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**A Concept for Order Change Management in ETO Supply Chains**

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**Abstract**

Order management might incur substantially challenging tasks for Engineer to Order (ETO) type manufacturing companies. A significant number of engineering changes and variations during the order management process constantly occur. These changes lead to modifications in product, design and engineering, and material management phases and ETO companies must react on these changes appropriately. Eventually these modifications compel changes in the project schedule as well. This study primarily focuses on the material management issues implied by the engineering changes and aims for developing a conceptual framework aiding these challenges, in sync with the management of entire project to deliver the product efficiently in time and cost wise. The applied research methodology is qualitative exploratory research. The data is collected theoretically and empirically. The relevant literature is reviewed and a case company from the shipbuilding industry is studied and represented in this paper. Limitations of this research appear due to the lack of literature in this field and single case study approach which reduces the chances to generate the results. However this study contributes to theory by increasing the understanding of EC problems in association with the

logistics and SCM, building a conceptual framework aiding these challenges, and forming a basis for further research. The practical contribution is made by investigating and outlining practical EC problems in the case company and introducing some ideas and solutions to overcome these challenges.

*Keywords:* Engineer to Order, Engineering Changes, Material Management, Seiban, SC Collaboration

## **1. Introduction**

The Engineer-to-Order (ETO) supply chain is usually associated with large and complex project environments and can be defined as a supply chain in which customer order penetrates the design and engineering phase of the product (Gosling and Naim, 2009). Many projects suffer from delays in completion, budget overrun, and quality defects. In many cases, client requirement changes cause delays, leading to the changes in the product specification (Hao et al., 2010). Engineering changes (ECs) are inevitable during the order management process, especially on large and complex projects like ship projects (Wasmer et al., 2011). Kocar and Akgunduz (2010) reported that ECs can consume as much as one-third to one-half of the engineering capacity. Thus, the importance of proper change handling is unquestionably crucial for a company's competitiveness. Despite of their significant impact on the ETO manufacturing environment, it is actually not too surprising to see the lack of research done in ECs within the context of logistics and supply chain management. This is because most of the published research in supply chain management has already neglected the ETO sector itself (Hicks et al., 2000).

This study primarily focuses on the logistical consequences of the ECs requested from the customer. ECs lead to modifications in shape, function, material or dimension of a product (Huang et al., 2001). Eventually, the need for synchronization between engineering change, material management, suppliers, and project schedule becomes unavoidable. Thus,

engineering change process becomes a rather complex process, involving different disciplines both from within the company itself and from physically dispersed supply chain partners (Terwiesch and Loch, 1999). Considering that approximately 60-80 per cent of the ship value is outsourced, the chances are, a supplier will most likely be involved in the various ECs (Mello and Strandhagen, 2011). Hence, this is further extending the EC process to a collaboration issue across supply chain actors in the ETO manufacturing environment. In order to handle ECs properly, supply chain partners should have an integrated system and build a unified collaboration network (Koçoğlu et al., 2011).

In contrast to the academic research, information system (IT) vendors have attempts to provide solutions regarding the complexity of the ETO sector. Enterprise Resource Planning (ERP) systems gained a major share as an information system in the market, seeing that the 80% of the Fortune 500 firms are now using ERP systems to manage their business processes (De Ugarte et al., 2009). Traditional ERP systems are quite incoherent with the variability of product specifications and parameters in an ETO environment. However some IT vendors (see for example: Oracle, SAP, Glovia, and Baan ERP) have, over the recent years, developed systems, tools, and modules supporting manufacturing planning and control (MPC) in a project manufacturing environment. However there are still existing challenges with the ERP systems is poor integration with other IT systems and tools both internally (Akkermans et al., 2003) and externally (Kelle and Akbulut, 2004).

This research paper primarily aims for developing a conceptual framework describing the project MPC and overcome the EC problems, particularly within the context of logistics and supply chain management. The remainder of the paper is as follows; in the next chapter, research methodology is briefly explained. After that, Chapter 3 provides insights to reviewed literature related to EC, while chapter 4 introduces the emerging technologies and solutions. Next, Chapter 5 presents the empirical study done in a case company from the ship production

industry. Chapter 6 discusses a conceptual framework for project MPC and EC handling, based on the findings from the previous chapters. Finally chapter 7 draws the conclusions.

