Reducing delivery times in Engineer-to-Order firms: Challenges and solutions

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Abstract

In engineer-to-order industries, rapid order fulfilment can yield a significant competitive advantage. Firms with short delivery times win more orders, have higher agility, reduce their work-in-process and overheads, and can thus achieve lower costs. Yet, reducing delivery times has proven extremely difficult in practice. We use the literature to summarize 25 keys for reducing delivery times in engineer-to-order companies. Through three in-depth cases companies in the maritime industry, we study and discuss the application, challenges, and opportunities of these keys.

Keywords: Engineer-to-order, Lead time, Agility

Introduction

In ETO industries, time has been identified as a critical performance objective in order fulfilment (Akinc and Meredith, 2015). Engineer-to-Order (ETO) companies are typically engaged in the manufacturing of capital goods with delivery times that are counted in weeks instead of days. Shorter delivery times increase the chance of winning contracts, contribute to higher delivery precision, reduce work-in-progress inventory and overhead consumption, and help offset the investment cost of infrastructure and equipment. More generally, short times are associated with lower costs and higher effectiveness (Suri, 2016). The purpose of this study is to investigate how ETO manufacturing companies can achieve shorter delivery times.

By delivery time, we mean the time from contract signing to the product is delivered to the customer. This is also called order fulfilment time, or manufacturing critical path time (Suri, 2016). For ETO manufacturing, every product is the ultimate result of a project that includes design and engineering, purchasing and supply chain management, and manufacturing and assembly. There are three main phases of order fulfilment in ETO: Design and engineering, purchasing and supply chain management, and manufacturing and assembly. ETO companies aiming to reduce delivery times need to analyse and improve operations in these three main phases.

We addressed the following research questions:

- What distinct measures can reduce delivery times in ETO industries?
- Which measures are considered to have a high impact, and under which circumstances?

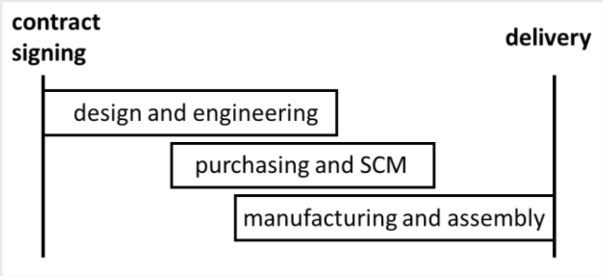

Figure 1: Main processes of order fulfilment in ETO

Methodology

Three in-depth case studies were performed. The case companies had been working systematically with delivery time reduction over the last years and had responsiveness as a key competitive priority. We had collaborated with all three case companies through long-term research and consultancy projects, and had already gained some familiarity with their current challenges and practices. We wanted the evaluation of the key measures to be based on a shared understanding among the company participants regarding their order fulfilment process and challenges related to delivery time.

Our first step was to perform a thorough mapping of current practices and challenges affecting delivery time. We mapped in detail the main processes of the order fulfilment in each company, i.e. sales, engineering, purchasing, planning, production, and testing, allowing us to understand activities, information flows, and milestones for each process. Further, each company selected 4-5 representative projects with different level of success, from disaster projects in terms of time and costs, to projects that were executed efficiently and delivered on-time. Data was gathered from ERP and PLM systems regarding main activities, milestones, due dates, delays, and planned versus actual number of hours.

The second step was to map the main challenges related to delivery time. Employees from each process were interviewed regarding the challenges they experienced in performing their activities on time, and what they perceived as the particular causes for failure or success of each of the selected projects.

The third step was to introduce the keys measures to the companies and inquire their importance in addressing the identified challenges. Focus groups assessed the level of implementation of each measure, and also to what extent a full implementation of each measure can reduce the total elapsed lead time in order fulfilment.

