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IFAC PapersOnLine 51-11 (2018) 128–133

Operationalizing lean principles for lead time reduction in engineer-to-order (ETO) operations: A case study

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Abstract: The engineer-to-order (ETO) manufacturing approach is used in companies developing and producing highly customized products. ETO operations include some characteristic business processes such as the sales and tendering process, engineering and design and project management. The characteristics of the ETO environment creates high complexity in these processes, resulting in considerable amounts of waste. The potential for lead time reduction is therefore high also in these processes, not only in the production and assembly processes. Building on lean manufacturing this paper seeks to operationalize lean principles in ETO operations. Through an in-depth case study of an ETO company this paper investigates the challenges, problems and improvement opportunities in the business processes of an ETO company by applying an adapted value stream mapping (VSM) approach. The study served to identify main sources of waste which negatively affect lead time in ETO operations. The paper further presents specific guidelines that operationalizes lean principles in order to reduce waste and improve lead time in ETO operations.

Keywords: Engineer-to-order; lean; production management; lead time reduction; production planning and control; business process management systems; logistics in manufacturing.

1. INTRODUCTION

In today's manufacturing industry we see a constantly increasing demand for customized products, especially within the industries with advanced, capital intensive, heavy equipment, such as the shipbuilding, maritime and oil and gas industries. To be able to respond to this demand companies must deliver products that are manufactured and engineered based on very specific customer requirements. This type of manufacturing is called engineer-to-order (ETO). An ETO approach is one in which a product is designed, engineered and manufactured based on very specific customer requirements. Therefore, the customer order decoupling point is located at the design stage with production flow being driven by actual customer orders, and typical order winners are design, delivery speed and flexibility (Olhager, 2003). This means that, in addition to the traditional manufacturing processes, ETO operations require a substantial effort in sales, procurement, engineering and project management, to ensure that these order winning criteria are fulfilled.

The large degree of customization, the product structure complexity, and the overlapping of manufacturing and design activities are reasons for a very high complexity of the internal ETO supply chain (McGovern et al., 1999). Failing to handle this complexity results in long delivery lead times and high costs. In ETO operations, the customer is exposed to the total product lead time, which includes the conceptual and detailed design, procurement, manufacturing, assembly, testing and commissioning (McGovern et al., 1999). ETO companies have several distinguishing business processes that constitutes a significant amount of the total lead time, and reduction of lead time in these processes is crucial for improving the performance of ETO companies.

Several strategies and concepts have been introduced in the ETO environment, aimed at reducing lead time of manufacturing operations. Furthermore, several efforts have been made to apply lean thinking and lean manufacturing in the ETO environment in order to reduce waste and lead times. However, the deployment of lean in ETO operations has mainly concerned the production processes or comprised very broad and general principles. Therefore there is a need to operationalize lean across all ETO business processes. The purpose of this paper is to address that need by identifying the main sources of waste that affects the lead time of the business processes in ETO operations. Further, lean principles in ETO are used to develop operationalized lean guidelines. This is done through a case study of a Norwegian ETO company within the maritime industry.

The next section will introduce some of the efforts made to improve ETO operations, while section 3 concerns lean in ETO. Section 4 introduces the case company and the methodology and work process used in the case study, followed by the case findings in section 5. Finally, a discussion and concluding remarks are provided in section 6.

2. IMPROVING PERFORMANCE IN ETO OPERATIONS

Although the ETO approach gives certain competitive advantages such as high customization, flexibility and innovativeness, it also has a range of challenges. There is a large amount of information exchange between company-internal departments, suppliers, customers, third party

10.1016/j.ifacol.2018.08.246

consultants, as well as governing bodies, which leads to coordination difficulties (Mello et al., 2015). Customers often request changes in the design phase, as well as the engineering and manufacturing phases. Managing such changes proves to be a challenge for many ETO companies (Kanerva et al., 2002). Engineering and manufacturing activities are to some extent conducted in parallel in ETO environments (Semini et al., 2014), making it difficult to plan manufacturing processes. To be able to offer highly customized product, while also competing on delivery lead time and price makes ETO operations challenging.

