Synchronization of Engineering, Manufacturing and on-site Installation in Lean ETO-Enterprises

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Abstract

In the past few years and decades there have been major efforts to optimize production by methods such as Lean Manufacturing. After introducing these methods with success in the production area, the Lean philosophy spilled over to other areas such as administration, healthcare or even the construction industry. Especially with Lean Construction helpful methods were developed to reduce waste in the organization of the installation work on-site. Many industrial companies, particularly from the Engineer-to-order (ETO) sector, have great difficulties to interlock with each other the areas of engineering, manufacturing and installation on-site. Thus, this paper describes a holistic Lean Enterprise approach to avoid waste in the whole process by synchronizing all activities throughout engineering, production and the execution phase on-site.

Keywords: Lean Manufacturing, Lean Engineering, Lean Product Development, Lean Construction

1. Introduction

In Engineer-to-order (ETO) typically, small production volumes and a huge variety of unique parts must be managed in a project. ETO projects usually start with a design stage where the projects have to be engineered and developed. In a next realization phase, the engineered elements have to be realized, assembled and put into operation. Not infrequently, this realization stage is split into a realization in a job shop and an installation on the construction site. Examples are façade builders, shipyards or steel fabricators.

The synchronization of manufacturing and engineering is crucial for companies in the engineer to order or the make to order environment [1]. Companies in the ETO world have different requirements than other industries. Designing and building complex products to exact customer specifications frequently involves long lead times and heavy engineering content. Often, you will not receive payment for a project until it is installed and operating at a customer’s site [2]. Thus, it is of vital importance of these companies to accelerate the whole supply chain and on-site installation avoiding long waiting times in the physical delivery of material at the fabrication shop and on-site. In addition, also waiting times for delays in engineering, such as non-physical delivery of drawings, technical solutions or simple decisions can put the planned due date at risk.

The success factor is the capability to deliver the specific order in time [3]. Therefore a short lead time and effective synchronization of manufacturing, installation and engineering could be viewed as crucial [2]. The organization of the manufacturing process in ETO are usually fabrication shops [4, 5], which cooperate closely with the engineering process. The engineering process is directly related to manufacturing in the fabrication shop as well as to installation on-site, providing them with the necessary information to start or continue the orders [2].

One challenge faced by ETO companies is the synchronization of project engineering and planning initiated...
in the design phase with production and installation program. This research paper analyses the actual situation of ETO companies and the objective of an improved synchronization of the whole supply chain. After giving an overview of the actual state of the art of lean initiatives in manufacturing, construction and engineering the concept of virtual and physical Just-in-Time delivery will be explained. Following the research team shows an approach to achieve a customer oriented planning and scheduling of production and engineering, measuring constantly the progress of installation on-site.

2. Initial situation and objectives

Usually engineering functions are not always integrated with manufacturing operations. Because ETO companies design and build products to customer specifications a significant amount of time and cost goes in to the engineering and design stage of the project. Modern software applications have greatly improved the speed and productivity of the design engineer. However the engineer’s view of the world is different from manufacturing operations. The engineer creates part and BOM information in the CAD and PDM system [2].

Often this information has then to be re-keyed manually of manufacturing and production planning because of a lack of integration between engineering systems and production planning. On the other side, if changes occur on the shop floor or on the installation site project planning and scheduling are not always updated automatically.

Generally used principles for engineering management and project scheduling are [2, 6, 7]:

- Project planning by estimation: planning of engineering, manufacturing and installation activities.
- Planning through human based experiences of previous projects.
- Knowledge management and planning through a well-documented database of average durations and workloads of previous projects.

Especially in planning engineering workload the creative character of engineering activities is problematical because it creates uncertainty in planning parameters. Thus engineering has been identified also as capacity bottleneck for ETO companies [6]. A possible solution for planning engineering parameters is to compute average durations and workloads of previous engineering projects based on the experience or on knowledge management databases [7]. About 69% of all engineering processes can reuse at least 25% of the parts for several times [8]. This knowledge transformation process can be supported by various software tools for Product Data Management (PDM) or Product Lifecycle Management (PLM) [2, 9, 10].