Literature study

ETO is a broad classification of manufacturing processes where some parts of the final product are engineered during customer order fulfilment (Wikner and Rudberg, 2005). The engineering component of ETO companies differs widely, some produce make-to-order products with very limited engineering, and others produce large and very complex systems that require hundreds of engineering hours. Some of the most important contingency factors to characterise differences in ETO environments are degree of customization, level of outsourcing, extent of activities after receipt of order (Amaro et al., 1999), customer involvement, product modularity (Duray et al., 2000), engineering complexity and average orders sold (Willner et al., 2016b). Our analysis and discussion regarding the applicability of key measures for reduction of delivery times are based on these contingency factors.

As shown earlier, we distinguish between three phases of ETO manufacturing. The first phase, design and engineering, involves product specification, conceptual design, detailed engineering, documentation, development of manufacturing instructions, and engineering change order management. The second phase, purchasing and supply chain management, involves evaluation and selection of suppliers, negotiating of contracts and schedule deliveries, managing inventories, assessing supplier performance, and ensuring that payments are made when appropriate. The third phase, manufacturing and assembly, involves activities such as planning, component fabrication, subassembly, final assembly, and testing. The operations management literature provides many measures to reduce delivery time. The key approaches derived from literature are explained in Table 1.

Table 1: Key measures for delivery time reduction in ETO

Key Measures	Description
	Design and engineering
Product standardization	Reuse components across products; use product platforms; offer customization where it is critical for the customer, standardize the rest (Haug et al., 2009).
Product modularization	Create product structures consisting independent units with standard interfaces (O'Connor et al., 2015).
Delayed product differentiation	Design products in a way that customer specific components can be assembled as late as possible (Semini et al., 2014).
Fast track for industrial orders	Separate work flows for industrial orders with higher volumes and a large number of similar or equal elements, and for special orders with lower volumes and higher complexity (Matt and Rauch, 2014).
Concurrent execution of engineering and production	Perform engineering, purchasing, and production concurrently (Emblemsvåg, 2014).
Sales/product configurator	Deploy a rule based software supporting sales in the development of a valid product structure with price and delivery time (Willner et al., 2016a).
Design/engineering configurator	Deploy software supporting or executing routing tasks in engineering (Willner et al., 2016a).
Seamless transfer of product designs and specifications to production	Create seamless transfer and conversion of product structures, drawings, and specifications from PLM/CAD systems in engineering to ERP/MES/CNC systems in production (Dean et al., 2009).
Business process re-engineering	Organize tasks in service families. Create effective flows and reduce waste in the value stream for each family (Kumar and Wellbrock, 2009).
Engineering change order mgt.	Develop an effective system to classify and handle engineering change orders – both from customers and internal revisions (Sriram et al., 2013).
Integrated product development	Integrate design, manufacturing engineering, and other functions in order to include customer, supplier, and manufacturing concerns during the design stage (Rahman Abdul Rahim and Shariff Nabi Baksh, 2003).
	Purchasing and supply chain management
Locate suppliers in close proximity	Choose suppliers in close proximity to manufacturing facility to increase responsiveness and make JIT-delivery possible (Holweg and Pil, 2005).
Supply chain collaboration	Collaborate with suppliers to improve planning, information sharing, and visibility in the supply chain (Rød et al., 2016).
Supplier development	Develop crucial suppliers capabilities, such as handling change orders, rush orders, and/or provide excess capacity when needed (Krajewski et al., 2005).
Inventory of Long lead time items	Keep inventory of long lead-time items that are purchased regularly to satisfy a recurring demand (Radke and Tseng, 2012).
	Manufacturing and assembly
Keep excess capacity	Keep capacity utilization below 80% at critical resources to allow for volume variations (Suri, 2016).
Drum-buffer-rope	Planning based on identifying and managing the constraints (bottlenecks) of