Several concepts, approaches and strategies have been developed in order to improve performance in ETO operations. Concurrent engineering, standardization and modularization are examples of concepts for shortening project time span in ETO. Supply chain integration, Information management, Business process re-engineering, flexibility, time compression and New product development process improvement are some of the strategies developed for the ETO sector (Gosling and Naim, 2009). Semini et al. (2014) analyzed the effects of customized design versus standardized designs in the shipbuilding industry, and found that giving the customer a limited choice of predefined, standardized design options can lead to more predictability and stability in processes, shorter lead times, higher delivery precision and lower prices. Efforts have also been put into investigating a possible combination of ETO and mass customization strategies, in order for ETO companies to increase efficiency while maintaining a high customization level (Duchi et al., 2014). However, there are still challenges and need for further research related to the application of mass customization principles in ETO companies (Thomassen and Alfnes, 2017).

Although the mentioned concepts, approaches and strategies have contributed to improving performance of ETO companies, there is still potential to reduce waste and the long lead times in ETO operations. In many cases lean may be the answer, also in the less repetitive environments, such as the ETO environment.

3. LEAN IN ETO

Since its development from the Toyota Production System and the publication of *The Machine That Changed the World,* the lean production philosophy has been widely applied in manufacturing (Womack and Jones, 2010). Although originally developed in Toyota's highly repetitive production environment, lean thinking, principles and tools are increasingly implemented in other production environments as well.

Value stream mapping (VSM) is a lean mapping tool used to identify waste and improvement opportunities in businesses (Rother and Shook, 1999). Traditionally, VSM has been utilized on the physical production process on the shop floor in highly repetitive production environments. More recently, the applicability and adaption of VSM for less repetitive production environments, such as the ETO environment, have been studied (Braglia et al., 2006, Matt, 2014, Seth et al., 2017, Thomassen et al., 2015). However, most cases of applying VSM in the ETO environment focuses mainly on the physical processes, not covering the important non-physical processes found in ETO manufacturing, such as sales, engineering and project management. However, there are clear similarities between these processes and what is called office operations. The need for lean thinking in other areas than the physical production processes has led to the development of what has been termed Lean Office, where the VSM methodology is applied in order to identify and eliminate waste in office operations (Chen and Cox, 2012).

In order to improve planning in ETO projects, the Lean Construction Institute developed the Last Planner System (LPS). This is a collaborative planning system supporting lean project planning and execution. LPS is supposed to achieve better performance in design and construction through increased schedule predictability, and more efficient management of handoffs of assignments or tasks in ETO projects (Ballard, 2000).

Although the applicability of different lean tools and techniques may vary between production environments, the lean principles are more universally applicable. Thusly, the original lean principles have been adapted for different areas. Based on the principles from traditional lean production, lean project management, and lean product development, Powell et al. (2014) developed principles that are more aligned to the ETO manufacturing environment. These principles are: (1) Defining stakeholder value, (2) Leadership, People and Learning, (3) Flexibility, (4) Modularization, (5) Continuous Process Flow, (6) Demand Pull (7) Stakeholder- and Systems Integration, (8) Transparency, (9) Technology, (10) Continuous Improvement. Although these are specifically developed for the ETO environment, there is still potential to further operationalize and deploy them across the entire ETO supply chain.

4. CASE STUDY

In order to investigate lean in an ETO context a case study was conducted. The case company and the work methodology for the case study will be presented in the following two subsections.

4.1 Introduction to case company

The case company develops and manufactures power electronic equipment such as propulsion systems, oil drilling systems, uninterruptible power supply systems, converters for subsea systems and low voltage distribution systems. The company has approximately 170 employees and is located in Norway. With an ETO approach, with all products are designed, engineered and manufactured based on customer requirements. Each customer order is managed as a project, with an average throughput time of approximately 24 weeks. The main business processes include the departments Sales, Engineering, Procurement, Production, and Project management. They are all located in the same facility.

The company currently offers products within four main product families. Each product family has 10-20 main types, with customizations and modifications from the customer allowed. The product complexity varies, although most of the projects have specific requirements from the customer. The bill of materials (BOM) for products can consist of hundreds of components to a few thousand components.

Table 1: Overview of main business processes at the case company.

