Sustainability in the supply chain through synchronization of demand and supply in ETO-companies

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Abstract

In the Engineer-to-Order (ETO) industry every product is unique and therefore, engineering design, production and installation is made to the specific customer order (batch-of-one production). Traditionally, Engineering, Fabrication and Installation work as separate departments connected in series. This means that customer orders are pushed from Engineering to the Installation on-site which causes long lead times, inefficient material transport and high and uncontrolled levels of Work-in-Progress (WIP). As a result, resource inefficiencies occur (costly labour delays) when the required quantity or quality of drawings or materials is not on hand in fabrication and on-site. This work presents a concept for aligning demand with supply using the Constant Work in Progress (CONWIP) control circuit and thus enabling a sustainable supply chain for ETO-companies. An industrial case study shows the current implementation in an ETO company acting as a first tier construction supplier.

Keywords: Engineer-to-order; Resource Efficiency; Constant Work in Progress; Sustainability

1. Introduction

Industrial production can be classified according to different market interaction strategies: 1) Make-to-Stock (MtS), 2) Assemble-to-Order (AtO), 3) Production-on-Demand (PoD), 4) Build-to-Order (BtO), 5) Configure-to-Order (CtO), 6) Engineer-to-Order (EtO) \cite{1}, \cite{2}.

The Order Penetration Point (OPP) means a process stage where customer neutral production assignments transition to customer related production orders. In Fig. 1 the OPP which defines the different process chain types (from EtO to MtS) is visualized.

In traditional ETO construction supply chains, 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. Normally, economic benefits of a project reached through scale effects in production, are lost due to an inefficient installation process on-site.

In the ETO process chain type, the product or its singular components are engineered (developed) and produced according to the customer order. More in detail, this means that every product is unique (always new) and therefore different from the other (the production is not standardized).

Considering first-tier construction supply chains, three different phases can be emphasized:

1) Engineering
2) Fabrication
3) Installation on site

Within these three phases, special competences of the needed personnel are required. Moreover, since products are not standardized, a learning curve effect in the three phases has to be considered. ETO-companies usually manage several projects at the same time, which are spread all around the world, making this task even more complicated. Therefore, switching frequently among different projects for meeting the deadline is not recommended because this would mean an initial learning effort that has to be repeated every time.
Traditionally, projects are not synchronized to the three phases and therefore budget overruns occur. In practice this happens when a specialized crew has to wait for the needed components on-site. More in detail, companies do not have access to detailed real time information about the ongoing work on the construction site. Therefore, correcting actions for budget overruns cannot be taken in advance, but only when the project is already late.

The paper is structured in three different parts: section one contains the detailed problem description; section two summarizes the current state and the gap in research; section three explains the concept for problem solving as well as the case study and its current state of implementation.

1.1 Traditional process of ETO construction suppliers

Phase 0 - Preparatory
Generally, before the project starts, an architect external to the company defines the concept of the building. The project manager of the company elaborates the master plan (usually a Gantt chart) where he specifies/estimates the content (work packages), the duration (milestones) for the different phases, and the deadline of the project. Usually at this point just time, without the needed resources, is considered. Based on the master plan, the company participates in the bidding process.

If the company wins the bidding award, the project enters the pipeline. The traditional approach for ETO construction suppliers consists of three phases:

Phase 1 - Engineering
First of all, the project team is defined, which consists usually of different key players (e.g. project director, project manager, designers and installation foreman). The technical office elaborates the approval design, which consists of a detailed design of the project for the customer approval. Usually, the approval design is a 2D plan, only specifying the geometry of the objects. The approval planning is presented to the customer for the agreement. When the customer releases the approval design, shop floor designs are created. They specify the different components, their material and so on. At the same time the bill of material (BOM) is elaborated which contains the make and buy components.

Phase 2 - Fabrication
Once the shop floor designs are created, they are sent to the Production Planning department. The Fabrication produces according to the Production Planning department. Furthermore, the Logistics department organizes the supply to the construction site.

Phase 3 - Installation
The Installation Planning department defines and schedules the installation team (who, where and for how long). Normally, by defining the personal resources for the projects learning curve effects are not considered. Given the available resources (labor), the installation foreman schedules the assembly process on-site.