(TOC)	a production system. Darlington et al., 2015).
Workload control	Deploy optimization-based scheduling of order release based on available capacities and due dates (Thürer et al., 2012).
Card based control systems	Simplify production control by using card-based. control systems (such as Kanban, Conwip, Polca, etc.) for input/output rate control and priority of orders (Thurer et al., 2016).
Last Planner® System	Move focus from production efficiency to flow, by letting foremen / team leaders plan and commit to tasks (Ballard and Howell, 1997).
Make-to-forecast	Release production orders for products before customer is known. Allocate to customer later, often with a modification cost (Akinc and Meredith, 2015).
Performance measurement	Implement time-based KPIs that show and allow improvement of delivery time (Emblemsvåg, 2014).
Reduce setup/changeover time in production	Reduce changeover times and batch sizes through lean set-up time reduction techniques (SMED), automation, or through more flexible machines (Singh and Khanduja, 2012).
Flow in manufacturing	Organize products in families and rearrange layout towards product orientation; Create effective flows and reduce waste in the value stream for each family (Duggan, 2012).
Cross-trained workforce	Cross-train employees to increase workforce flexibility (Yang, 2013).

Company descriptions

We conducted this research in collaboration with three companies operating in the maritime and offshore sector. A summary of the characteristics of the companies and their products is shown in Table 2.

Table 2: Collaborating ETO companies and their products

Characteristic/ Case Company	A Thruster	B Power Electr. System	C Pressure Vessels
Turnover (MNOK)	700	300	200
Number of employees	300	140	90
Typical order (MNOK)	1-30, typical 5	4-10, typical 7	5-80, typical 15
Engineering effort (hours/order)	75-100	700-800	600-1500
Product differentiation stage	Final assembly	Subassembly	Fabrication
Customisation (% of components)	Low, 5%	Low, 5%	High, 98%
Typical Delivery time (weeks)	8-16	24 -30	52

Company A manufactures thruster systems for ships. Each system is designed to fit a particular water flow condition and to provide the best interaction between thruster and ship hull. The targeted product family was a complete thruster system including thruster control, alarm and monitoring system. A typical product is a large assembly of mechanical, hydraulic, and electrical components. The product is highly standardized and modularized, but are provided in numerous variants and sizes. Some mechanical engineering is required to fit the thruster to a particular ship hull, and electrical and software engineering is required to set up the control system. A large share of the machining of components and sub-assembly of modules are not customer specific. However, they are still made to order due to high mix and low volumes.

Company B is a development, engineering and production centre for power electronics to the maritime and offshore sector. The targeted product family was an innovative electronic powers system for ships that was introduced to the market early 2017. A typical product consists of a set of cabinets with complex electronics and wiring that are engineered to customer requirements. Standard electrical components such as transformers, switches, and sensors are assembled and wired together to complex and integral systems. Rapid technological development within electronics technology and the high innovation rate at the company's R&D department regarding these products, results in a continuous flow of new options and architectures that can be offered to customers.

Company C offers design, engineering, project management and manufacturing of separation equipment and pressure vessels for the oil and gas industry. The targeted product family was large pressure vessels that are custom-built to a range of different applications onshore, offshore and subsea. A pressure tank consist mainly of customised pieces of materials that are welded together to a cylinder with top and bottom heads. Equipment such as nozzles, valves, pumps, and sensors are installed and customized to meet the customers interface and application requirements. The product is integral, and any change in the positioning of equipment will require re-engineering of welding seams. As such equipment is exposed to some of the most aggressive industrial environments, each project is challenging regarding design methodologies, as well as materials- and welding technology. Pressure vessels can be dangerous and fatal accidents have occurred. Consequently, the construction is regulated by engineering authorities and legislations. The parameters used in design, such as maximum safe operating pressure and temperature, safety factor, and corrosion allowance, need to be thoroughly documented and approved by third-party authorities. During manufacturing they undertake extensive testing such as ultrasonic testing, radiography, and pressure tests at several stages before a product is ready for delivery.