Additional problems occur due to constant changes in the project by manufacturing, installation or the customer itself. At the installation site short-term problems or bad weather conditions can require changes in scheduling. In the fabrication shop often changes in time schedules are due to technical or logistic problems in order processing. Mostly, changes are caused by the customer before and during the production or installation of components. This leads to capacity bottlenecks and complexity in project management.

All these changes in engineering, manufacturing and installation have to be aligned and coordinated. Usually this gap of synchronization creates inefficient processes because of a missing alignment and transparency of the progress in each of the three areas. Manufacturing produces parts that are not needed on-site, while installation stands still due to parts not delivered in time. Further installation and/or manufacturing are not able to go on with their work because of missing information or drawings from engineering. This happens very often in ETO companies where the design and even the development of technical solutions is executed in the engineering department almost parallel to the production, assembly and installation.

The degree of uncertainty is related to the novelty of the engineering task and usually very high in specialized ETO companies [11]. Usually this gap of uncertainty leads to bottlenecks in order process management. Bottlenecks can appear in several dimensions, e.g. capacity, material or information [2]. To avoid this kind of bottlenecks authors suggest to introduce buffer oriented scheduling methods like the Drum-Buffer-Rope (DBR) methodology [12, 13, 14]. The primary focus in DBR is the inventory control of a production system. In the DBR method a first buffer is introduced in front of the bottleneck, which protects the bottleneck from variances in the upstream functions. The performance of the production system is maximized with the utilization of the bottleneck. The second buffer is placed as a shipping buffer to the customer and protects the system from delivery difficulties [2, 15].

In Lean Management, inventories or buffers stand for waste (muda) and thus they are handled as not value adding activities. For the purposes of a lean process along the entire value chain from engineering to manufacturing to installation, inventory should be reduced at a minimum. Thus there is a need to close this gap of uncertainty through a high level of synchronization of engineering with manufacturing and on-site installation enabling a low inventory and a Just-in-Time supply of material and information.

![Fig. 1. Actual situation of missing synchronization in ETO.](image-url)
3. Theoretical background

In this section the theoretical background of Lean Management in Manufacturing, Construction as well as Engineering are briefly explained. To achieve the status of a whole Lean Enterprise typical lean concepts and principles should engage every phase of the value chain in ETO.

3.1. Lean Manufacturing

In ETO and MTO job shops are primarily used, which are producing customer individual goods. However, a low variety manufacturing process contains repeated and divided tasks, which are carried out in a continuous process flow [2]. The specific information for order processing in manufacturing is provided from the engineering process.

While in the automotive or aerospace industry the application of Lean Manufacturing methods is common nowadays, the ETO environment is lagging behind these developments [16]. Lean tools and methods are usually known from repetitive production environments, such as series production with a low-mix high-volume production, while there are only few experiences in the use of these methods at Engineer-to-order manufacturer. One of the major issues still needed to be tackled is unfolding the full potential of Lean in other non-repetitive manufacturing environment [17]. Recently also some research has been done in a high-mix small-lot size environment [18, 19]. The Egan Report [20] argued that Lean principles, such as standardization, Just in Time (JIT) and long term partnerships with suppliers should be adopted. The JIT concept is one of the most important principles of Lean Production.

3.2. Lean Construction

By modern concepts such as Lean Construction, waste and lead times should be reduced in ETO companies [21, 22]. In recent years, the concept of Lean Construction has increasingly gained in importance. The most important core element of Lean Construction is waste reduction [23, 24, 25, 26]. A related aspect, crucial for waste reduction in Lean Construction, is efficient transportation and stockholding of material, often termed JIT delivery [25, 27, 22]. Another central aspect of waste reduction is off-site manufacturing of components and units [23]. Approaching production management through a focus on process and flow is a core element of Lean Construction [26]. The Last Planner System (LPS) is a key aspect that enhances efficient production planning and control [22, 28, 29]. 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 [30]. Cooperative relationships among the supply chain actors are also an important element of Lean Construction [22, 23] facilitating the integration of different actor’s competences and efforts.

