industries, which impede an optimal synchronization.

3.1. Concept for aligning manufacturing to the construction site

Since supplier lead times are, for the most part much greater than the possible accurate foresight regarding work completion, JIT delivery of ETO components from production to the construction site is not possible. In Fig. 1 the concept for aligning manufacturing to construction is shown. Here, ETO components are released from the construction site within short time intervals. The last production process (assembly) sets the decoupling point from manufacturing to construction. To reduce the production lead time, components are prefabricated and stored in a lean manufacturing supermarket.

As soon as the construction site is ready for installation ETO components are released from production (assembly).

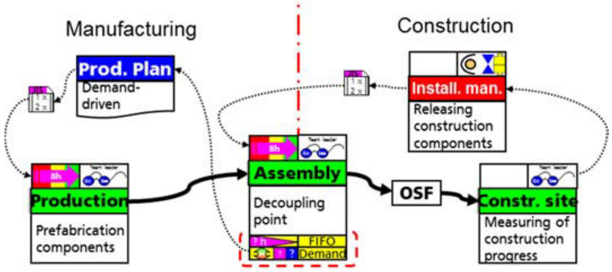

Fig. 1 Double control circuit for delivery requests from site

This is done based on a detailed measuring of the construction progress on site.

As explained in [17] production is pulled from the building site allowing so to eliminate intermediate stocks. As a result a continuous flow One-Set-Flow (OSF) of ETO components from manufacturing to the installation on-site becomes possible. As described in [17] according to the VSE approach the trigger for starting production should be connected with the construction site. In Fig. 1 two control circuits are shown, one for triggering the pre-production of ETO components and the other for releasing the finished components (according to the construction progress) by triggering the final assembly process.

As explained in section 2.2 this concept stands for a PULL system because at the consuming process (construction site) the quantity of needed components is measured and based on this, production orders are authorized. So, Production Planning changes from scheduling (forecasting) to a demand driven organization of production orders.

3.2. Alignment of production performance with on-site installation

In section 3.1, a control loop for steering the manufacturing and the construction performance for tier one suppliers, which produce and deliver their products to the site for assembly is described without considering a capacity adjustment between production and construction. In construction supply chains the building site stands generally for the bottleneck process. As described by Spearman et al. in [32], a CONWIP system with the correct number of cards will maintain just enough WIP to keep the bottleneck busy. If production orders begin to pile up behind the bottleneck, then cards will not be carried to the end of the line and new production assignments will not be authorized. On the other hand, if the bottleneck is finishing very quickly, then cards will be recycled quickly [32]. Adapting this to construction supply chains means that if installation (construction) performance decreases, due to unpredictable events (like weather conditions), production performance will be decreased without filling inventories. Otherwise, if installation performance increases on site, due an improvement in efficiency (like learning curve effects) the production performance follows it avoiding construction stops. The difficult part here is to define the backlog for production authorizations considering the sequence according to the assembly on site and a parallel integration of different construction sites (Multi-Project Management).

3.3. Sequencing manufacturing for an ideal installation on site

Normally, production strategies determine the installation sequence on the construction site. Scale effects of large batch production and economies of transportation charges determine the assembly sequence on-site. This means that production planning is done without considering if an immediate installation on-site is possible. So, finished good buffers arise which create problems especially in urban areas where space for storing material is scarce.

For planning in a detailed way the building execution process a methodology called Integral Building Execution Planning (IBEP) was developed [27]. Using this methodology for every task on-site suitable information like the responsible craftsman (i.e. the electrician), the number of "Pitches", the number of workers executing the task, and the location (construction section and level) is recorded (Fig. 2).