Results and discussion

In this chapter, we present and discuss some preliminary findings from our case study of three engineer-to-order companies. We first summarize challenges and obstacles the companies experience in achieving short delivery times. We then present the measures the companies rated as having a high potential impact on the delivery time, and we provide an overview of the measures the companies have actually implemented. Finally, we compare the three case companies' results in order to link the measures' impact to company characteristics.

Challenges and obstacles

The mapping of the order fulfilment process in the companies identified several challenges that delaying orders. In this section, we briefly present the most important of these challenges.

During design and engineering, products are sold with vague technical specifications and unnecessary demanding special features. This creates misunderstandings, mistakes, and engineering change orders in downstream processes. Much technical work is still manual and require collaboration between several engineering disciplines. Engineers are working simultaneously on several complex and technically challenging projects with a number of change orders. As a consequence, it is hard to deliver detailed component specifications on time. During purchasing and supply chain management, components are ordered too late from suppliers due to late technical specifications and engineering change orders, resulting in delays. During manufacturing and assembly, capacity planning is challenging due to high uncertainty and variation in the projects. Shop floor scheduling is also challenging due to frequent due date offsets and many engineering change orders. There is a lack of flow and visibility at the factory floor. Too much time is used to understand drawings and instructions, and find the right material for assembly. Manufacturing is interrupted due to technical changes, defects, lack of operators with the right skills, or delayed components from suppliers.

Measures with highest expected impact

Table 3 gives an overview of measures that were ranked as having highest impact on delivery time:

Table 3: Measures ranked as having highest impact on delivery time reduction

Case A Thrusters	**Case B Power electronics**	**Case C Pressure vessels**
	Design and engineering	
Product standardization Product modularization Delayed product differentiation Fast track for standard/repeat projects Seamless translation of product designs and specifications to production	Product standardization Product modularization Sales configurator Design/Engineering configurator Engineering change order management Integrated product development	Concurrent execution of engineering and production Design/engineering configurator Business process re-engineering (office operations) Seamless translation of product designs and specifications to production
	Purchasing and supply chain management	
Inventory of Long lead time items	Supply chain collaboration	Inventory of Long lead time items
	Manufacturing and assembly	
Card based control systems Flow in manufacturing operations	Flow in manufacturing operations	Work load control Last Planner System Flow in manufacturing operations

A key observation from table 3 is that design and engineering is regarded as most influential for delivery time reduction. This seems reasonable, since design improvements such as standardisation and modularisation often have a positive effect on all processes in the order fulfilment cycle. We also observe that none of the measures have been ranked as high by all the three case companies. This suggests that the degree of impact of the measures depends on contingency factors such as characteristics of the product and the manufacturing environment, as will be addressed in this chapter's last section (see table 5).

Implemented measures

Table 4 shows the measures with highest level of implementation in the companies, based on the interviewees' ranking.

Table 4: Implemented key measures in case companies

Case A Thrusters	**Case B Power electronics**	**Case C Pressure vessels**
Standardization Modularization Delayed product differentiation Keep excess capacity Cross-trained workforce Locate suppliers in close proximity	Standardization Concurrent execution of engineering and production Integrated product development Cross-trained workforce Locate suppliers in close proximity Inventory of long lead time items	Concurrent execution of eng. and production Sales/product configurator Design/engineering configurator

We make similar observations as for the measures ranked as having highest impact on delivery time reduction. Design/engineering-related measures play a particularly important role, and no measures have been implemented to a high degree in all the three companies. Some measures are considered to have a high impact, yet are not extensively implemented. In some cases, this is due to the costs and risks associated with the measures, which makes their implementation inappropriate despite a high impact (for example inventory of long lead time items when they are valuable and required in low volumes). In other cases, the measures require a certain product maturity (e.g., for modularization), or they require considerable efforts in IT and organizational development (e.g., seamless translation of designs/specification to production).