## **2. Research methodology**

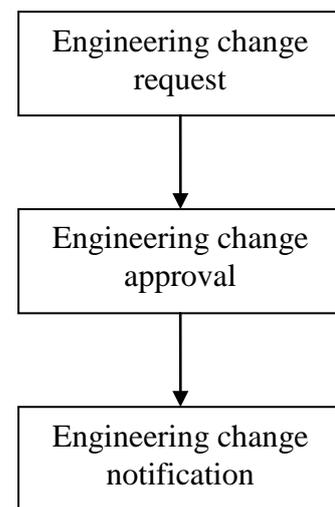
This study has qualitative exploratory approach due to the nature of the research field and problem identified. The literature is rather scarce and the knowledge in this field is not sufficiently mature. Therefore it has been necessary to conduct an inductive empirical research along with the investigation of the existing theory and emerging IT solutions. The combination of the empirical study and theory has enabled to better formulate the problem and developed a basis for further research. Furthermore it has extended and refined our knowledge within this relatively immature field. As a result a conceptual framework is developed based on the combination of theoretical insights and empirical findings. Hence, two research methods applied to collect data: literature review and case study. The literature research, along with the IT vendors' solutions, helped to gain needed skills and knowledge in this field, identified the potential contributions to theory as well as defined a feasible scope for this study. In parallel with the theoretical study, we conducted a single case study over a top-notch ship producer that frequently faces the challenges introduced earlier. Single case study approach gave us greater depth but limited the generalization of conclusions drawn (Karlsson, 2009). During the visits to the case company a series of interviews were conducted. The authors also participated in project workshops and meetings with representatives from the company.

## **3. Engineering change management and logistical challenges**

*Engineering changes* are the modifications in forms, materials, dimensions, functions, etc of a product or a component (Huang and Mak, 1999). The change might occur in any size or type, involving any number of people and take any length of time (Jarratt et al., 2011). *Engineering change management* (ECM) is defined as the process of organising, controlling and managing

the workflow and information flow for engineering changes (Kocar and Akgunduz, 2010) (2010). The literature is more or less in consensus in the ECM process. Number of involved stages is slightly different, but the content is very similar. There are mainly three stages gone through in an engineering change process; engineering change request stage, engineering approval stage, and engineering notification stage (Terwiesch and Loch, 1999, Kocar and Akgunduz, 2010, Jarratt et al., 2011)

- *The engineering change request (ESR) stage* is where the need and request for a change is placed by an initiator. The initiator can be the customer, an engineering team, or anyone else who is involved in the product development. The ECR should contain detailed information on which part to change, the changes in parameters, a reason for the change, and finally a technical engineering drawing to represent the change graphically.



*Figure 1: EC Phases*

- *The engineering change approval stage* contains the revisions and acceptance or rejection of the change. All the departments/teams that might be associated by the change should be involved in this process. This also includes identifying change propagation and the corresponding departments and teams affected.
- *The engineering change notification* is given when a change is approved by all the involved parties. The associated departments then get an engineering change notification including parametrical and graphical information regarding the change to be executed.

Based on the literature review and analysis, several categories of challenges identified within the engineering change management, including knowledge management, decision making, network collaboration etc. As specified previously, logistical and supply chain management

related challenges are on the focus of the study. Thus, these challenges will be elaborated further.

***Change propagation;*** possessing the capabilities to identify change propagation has been recognised as an important and critical skill in the ECM process (Giffin et al., 2009). Change propagation stems from components being coupled with each other, either directly or indirectly (Keller et al., 2005). This implies that when there is a coupling between components, there is a chance that changing one component will also require the other component to change. The stronger these couplings are, the more likely is a change to cause further downstream changes (Cheng and Chu, 2010). Complex products often experiences more change propagation than other products, due to more couplings (Cheng and Chu, 2010). Another issue with complex products is that very few people have a good understanding of the entire product, and thus will have problems identifying change propagation throughout the product (Eckert et al., 2004). Hence, it is also important to involve several disciplines in order to get different views on the change. Change propagation is a very challenging issue in ECM. The study conducted by the Aberdeen Group reveals that only 11% of the companies participating in the study had capabilities to both provide a precise list of affected components by a change, and automatically propagate the change to related components (Brown, 2006). Besides the identification of the affected materials, required materials down through the entire BOM must be shown. This can be to some extent done in today's ERP systems by the pegging functionality which shows where-used information of the materials, and links demand and supply. However this functionality is often underused by companies (Koh and Saad, 2006). Improving the pegging functionality will potentially enhance management of orders. Additionally, in project based ETO manufacturing, related activities must be hardly linked to these materials and updated, eventually resulting in adjustments to the project

schedule. Hence engineering change, material management and project schedule can be synchronized efficiently.

***Supply chain communication and collaboration;*** As stated earlier, the ECM process is a rather complex process, involving different disciplines within the company and across the supply chain actors. Although the importance of collaboration and information sharing has been stressed, one can easily find many companies and even internal departments working in a decentralised and none-collaborative manner (Koçoğlu et al., 2011). However they should have been moving towards the efficiency associated with an integrated system and close cross-company collaboration (Koçoğlu et al., 2011). To achieve this, a unified collaboration network is required. The ECM literature has identified the following issues related to information sharing and integration in the ECM process: (i) Bad integration of different IT-systems employed internally in the company (Huang et al., 2001), (ii) Simultaneous access to an ECR by multiple disciplines is usually not permitted, especially when they are geographically distributed (Huang et al., 2001), (iii) Collaboration across company borders (Wasmer et al., 2011).