1.2 Problems endangering the sustainability in ETO construction suppliers

According to the traditional process building components are produced according to the Push principle. This means that shop floor drawings are pushed from Engineering to Fabrication. In the Fabrication department components are produced according to the available shop floor drawings. Finally components are pushed from Fabrication to the Site for installation.

Five of the seven types of waste (identified by Taiichi Ohno [3]) are described as problems which endanger the sustainability of ETO construction suppliers: Overproduction, Waiting Time, Motion, Inventory and Correction. Overproduction means that an upstream process, like Engineering or Fabrication, produces outputs (like drawings or components) in too a great quantity and before actually needed by downstream processes. According to practitioners, the justification of large batch sizes is that “this is how we have always done it” or that some of the machines need long setups. Moreover, materials are ordered from outstanding suppliers more and sooner than needed assuring to have them when needed. As a result, overproduction is seen as the principal type of waste because it triggers the other ones mentioned previously.

Every department or ETO-phase controls just the own budget. More in detail, errors in the Engineering department are most of the time discovered only on-site. In this case the defective components have again to be engineered, fabricated and finally reinstalled. Especially by using big batch sizes, correction operations create cost explosions. Especially the lack of synchronization between Engineering, Fabrication and Installation is the main cause of big levels of inventory and so high expenditures for motion operations.

Every department represents activities at a different level of detail which makes the synchronization difficult:

1) The Engineering department is focused on elaborating drawings;
2) The Fabrication department is focused on producing components;
3) The Installation department is focused on performing all needed tasks on-site;

This means that, one task may require more than one component and one drawing can specify more than one component. Therefore, the communication between different departments becomes complex.

In practice, the foreman on-site reports which tasks have been executed and which tasks are planned for the next period. Based on this, the project manager has to determine the components that will be needed next and communicate this information to the Fabrication department. Often, the cause for missing components on-site (creating construction interruptions and so waiting times) is that the Fabrication department cannot produce them due to missing shop floor drawings. These latter are missing because the customer may not have released the approval planning. This lack of synchronization is due to the fact that project planning and -management in the three phases is done at different levels of detail (Fig.2).
2. State of the Art

In manufacturing, releasing large batches of work to the shop floor causes several problems. A large volume of work typically occurs over time and it is difficult to monitor the production progress. In addition, this makes responding to changes in customer requirements very complicated [4]. The same also applies to the construction sector. Establishing a constant production pace could create a predictable construction flow that would enable quick correction action to be taken in case of unforeseen problems. In Lean Manufacturing, the consistent amount of production instructions released at the pacemaker process and simultaneously the taking away of an equal amount of instructions released at the pacemaker process, is called “paced withdrawal” [4]. This consistent increment of work is called “Pitch” and is calculated by determining how much work can be done at the bottleneck process in 1 Pitch interval (i.e. 10 min) [5]. So, a common unit for production instruction between different customer orders becomes possible. This “Pitch” becomes the basic unit of the production schedule for the considered product family.

In the construction industry project orders are common. These types of orders can be defined as one time orders with especially large order volumes placed by individual customers in order to meet special needs which are generally not recurring [6]. According to [6] it has to be determined what information will be available early on to understand if volume can be divided into small lots to ensure optimal capacity and minimal nonproductive time. Usually, ETO-manufacturers release work by customer order which has several disadvantages [7]. Large projects in construction are usually affected by design changes from clients or planning actors. So, the technical department holds back the production release as long as possible limiting the risk of customer changes. On the other hand the production management department tries to anticipate as much work as possible to optimally balance the production capacities [7].