3.3. Lean Engineering

Engineering is usually concerned with the transformation of specific customer requirements into information to satisfy the customer needs [31]. The outputs of the engineering process are mostly attributes or specifications of products, processes or systems. These outcomes are information for the related processes, which become manifest in form of documents, e.g. construction drawings, bills of materials, working plans or process descriptions [2]. Engineering departments are mostly multi-project management environments and have often a matrix structure [32].

First attempts in the early nineties with lean principles [33] and JIT [34] in Engineering were very promising. Many companies that have been working successfully with Lean for some years are now implementing Lean also in Engineering and Product Development. The Lean Engineering philosophy aims for a highly efficient, customer focused development process eliminating waste and increasing value. Tools and methods in Lean Engineering can be mapped in the following categories: 1) Customer focused tools, 2) Knowledge sharing tools, 3) Tools for Visual Management, 4) Efficiency tools, 5) Problem solving tools, 6) Quality assurance tools [35]. In this work, primarily JIT- delivery will be discussed as a method to improve efficiency.

4. Physical and virtual JIT delivery throughout the value chain

In this section will be discussed the difference between physical JIT delivery in Manufacturing and Installation and virtual JIT delivery in Engineering.

In construction supply chains the site stands for the consuming process where ETO-components are installed into the building. The shop floor stands for the producing process and should provide the right material, at the right time (JIT) and in the right sequence (JIS). Between manufacturing and installation the material flow is based on the delivery of physical goods in different stages of value creation like raw material, components, sub-assemblies or entire prefabricated elements. Often, the cause for missing components on-site (creating construction interruptions and so waiting times) is that scheduling between manufacturing and installation on-site is not synchronized. Often manufacturing is interested to produce in large lot sizes and to improve their capacity usage of machines and personnel instead of a just-in-time supply of ETO components. Additionally installation on-site cannot follow always, planned time schedules to carry out their installation tasks. A reason therefore can be unpredictable events on-site like bad weather conditions or else.

JIT delivery is not only based on the delivery of physical goods but also on the exchange of virtual or digital information. Engineering usually produces such virtual goods with the focus on technical or logistic information content in different forms. This virtual information can be visualized and stored in a digital way or also paper based. Nowadays the trend goes towards a digital storage, exchange and visualization of such information contents. Typical virtual outputs in Engineering are:
Bill of material (BOM)  
Shop floor drawings for manufacturing  
Working plans for manufacturing  
Installation instructions for installation on-site  
Technical drawings and specifications for purchasing  
Due dates for manufacturing or purchasing  
Selection of processing technology.

Often, the cause for missing components on-site is that the fabrication shop cannot produce them due to missing shop floor drawings. The same happens if installation cannot go on with their work because of missing installation instructions from Engineering. This lack of understanding is due to the fact, that Engineering often is not synchronized with Manufacturing and Installation and works on non-priority tasks while operational departments are waiting.

5. Concept to synchronize Engineering, Manufacturing and Installation in Lean ETO-companies

After an introduction in the theoretical background of lean principles and JIT as lean method for reducing waste in value chains will be shown a concept for synchronizing Engineering, Manufacturing and Installation in ETO-companies. In a first step will be explained how the work on the installation site ("sink" or "consumer") could be scheduled through the developed Integral Building Execution Planning (IBEP). In a next step will be discussed the synchronization of Manufacturing and Installation based on the measured progress on-site. In the third step will be shown a concept for synchronizing Engineering with Manufacturing and Installation.