#### **4. Advanced solutions**

Previous chapter outlined some of the main logistical challenges triggered by the engineering changes. This chapter will introduce some advanced concepts, systems, and functionality that go beyond the traditional ERP systems.

***Project MPC and Seiban:*** Seiban is a technique for managing orders in the supply chain which is an alternative to the traditional MRP logic currently implemented in most ERP systems. A Seiban is a number associated with a specific sales order or customer requirement. All manufacturing activities, including planning and control, are identified by the Seiban (Matsuura et al., 1995). Using the logic of Seiban in the whole supply chain means that all materials and activities related to a customer requirement are visible throughout the supply

chain. The materials and supply activities have an assigned purpose, and cannot be used to satisfy a different customer requirement. Seiban functionality with hard links between supply and demand is naturally related to the logic of pegging which is the ability to trace requirements through an MRP plan and also the process of identifying requirements that generated a lower-level activity. An item's attribute can be set to different pegging levels, allocating supply for a project task/seiban in accordance with the reservation level set in the plan level options (Weir, 2000). For a soft pegged demand, excess project supply (or common supply) is always available for another project's demand. No project references are made to planned orders issued to soft pegged items. For hard pegged items, excess common supply from one project can only be shared among projects in the same planning group. Project references are attached to planned orders for hard pegged items. Another benefit of Seiban is that orders can easily be planned, re-planned, and managed using the identifying number (Glovia, 2008). A schedule change can be made to an item, and subsequently a system can adjust the schedule of all related activities by the same amount. When all orders are linked, the status of the series of orders can easily be retrieved by using the Seiban. This premise makes Seiban more intriguing to use in ETO project manufacturing. Furthermore, Baan ERP (1998) provides a comprehensive solution for project manufacturing system control. The reader is referred to these IT vendors web-pages for more information.

***Web integration and cloud computing:*** Integrating web functionality to ERP systems has been identified as a key to improving supply chain level processes (Kelle and Akbulut, 2004, Slack et al., 2007). A web based solution will provide all the involved parts with simultaneous access to all the EC information (Huang et al., 2001). Cloud computing allows companies to access IT-based services such as infrastructure, applications, platforms, and business processes via the Internet (Schramm et al., 2010). One of the characteristic attributes of cloud computing is its multi-tenant, or one to many, capability (Schramm et al., 2010). That means

that a cloud service can house many users, instances, or customers, and new tenants can be added quickly. In a supply chain management context this scalability and power to connect different actors in a cloud environment enables collaboration and communication in the supply chain. Users at different locations can access the same applications and the same data, and the integration enabled by cloud-based applications will enable more effective cross-enterprise and extended supply chain analysis and reporting (Schramm et al., 2010).

## **5. Case study**

The investigated case company is a Norwegian company in the shipbuilding industry, providing sophisticated vessels for demanding marine operations. Currently, the company operates with an ETO approach, which is characterized as being highly flexible, producing “one-of-a-kind” products. Two different ECs are identified: (1) Miss-match changes that occur because the initial idea cannot be done, in other words a construction error. These changes often appear in the beginning of the project (2) Customer requested changes that are requests from the customer. These changes often appears later in the process, and thus might cause greater harm to the initial production plan. In this case, the customer requested changes is analysed in terms of cost, propagation, and plan consequences. A new offer is then given to the customer with possibly increased price and delivery time. However, miscalculations might happen, and sometimes inquire a loss on the added change. This is often due to undetected change propagation. The company faces some challenges in the categories discussed earlier in the theory section.

***Change propagation;*** The main challenge observed in this category is budget overrun on customer initiated ECs. There are of course many potential reasons for a budget run. However, in regards to ECM, EC propagation has been identified as one of the most significant reasons as also reported by (Keller et al., 2005). There are currently no systems at the company which

can identify change propagation. All propagation analysis is based on personal experience, and a thorough discussion of the engineering drawing among the different departments.

***Supply chain communication and collaboration;*** The company faces substantial challenges related to this category. It is no surprise that distributed members from different disciplines do complicate the communication aspect as also stated by (Rouibah and Caskey, 2003). Most of the communication is carried out by e-mails, meetings and paper deliveries. This results in sequential information sharing where job that could have been conducted in parallel, ends up being done sequentially, prolonging the lead time. As for the systems, a long lasting problem has been the diversity of IT-systems. Most of these systems usually stems from different vendors, hence they are not compatible with each other. Different IT-systems usually also means different databases, thus limiting the information availability.