According to the Value Stream Engineering (VSE) approach the flexible use of human resources is of primary importance [2]. At the consuming process the quantity of needed components is measured and then visualized at the producing process (controlled variable). This stands for a control circuit capable to 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 an error in demand forecast causes bullwhip effects. However, in Just-in-Time (JIT) ordering systems, amplifications are avoided because the actual demand is used instead of the demand forecast [8]. Two types of JIT control circuits are generally used for production management. The KANBAN system was developed by the Japanese automobile manufacturer Toyota [9]. Pull production controlled by Kanban requires a steady part flow. However, production in high volumes contradicts the fundamental principle and JIT performance objective of WIP minimization [10]. Afterwards, Spearman et al. published an article where they described a pull based production system called CONWIP (CONstant Work in Progress) which can be used in a wide variety of manufacturing environments [11]. A CONWIP production line sets the Work in Progress (WIP) levels and measures throughput [11]. The fundamental difference/advantage is that WIP is directly observable while capacity, which is needed to appropriately release work in a push system, must be estimated.

The general practice in multi-project management enables the beginning of work on an in-coming project immediately upon its arrival (provided the first relevant resource is available) [12]. According to [12] this practice is equivalent to the “push” principle in production management where there is no control over the number of products in the system. In [12] researchers try to adapt the CONWIP principle to multi-project management. They present two variants of the control circuit, one limiting the number of projects and the other limiting the number of worked hours in the system. The concept focuses on the backlog list where projects arriving at times when the system is unable to accept them, enter an external queue (the backlog list) where they wait until the load of the system has fallen under the threshold. The first variant Constant Number of Projects in Process (CONPIP) limits the number of projects that are allowed in the system to a fixed number. If there are less than the maximum allowed projects in the system the backlog list is empty and incoming projects are immediately accepted. When the project is activated it is broken down to its individual tasks. The completion time of an activated project is dependent on the status of the system because the task has to be ready (all its predecessor tasks have been completed) and the needed resource has to be available (not occupied with another task) [12].

The second variant Constant Time in Process (CONTIP) controls the total processing time required by all the projects that are active in the system. When a task of an active project is completed by one of the resources in the system, the remaining processing time needed for all active projects is updated. When it falls/goes under a certain limit, a new project is allowed to move out of the backlog list and into the active system. So, the second variant considers and controls the available capacity (in terms of labor resources) when activating a new project. One of the results (mentioned in
states that by holding projects in the backlog list when the system has reached his capacity no flow time performance is lost and no accumulation of overhead costs occur. Moreover, the mentioned pull approach (CONPIP and CONTIP) allow an easier forecasting of completion times. According to [12] many of the synchronization delays disappear, which consist of a task is waiting for its predecessor to be completed but those cannot even start since the relevant resources are faced with queues of tasks from other active projects. The proposed approaches CONPIP and CONTIP address the problem of synchronization between different projects.

3. Concept for synchronization of demand with supply in ETO

In the ETO industry every product is unique and therefore engineering design, fabrication and installation is made to the specific customer order (batch-of-one production). Even if the final product can involve some standard parts every customer order requires individual engineering designs and bill of materials, individual production routings and individual installation procedures. Generally, in ETO construction companies the tree phases/departments Engineering, Fabrication and Installation are not synchronized with each other. This means that the Engineering department elaborates drawings which are pushed to Fabrication. The Fabrication department manufactures according to drawings delivered from the Engineering department. Afterwards ETO-components are pushed from Fabrication to the site for installation. As a result, in the traditional approach customer orders are pushed from Engineering to the Installation on-site. So, high and uncontrolled levels of WIP occur between the three departments which are the main causes of long lead times [13].

The aim of the new concept is that ETO-components arrive in the right sequence and quantity needed for installation on-site. More in detail, ETO-components arrive on the construction site Just-in-Sequence (JIS) and JIT for installation. The concept for aligning demand with supply uses the CONWIP regulation circuit (Fig. 2). In the concept, the Engineering department defines in collaboration with the Installation department the optimal installation sequence and performance. So, the Engineering department designs ETO-components in the right sequence needed for installation. Moreover, the right granularity for Engineering, Fabrication and Installation is defined.

In detail, the concept consists of two regulation circuits, a long- and short term (Fig. 3).