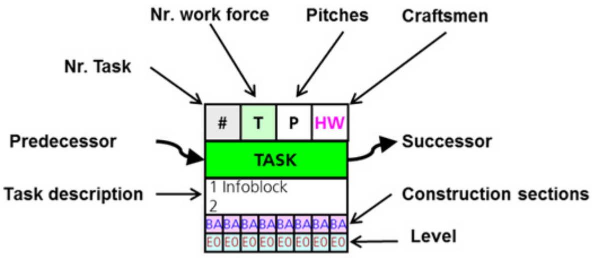

Fig. 2 Detailed IBEP-Network Planning description

As explained in [27] the quantity of "Pitches" determine the job content for a craftsmen-team in one specific time interval (day or week) completing it in a defined construction section. Planning and measuring with units of "Pitches" within small time intervals, allows measuring in a detailed way the construction performance on-site.

A peculiarity of construction is the high variability or unpredictability of future events. So, a static long time scheduling of construction works cannot be used for coordinating the construction site and for aligning the manufacturing of ETO components. The concept presented in this section combines the bill of material to the working process (task list) on-site. Furthermore the planning of construction works and the sequencing of part numbers is based on a Rolling-Forecast (Fig. 3).

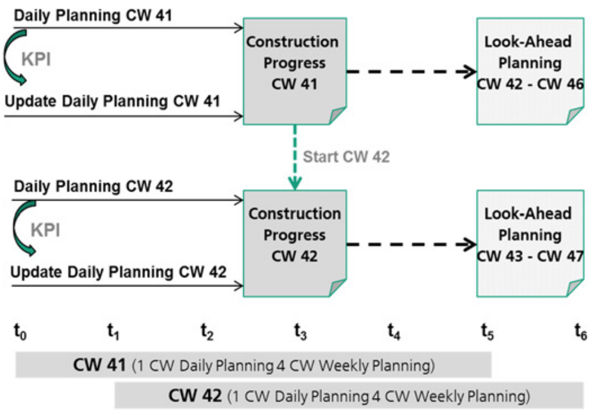

Fig. 3 Rolling Planning for aligning manufacturing with construction

The installation process of ETO components on-site is planned in a daily granularity. At the end of the week an update of the planning is done by recording the effective realized tasks within the construction sections. So, measuring in an accurate manner the construction progress on-site becomes possible. In the concept, based on the detailed construction progress a Look Ahead Planning for 4 calendar weeks is done. The Look Ahead Planning is done in a weekly time interval and is needed for triggering the prefabrication of components which are than stored in a supermarket (Fig. 1). As explained in section 3.1 the supermarket is needed for reducing the lead time for ETO components. So a short-term release of ETO components from construction to production becomes possible.

4. Implementation in an industrial case study

The case study is going on within the research project build4future which is composed of 12 small and medium sized enterprises (SMEs) situated in the province of Bolzano. It treats the expansion project of the central hospital of Bolzano in North Italy. The enlargement project consists of an additional erection of a new clinic and stands currently for the biggest construction site in the region.

The enlargement project consists over ground of tree wings (A, B and C) with respectively four levels, a north-wing with respectively three levels and a new entrance area (Fig. 4). One of the build4future partner-companies Frener&Reifer GmbH (F&R) realizes as leader company in a bidder-consortium the facades of the tree wings (A, B and C). The construction site was launched by the bidder consortium at the end of April 2013.

The case study consists in implementing the previous described methodologies for manufacturing and installation within the company F&R.

Fig. 4 Enlargement project hospital of Bolzano

4.1. Case study objectives and procedure

The primary objective of the implementation project is structuring and rationalizing the façade installation process. Most of the non-value-adding activities (like waiting times) are caused by an interruption of construction due to a lack of material on-site. Moreover, an alignment of manufacturing and construction should help to control the WIP level in manufacturing and construction.

In weekly meetings the previously explained research arguments are implemented in practice with the responsible employees of F&R – production planner, project manager, production manager and site manager.

Fig. 5 Network planning workshop with experts from F&R

4.2. Sequencing the manufacturing process

First of all, based on the IBEP methodology the network planning for the façade installation process on site was performed (Fig. 5). A detailed description of the IBEP-implementation is not presented in this paper avoiding a deviation of the central theme.

Information like the task sequence and the job content for the installation process were tracked. Furthermore, special emphasize was set for tasks which request a prefabrication of ETO components in the fabrication shop of F&R.