Main business processes	Description
Sales	Includes the reception and management of the request for proposal (RFP) from customer, contract development and negotiation, and preliminary specification of product.
Engineering	Software development, engineering and design of electrical and mechanical product components, development of documents needed for production, assembly and testing.
Procurement	Purchasing of components based on BOM developed by the engineering department.
Production	Material requisition, production and assembly of final products. This process also includes administrative processes to support production, such as workforce planning and conducting pre-testing and final testing of products.
Project management	Overarching management of each project, from receipt of a RFP to packing and shipping of the final product. In addition, this process includes the overall continuous improvement of all business processes.

4.2 Methodology and work process for case study

VSM was used as the basis for the work process The case study work process was developed based on the systematic procedure presented in Chen and Cox (2012), which allowed mapping of both manufacturing and non-manufacturing processes. The adapted process is shown in

Fig. 1.

The first step was to create a *Lean team*. Investigation of the internal business processes required having representatives from all departments involved in the main business processes. This step includes also an introduction to the VSM methodology to those involved, to provide common understanding.

In order to have an efficient and structured mapping process, it is necessary to focus on one product family at a time. Product families should be defined based on commonalities in product, process and market characteristics (Thomassen et al., 2015). Selecting a product family for mapping makes the VSM easier to visualize and understand (Chen and Cox, 2012). Finally, Draw current-state includes drawing a value stream map, that shows processes as well as material and information flows.

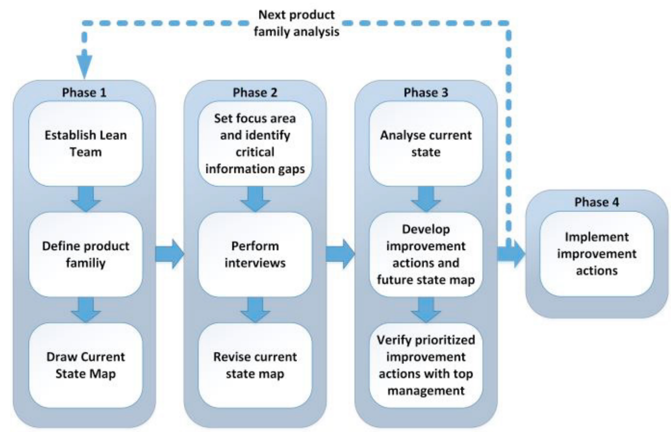

Fig. 1: Work methodology for case study

After drawing and discussing the current state map it was possible to determine the focus area, and see where the critical information gaps were. Additional information was collected after the initial mapping through semi-structured interviews from employees from relevant departments. The goal of these interviews was to verify and improve the current state map, as well as identify problems, challenges and potential for improvement for each department. The semi-structured interviews were based on five main questions:

- *Which business processes are you involved in, and what does your work include?*
- *Which input do you receive and from who?*
- *Which output do you create and to whom do you send it?*
- *What are the problems in the process?*
- *What are the improvement opportunities in the process?*

All information from project workshops and interviews were then further analyzed. Problem identification methods such as the five why's and root cause analysis (RCA) were used in this step to identify root causes of the problems and challenges. With the current state analyzed and root problems identified, it was possible to develop improvement actions that could reduce or eliminate waste in the value creation process.

The last step before implementation of the improvement actions is to verify the prioritized improvement actions with the top management, in order to have full support and drive to implement the improvements. Top management involvement from the project start is a means to ensure that top management also support the improvement actions.

5. CASE FINDINGS

This section will describe the findings from the study of the sales, engineering, procurement, production and project management processes of the case company. These are described in subsections 5.1 to 5.5, which highlights the main sources of waste affecting lead time within each of these processes. Furthermore, guidelines for waste and lead time reduction corresponding to the sources of waste are presented in an overview at the end of the section.

5.1 Sales process

The sales process mainly includes the sales department, and starts with the reception of a request for proposal (RFP). The RFP is communicated to the company's internal sales department from an external sales department, on behalf of the end customer. Thus, the case company's interaction with the end customer is indirect. With a RFP in hand, the sales department starts the contract development and contract negotiation, to get both the main technical and commercial specifications in place. This requires several activities. For one, the sales and preliminary specification process is characterized by several, tedious interactions with the customer for the development and negotiation on the contract.