3.1 Long term control loop

In the long term control loop the so called master plans of different projects are combined for calculating the needed work capacity. This requires that the traditional master plans will contain the needed resources (in terms of workforce). As described in [12] every project is broken down to its individual tasks which are assigned with the needed resources (labor resources). So, in comparison to the traditional approach, employees for installation should be planned in advance avoiding the switching between different projects and between Fabrication and Installation. Furthermore, the needed work capacity (for new projects) can be calculated and compared with the available work capacity (used for running projects). Important milestones within the three phases (Engineering, Fabrication and Installation) should be set which consider the available work capacity. As a result, new projects can be sequenced in an optimal way for reaching the defined milestones. The long term control loop uses the CONWIP approach for determining when a new project can enter the system by considering the available work capacity.
3.2 Short term control loop

In the short term control loop, an appropriate granularity should be defined by the three departments/phases (Fig. 4). The same granularity means in this case that a Constant Work in Progress (e.g. work for one week or one month) flows from the Engineering to the Installation department. More in detail, the Engineering department should elaborate shop floor designs which contain a complete construction lot (e.g. room 1). Most of the time, due to lack of time shop floor designs are created for the main parts (east façade of fourth level) and details (connection east and west façade) are missed and worked out at a later stage. So, not every needed component for completing a construction area will be produced and delivered at the right time. This means that remaining work on-site results. For completing the remaining work on-site a higher amount in comparison to the normal is needed. This is one of the major causes of budget overruns. In the short term control loop every department (Engineering, Fabrication and Installation) works with a self-regulation control loop. This means that the phase Engineering is split in its sub tasks for creating the approval design and shop floor drawings within one project. Every task should contain the needed workforce (W=nr. of workers) and its duration (CW=calendar week). Furthermore, according to the customer demand Pitch A in Engineering, Fabrication and Installation will be performed for the specific construction lot 1 (e.g. room 1).

4.1 Case study description

The concept is currently developed and tested in two projects of the company F&R. The first project is called “Softbridge”, and consists of the new library, research center and archive for St. Antony’s College in Oxford (UK). It was designed by the world famous architect Zaha Hadid for expanding the current Middle East Center with a library and an archive.

4.2 Practical implementation

For the previously mentioned case studies the so called “Process Planning” workshop was held (Fig.6). Here, the responsible project director, the project manager, the technical designers (shop floor planning) and the installation foreman met and defined the singular “Pitches” for the construction site (as described in [14]). In this workshop the project is structured starting from the building site (customer demand). The construction lots which contain the needed tasks, the workforce and duration were estimated by the involved experts of the project. Moreover, estimates were compared with budget calculations and possible shortenings of available hours per task were discussed together. The “Process Planning” workshop is used for defining the available work content per task (in terms of available working hours). This sets the basis for an accurate Budget Monitoring within the three different phases (Engineering, Fabrication and Installation).
synchronizing Engineering, Fabrication and Installation operations like waiting or searching. Moreover, by keeping WIP levels low helps to avoid non-value-adding effects (and so of efficiency) due to a switching of tasks by ETO-components creates also a loosing of learning curve.

Due to a missed synchronization of the three departments (Engineering, Fabrication and Installation) problems caused in previous process stages are measured as budget overruns on the construction site. One of the major problems here consists of a lack of ETO-components needed on-site due to a non-synchronous work organization in the three departments (3.2 Incorrect & missing prefabrication). Furthermore, a lack of ETO-components creates also a loosing of learning curve effects (and so of efficiency) due to a switching of tasks by the crews on site.

5 Conclusion and outlook

Keeping WIP levels low helps to avoid non-value-adding operations like waiting or searching. Moreover, by synchronizing Engineering, Fabrication and Installation processes, project lead times in ETO projects can be reduced. However, prioritizing the backlog list by handling the high variability of construction processes and considering a multi-project environment is one of the critical issues for using a CONWIP system. Within the next months, the concepts presented in this paper are going to be tested in a further project of the company F&R which is currently at its starting phase. Over the last years, the shown concept of synchronization of demand (construction site) and supply (fabrication shop) has become an important issue for empowering sustainability in ETO companies. The harmonization of demand and supply has a positive impact on every dimension of sustainability creating more cost-efficient (reduction of waste), ecologically (reduction of transports caused through a lack in coordination) and social (improvement of employee satisfaction) processes.

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