Comparing the characteristics of the products and the manufacturing environments of the three case companies, we identify the level of customisation, the level of complexity, the product structure, and the level of innovativeness as important contingency factors affecting the applicability of the studied measures. Specifically, the level of customisation and engineering complexity increases from case A to C. The products in case A are rather mature, standardised, and consists of modularised products with limited engineering effort. In case B, the products are novel, built mainly from standard components, but each cabinet is a highly complex and integrated system that require of a substantial number of engineering to construct. The products in case C are rather mature, but large and highly customised, requiring many hours of engineering to accommodate customer requirements. In the next section, we use these characteristics to predict the circumstances under which the measures are expected to have a high impact.

Linking measures to product and manufacturing characteristics

The following propositions list measures with highest impact on delivery time reduction and their main application areas, based on the challenges, level of implementation, and rankings from the cases (Table 5).

Table 5: High impact measures and their application area

Approach	**Main application area**	**High ranking in:**
Design and engineering		
Product standardisation	Product families where a limited solution space is sufficient to cover the majority of demand.	A
Product modularisation	Product families that consist of several distinguishable components with standardised interfaces.	A
Delayed product differentiation	Product families with a medium to high level of component commonality at an early stage of the manufacturing process.	A
Fast track for standard/repeat projects	Product families where a number of products have similar design specifications.	A
Concurrent execution of engineering and production	Product families with high engineering complexity and high level of customer involvement during the entire engineering process.	B and C
Sales configurator	Product families that have passed the introductory phase of their lifecycle and have a predictable solution space.	A and C
Design/engineering configurator	Product families where product dimensions can vary incrementally such as in case C. For products that are offered with a limited set of dimensions, or for highly innovative and integral products, manual engineering based on templates is a simpler and faster approach.	A and B
Seamless translation of product designs and specifications to production	Automated fabrication of customised components.	A and C

Business process re-engineering (office operations)	Particularly influential for product families with a high engineering complexity.	C
Engineering change order management	Particularly influential for order fulfilment processes with a high level of engineering and manufacturing concurrency and many changes	B
Integrated product development	Particularly influential for product families with manual manufacturing processes that require manual skills and considerable practice.	B
Purchasing and supply chain management		
Supply chain collaboration	Critical component suppliers in geographical proximity.	B
Inventory of Long lead time items	Works for cheaper, standard materials or components.	B
Manufacturing and assembly		
Work load control	Product families with complex product structures and large variations in work load per product.	C
Card based control systems	Product families with sufficient volumes to sustain a regular flow of similar products or components.	A
Last Planner System	Large, complex, and highly customized products.	C
Flow in manufacturing operations	Products that has enough similarities in routings and workload to allow grouping in product families.	A, B, C

Conclusion

In this paper, we have investigated the use of measures for delivery time reduction in engineer-to-order manufacturing. We have identified 25 such measures proposed in the literature and evaluated their potential impact as well as their level of implementation in three engineer-to-order manufacturing companies. The identified measures address several of the companies' delivery time challenges, so their implementation is likely to have a remarkable effect on the delivery time. The study allowed us to develop some simple propositions linking the measures' likely impact to characteristics of the product and manufacturing environment, in particular the degree of customization and engineering effort, the level of complexity, the product structure, and the level of innovativeness. The paper contributes to the field of operations management in engineer-to-order by increasing knowledge about how to achieve short delivery times. Companies can use our findings to evaluate the appropriateness of various improvement measures, based on company characteristics and their specific challenges. A limitation of the work is that we have so far only studied three companies. Furthermore, the assessment of the measures is based on judgement from practitioners, which may be biased by their role and position in the company, among other reasons. For the future, there is therefore a need for additional empirical data about the impact of the proposed measures on the delivery time, by means of additional case studies as well as surveys. In particular, the post-implementation effect on the delivery time from various measures should be investigated in order to have a stronger empirical foundation to draw conclusions from. Further elaboration on the contingency factors affecting the measures' effect will also be important.

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