5.1. Integral Building Execution Planning (IBEP)

For planning in a detailed way the execution process on the construction site a methodology called Integral Building Execution Planning (IBEP) was developed by Dallasega et al. (2013) [36]. With the Integral Building Execution Planning (IBEP) a process plan for the operations on the construction site is developed by the companies responsible for executing the work and their key suppliers in collaboration with the design actors. In this phase, the “Pitching” concept is applied in order to synchronize all actors on site and to reach a constant work flow. Using the IBEP 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). In Fig. 2 the process plan according to the IBEP methodology for the construction of a hotel with an overall cost of 3 million Euros is shown. Here, MTO processes on-site (like window installation) and their connections to the fabrication shops are visualized and embedded in the whole construction process. Every box visualizes a single construction process containing a specific amount of work and arrows visualize predecessor and successor information.

As explained in [36] the amount of work is defined by using so called “Pitches” which 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. By using the IBEP methodology the customer demand on-site is defined. Engineering and Manufacturing should be aligned and synchronized to the customer demand on-site. For further information, readers are referred to [36].

Based on the initial time schedule (IBEP) the detailed installation progress has to be measured from week to week by the foreman on-site actualizing the time schedule for installation (see Fig. 3). In this way the influence of a fluctuating installation performance or unpredictable delays can be considered immediately in the planning. 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. After recording the actual progress on-site the foreman plans not only the next week but also further weeks in a Look Ahead Planning (forecast of several weeks). The time horizon of this Look Ahead Planning should be at least the longest lead time for procurement of material and processing as well assembly in the fabrication shop.

The Look Ahead Planning allows the production planner at the fabrication shop to align the production to the installation progress and performance. Through this preview he releases purchasing orders and triggers orders for prefabrication of components. The detailed planning of the next week generates a list of materials that have to be delivered JIT and JIS to the construction site. These orders are sent to the assembly department of the fabrication shop to prepare the material for delivery.
5.3. Synchronization of Engineering with on-site Installation and Manufacturing

Engineering acts as supplier for documents and drawings for Manufacturing (shop floor drawings, BOM,...) and Installation (installation drawings, working plans,...). Thus, it is important to synchronize also the Engineering department with Manufacturing and Installation. The foreman on-site communicates his Installation Look Ahead Planning to Manufacturing and Engineering. Manufacturing will define and re-schedule their production plan based on the progress on-site. After this planning of the production Manufacturing informs Engineering about the latest due dates for receiving related documents for every single project or component. Engineering receives the Look Ahead Planning from Installation and the due dates for shop floor documents from Manufacturing. Based on these inputs Engineering elaborates and re-schedules his Engineering plan. At the same time the installation planning for the next week generates a JIT-release of ETO-components at the fabrication shop and a JIT-release of documents for installation and the shop floor. Through the preview of more weeks Engineering should be able to plan their activities in a manner to guarantee Manufacturing and Installation to provide them with the needed information and documents in time. The approach is actually going to be implemented in two medium sized companies. At the moment, operational instruments for measuring the progress on-site and to synchronize it with the tasks in Engineering and Manufacturing will be developed and tested.
6. Conclusion

In the last years Lean Management principles were introduced also in non-repetitive manufacturing environment like ETO companies. Many of this firms began to introduce Lean Production in their fabrication shops improving productivity and quality. In a next step these Lean approach was brought to the construction site introducing Lean Construction methods on-site. Although there are still missing concepts to improve the whole value and supply chain between Manufacturing and Construction site. Nowadays JIT delivery is only possible with a high amount of inventory at the fabrication shop or at the construction site, due to long lead times in procurement, processing and assembly of components. In addition Engineering is not always ready with their technical solutions and drawings when they are needed to proceed in manufacturing or installation. Therefore a lack in methods and instruments of synchronization between the single phases in the ETO value chain has been identified. The paper illustrates a lean and consumption-driven approach to synchronize and harmonize engineering together with manufacturing and installation on-site.

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