Furthermore, several documents developed in this phase requires detailed quality checks and approvals. The company uses a third party consultancy firm to do this. However, it is not a legal requirement to have these documents approved by a third party meaning that this function could have been maintained in-house. The result is additional time spent sharing information and documents with this third party, in order to get the documents approved, and the third party's processing time is long.

Developing the contract also requires technical insight, as the product described in the contract must be technically feasible to develop, manufacture and operate. In practice, this means that the preliminary product specification takes place at this stage, with the sales department as the responsible department. There are no rules or procedures for involving the engineering department in developing or quality checking the preliminary specifications sent from the sales department to the customer.

The main document developed in this process is the contract, which is further used by the engineering department to generate the product specification and BOM. However, the contract does not easily translate into product specifications and BOM. The sales and preliminary specification process is concluded when the contract is signed and the preliminary specifications are sent to the customer, with a handover meeting where the engineering department takes over the responsibility for the project.

5.2 Engineering process

After the handover from sales the engineering process starts with converting the agreed contract and technical specification in the contract to actual product specifications. The contract may include parts, components, and sub-assemblies that are common or standardized, or that have never been developed before. The company does not differentiate between the degree of customization in the way projects are managed, planned or controlled.

The development and engineering of software, mechanical, and electrical components is complex and time consuming. The successful engineering of a product is dependent on an efficient flow of information, especially when engineering changes occurs, between the three engineering units software, mechanical and electrical. Engineering changes are common, and may result from both change requests from the customer as well as internal mistakes requiring a change.

There is today an insufficient degree of internal quality checks in the engineering department, and drawings and documents are often forwarded without a second hand quality inspection. Moreover, there is no defined process or routines for handling, tracking, or investigating engineering changes, neither for changes from customers, or changes that are the result of internal mistakes.

The engineering department is closely linked with the production department by being responsible for generating the BOM used for procurement, and developing the documents needed for production and assembly of the product. Thus, the computer-aided design (CAD) systems used by the engineering department should be integrated with the enterprise resource planning (ERP) system used for procurement. Today, integration issues have negative implications on the procurement of material, giving both excess and lack of material in different cases.

5.3 Procurement process

The procurement process involves two critical issues that may affect the lead time. One is the procurement of items that have long lead times. Long lead time items often must be purchased even as early as the sales and preliminary specification process, because the lead time may be equal or exceed the lead time requested for the entire product. The other critical issue is related to ordering standard and custom components for products. Some products have standard components which will always be required. Thusly, these products may be ordered once the type of product to be manufactured is known in order to ensure the supplier is able to deliver on time. Whereas, modified and customized parts take longer to design in the engineering process, which means ordering often must take place much closer to production start.

5.4 Production process

The production and assembly process is characterized by a fixed position layout, where products are stationary throughout the assembly process. As a result, there is a low degree of productivity in terms of value-added time as the operators spend a considerable amount of their time on preparing their workstations for the next process, looking for materials, equipment or product documents such as blueprints. Engineering documents used for production are made available in a printed binder which is updated by production managers. Assemblers are responsible for material requisition, by manually selecting each of the components from the ERP system, as there is no structuring into BOM's in the ERP system. Therefore, material requisition is done on component level, and not on subassembly level. This requires a large amount of time, effort and competence of operators to look through hundreds or thousands of components to manually select materials. Materials and components are then delivered to the assembly area. As components are ordered in an ad hoc way, workers use a significant amount of time searching for components for each subassembly that is to be built. In addition, the detailed assembly has no predefined process steps for any of the products. Workers use their own insight, and overview of available materials, components and tools to plan which subassemblies to assemble.

5.5 Project management process

The project management process is parallel with the other business processes described in Table 1. Each project is assigned with a project manager from the project management group, which follows the project from the RFP reception until the project is delivered to the customer. This includes project planning and control activities, and tracking and monitoring project status underway, although there is a potential for more efficient sharing of this status with relevant departments throughout the project.

The project management is also responsible for facilitating handovers and information sharing between departments, such as in the handover from engineering to production. However, the frequency of meetings with several departments represented is rather low. On the other hand, the frequency of intra-department meetings is considerably higher. Another task within project management is related to continuous improvement of operations based on previous projects. Lessons learned from previous projects have the potential to increase the performance of future projects.