## **6. A conceptual framework to overcome logistical challenges in ECM**

As stated earlier, change propagation, and SC communication and collaboration are the two main ECM requirements that lead to logistical challenges appear when an EC request is made. Change propagation requires (i) identification of directly affected materials/components and couplings (ii) identification of newly required materials/ components, and (iii) synchronizing the material/component changes with the activities and project schedule. Miss-match changes late in the production process, very time consuming EC evaluations, budget overrun, and lengthened delivery lead time are the main identifiers of these challenges. Moreover EC requires seamless communication and collaboration both internally with different departments and externally with the SC partners. Efficient information sharing, visibility and accessibility should be empowered. Sharing information on paper/ mail/ meetings etc., geographically dispersed actors, bad integration of different IT-systems, no unified access to aggregated data, and misinterpretations by different actors are the main identifiers of challenges.

	<b>Manufacturing Planning and Control (Vollmann et al., 2005)</b>	<b>Project Manufacturing Planning and Control</b>
<b>Demand Management</b>	<ul style="list-style-type: none"> <li>• Forecasting</li> <li>• Order management</li> </ul>	<ul style="list-style-type: none"> <li>• Market research</li> <li>• Sales orders management ( required items and quantities for each sales order line)</li> <li>• These demand items are regular stock items, made to order, or engineered to order</li> </ul>
<b>Sales and Operations Planning</b>	<ul style="list-style-type: none"> <li>• Aggregated sales and production planning for product groups</li> <li>• Aggregated capacity and inventories planning</li> </ul>	<ul style="list-style-type: none"> <li>• Aggregated sales planning by an entire project structure for all sales orders (One project for all sales order lines)</li> <li>• Network activity planning (subcontracting, operations, relations etc.)</li> <li>• Rough cut capacity requirements</li> <li>• Seiban pegging of activities to capacities</li> <li>• Capability to enter a new project (standard or customized)</li> </ul>

<b>Master Production Scheduling</b>	<ul style="list-style-type: none"> <li>• Master production schedule</li> <li>• Forecast consumption</li> <li>• Rough-cut capacity planning</li> <li>• Available to Promise</li> </ul>	<ul style="list-style-type: none"> <li>• Master project schedule for modules/ parts (manufactured, purchased, or customized critical parts with long lead times) based on the activity plan</li> <li>• Revision of volumes/ quantities</li> <li>• Available to Promise</li> </ul>
<b>Material Requirements Planning</b>	<ul style="list-style-type: none"> <li>• MRP for master scheduled items with routings and BOM structures</li> <li>• Detailed capacity requirements planning</li> <li>• Production and purchasing orders</li> </ul>	<ul style="list-style-type: none"> <li>• MRP for project parts (copy or adapt existing item data, routing and BOM structures)</li> <li>• MRP for project engineering (create routing and BOM structures for engineered parts)</li> <li>• Seiban pegging of activities to materials</li> <li>• Production and purchasing orders</li> </ul>

**Table:** MPC and Project MPC

The proposed conceptual framework refers to investigated solutions and ideas to aid these challenges. It has been built up by analyzing gathered data from existing literature and IT solutions. When an EC request is received from the customer, the Seiban approach, with its premises, can be used to aid challenges related to material management and respective adjustments on the project schedule. This can be enabled by its pegging logic. Having linked the orders with the supplies, activities, and project schedule, it facilitates change propagation of the EC request in an integrated and automated manner. The Seiban system can re-plan the material requirements by identifying (based on the preliminary evaluation of EC, done by

involved departments) directly affected materials and their couplings. Depending on the reconfiguration level of the product, it can also identify and select the newly required materials from the material pool. Then, these changes can automatically adjust the project schedule by the pegging functionality which is enabling the linkage between materials and activities. Hence, the updated schedule can update the timing, budget, and cost, which can be either used to negotiate with the customer or for control purposes.

The required information sharing, visibility and accessibility can be supported by internally integrated systems allowing for simultaneous data storage and retrieval, and cloud computing and web integration allowing for simultaneous data storage and retrieval, even for geographically dispersed members.

## **7. Conclusion**

This study has revealed that the ECs lead to modifications in material management and project schedule, and EC process should be handled with these tasks on an integrated manner. A conceptual framework has been proposed to achieve this objective and handle ECs properly in logistical context. The framework contains several functionalities. Propagating engineering changes to material requirements, in synch with the related activities and project schedule is one of the main functionalities of this concept. Seiban is a very promising approach to be embedded in current ERP systems and provide a solution for this. Moreover it has been discussed that integrating web technology and adapting cloud computing technology to the ERP systems can enable superior supply chain communication and collaboration. As mentioned earlier, this research has limitations due to the relatively scarce literature and single case study approach which makes it difficult to generalize the results. However it reaches its main objective by increasing the knowledge in this field and building a framework for further study on the outlined challenges and solutions.

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