Based on this, critical components for disturbing a fluent installation process were picked out and analyzed more in detail.

4.3. Process engineering for aligning production to construction

In Fig. 6 the process engineering for one ETO component (aluminum frames) is shown. Here, the concept explained in section 3.1 for aligning manufacturing to construction was discussed with the responsible employees.

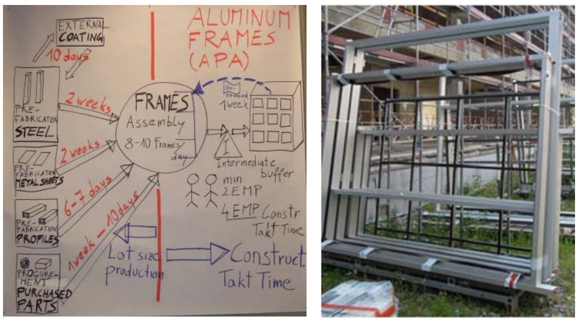

Fig. 6 Process engineering of critical ETO components

Within this workshop critical ETO components, like the aluminum frames, were further split in sub-components. For these sub-processes, like the pre-fabrication of steel components, the pre-production of metal sheet components or the procurement of purchased parts, the average lead time was recorded. Furthermore, as explained in section 3.1, the trigger point for pre-fabrication and for releasing ETO components from the construction site was defined. Considering the case of the aluminum frames the pre-production should be triggered 5 weeks before installation which allows then a weekly release of ETO components from site. To synchronize the pace of production with the pace of installation on-site a capacity alignment was done.

4.4. Capacity regulation for the fabrication shop and on-site installation

As explained in section 2.2 a CONWIP system sets the WIP levels and measures throughput. This is very important for the construction sector, because place for storing material is always scarce, especially in urban areas. In Fig. 7 the intermediate buffer for the construction project hospital of Bolzano is shown.

Fig. 7 Intermediate buffer – construction project hospital of Bolzano

The concept for aligning manufacturing and construction consists that the construction foreman plans the working process for the next time interval (i.e. one week) and at the same time he releases the needed ETO components from the fabrication shop. This means that production planning is based on formula (1):

$$\begin{aligned}&\text{ProductionPlan} =\\&\text{Installation Need}\,(CW+1) + \text{Traget Stock} - \text{Minimum Stock}\end{aligned} \quad (1)$$

Considering the case of the aluminum frames the construction foreman plans at the end of CW 40 to install 60 aluminum frames in CW 42 (12 each day) – for installing them in the fourth and third level of wing A. During CW 41 the pre-production of the aluminum frames will occur. At the end of CW 41 (Thursday) the construction foreman plans the daily installation process of CW 42. The installation of 12 aluminum frames for Monday CW 42 and for Tuesday CW 42 will occur. Therefore on Friday CW 41 one container transport quantity of 24 aluminum frames will be assembled and shipped on Monday morning to the construction site for installation.

In CW 42 the reordering of one container transport quantity will be done based on a minimum stock level. This, to handle the high variability of installation works on site.

5. Impact of the approach

Traditionally one of the major causes of budget overruns is the lack of ETO-components on site which causes wasteful construction downtimes. When construction interruptions occur, a change of scheduled tasks on site takes place, which leads consequently to rearranging materials or equipment on site (non-value-adding activities). Aligning manufacturing to the site could first of all avoid such non-value-adding activities. Furthermore by reducing the manufacturing lot size non-value-adding operations (like searching components on-site) could be avoided and the chances for early detection of quality problems could be improved.

Last but not least by pulling manufacturing from site a higher degree of capacity utilization (in manufacturing and on-site) could be reached.

6. Conclusion and outlook

In usual construction supply chains, economic benefits of a project reached through scale effects in production, are lost due an inefficient installation process on-site. Keeping WIP levels low helps to avoid non-value-adding operations. However, the backlog sequence is the critical issue for using a CONWIP system for aligning production to the construction site. Handling the high variability of construction processes and considering a multi-project environment are the future research challenges presented in this paper.

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