Table 2 gives an overview of the sources of waste affecting lead time in the ETO operations in the case company, as explained in this section. Additionally, corresponding guidelines have been developed for reducing waste and handling these critical issues. The guidelines have been developed based on the lean principles from Powell et al. (2014), see section 3.

Table 2: Guidelines for waste and lead time reduction in ETO operations

Processes	Sources of waste affecting lead time in ETO manufacturing operations	Guidelines for waste and lead time reduction
Sales	Customer interaction; Contract development and negotiation	Develop structured instructions for the customer interaction process that states who, when and how often customer interaction should take place in order to reduce uncertainty and non-value added time spent on customer interaction.
	Involvement of consultant or third party for document approval	Avoid external interference by maintaining competence to approve documents internally in order to reduce non-value added time with external parties.
	Quality of preliminary product specifications	Involve the engineering department in quality control of the preliminary specifications to ensure accuracy and quality of the preliminary specification.
	Conversion of contract into product specification	Ensure contract clearly defines tangible product specifications that translate easily to engineering to facilitate efficient handover to engineering.
	Degree of customer specification	Standardize product specifications as much as possible and differentiate projects based on degree of customization to effectively handle different varieties of products.
Engineering	Quality Control of engineering documents	Implement quality checks at necessary stages of the value creation process, and establish routines for cross checking, both within and between engineering units.
	Change order management	Define and implement Engineering Change Management process, in order to effectively manage and reduce impact of external and internal Engineering changes.
	Compatibility between CAD and ERP system	Properly integrate CAD software systems with ERP system to ensure appropriate material procurement.
Procurement	Timing and synchronization of procurement of long lead items with production start	Establish a differentiation of the procurement of items with long lead time and procurement of items with short lead time, in order to ensure component availability during production
	Timing and synchronization of procurement of standard and custom items	Establish a differentiation of the procurement of standard items and procurement of custom items, in order to ensure component availability during production
Production	Assembly operations productivity	Digitalize access to work instructions and product documents to facilitate efficient assembly operations
	Integration of product structures and BOMs with the ERP system	Modularize BOM into different subassemblies to facilitate efficient material requisition and handling
	Synchronization of material supply and assembly process	Utilize kitting for delivery of materials for subassemblies to increase value-added time during assembly
Project management	Information sharing and coordination between company departments	Establish regular cross-functional project meetings to enable more efficient sharing of critical information between company departments and define efficient information channels for communicating project progress and status between company departments when necessary.
	Learning and experience transfer from finished projects	Establish “lessons learned” process and routines to improve performance of future projects.

6. DISCUSSION, CONCLUSION AND FURTHER RESEARCH

This paper has through a case study identified a set of critical issues affecting lead time of internal business processes of an ETO company. The case study revealed that there are several sources of waste in the internal ETO business processes that negatively affects lead time. This was found to be particularly relevant in the non-physical processes such as the sales process, the engineering process and the project management process. The paper has further operationalized lean principles by proposing guidelines for addressing each of the identified sources of waste. These guidelines may be used by practitioners within the ETO industry to address and handle challenges and problems with lead times in their internal business operations.

Each of the guidelines presented here are developed to address a specific critical source of waste. Moreover, they are intended to be practical and to the point, in order for them to be easily implemented. In addition, the guidelines are independent of each other, such that they can be applied individually. This further simplifies and enables application in different contexts. Nevertheless, there is potential for further generalizing both the identified sources of waste as well as the guidelines, for them to be applicable in a wider range of ETO manufacturing companies. Moreover, additional guidelines may be required in other companies, thus additional case studies will have to be conducted in order to complement and refine the set of guidelines presented here.

This paper has further demonstrated that the principles of lean production can be highly relevant for identifying and eliminating waste also in ETO operations. Moreover, the principles are applicable in non-manufacturing processes such as the sales, engineering and project management processes, which are crucial business processes in ETO operations.

The ETO environment is complex and there are still large improvement potentials related to the reduction of cost and lead times. With the current trend of digitalization of manufacturing industry, an apparent topic for further research will be to investigate how emerging digital technologies can be applied to address the sources of waste presented in this paper. This can enable the efficiency and productivity required in the next-generation ETO operations.

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