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## Globally Distributed Engineering Processes: Making the Distinction between Engineer-to-order and Make-to-order

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### Abstract

This paper explores how the organizational and technological requirements of globally distributed engineering processes differ for make-to-order (MTO) and engineer-to-order (ETO) production and highlights potential research themes which might contribute to a better understanding of this field. The preliminary results presented in this paper are based on a literature review and an on-going exploratory case study with manufacturers from the mechanical engineering sector, responsible for the engineering of both MTO and ETO products in a global setting. We propose a preliminary framework to identify and structure the different requirements ETO and MTO products pose for globally distributed engineering processes. We hope to stimulate further research through emphasizing the main research gaps within this field.

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### 1. Introduction

In the last couple of decades, operations of numerous manufacturing companies have become increasingly distributed across continents. Whole company divisions - first and foremost sales, information technology and production - have been offshored to locations far away from the organizations' headquarters. In more recent years, product development and engineering functions have also become a target for offshoring activities. In the extant literature, several frameworks, stage models and key success factors for the internationalization of product development and engineering have been proposed [1,2,3]. These concepts have all been developed with several particular types of engineering and production environments in mind: make-to-stock (MTS), assemble-to-order (ATO), and make-to-order (MTO). However, the product development and engineering processes implemented for engineer-to-order (ETO) products usually differ from the processes common for MTS, ATO, or MTO [4]. Within this paper we explore if the global engineering

processes of an ETO producer encompasses genuinely different organizational and technological requirements than the global engineering processes of an MTO producer.

### 2. Methodology

This paper is based on a literature review and multiple case study research. The review of literature supports both the summary of a research field as well as the identification of specific research questions [5]. Exploratory case studies are suitable for gaining an understanding of nascent research fields and to identify research themes which can be used in future research [6]. We apply an exploratory case study design to improve our understanding on how global engineering processes for ETO products differ from global engineering processes for MTO products and which research themes might contribute to further understanding of this field. Multiple case research is more likely to create robust and valid theories than single case research [7]. This paper presents the preliminary results of a multiple case study that is

still in progress. So far, three manufacturers from the European mechanical engineering sector have participated in the case study, all of which are manufacturing ETO- as well as MTO products, and are performing globally distributed engineering activities to varying extents. From each company, multiple representatives (e.g. Director of Engineering, Process Manager) participated in semi-structured interviews regarding their current ETO and MTO processes. For purposes of triangulation, we also used presentations and documents from the companies, as well as information we received through our participation in company workshops as sources of evidence. To ensure the quality of the research design a case study protocol has guided all interviews and the case study reports were reviewed by the interview partners.

### 3. Literature Review

Literature in the field of ETO ranging from a description and understanding of ETO processes [8,9] to the delimitation of the ETO environment from other types of production environments [10,11,12] has been published since the mid-nineties. Nevertheless, publications specifically focusing on product development and engineering for ETO products are scarce: Gosling & Naim [13] merely identified three papers [14,15,16] covering product development processes in the ETO sector within their literature review. As well as the work identified by Gosling & Naim [13], we also consider the work of Alderman [4] within this field of research.

While literature in the field of product development has been published for decades, the majority of literature focusing on the aspects of global product development (GPD) and engineering has been published within the last ten years [1,3,17,18]. Very little research on global product development and engineering processes for ETO companies in particular has been conducted previously: Tripathy [12] focusses on GPD for complex engineered systems, a category somewhat representative of ETO products. Additionally, Ayubi [19] carried out a single case study to evaluate the skills required for engineering leaders in GPD in the context of aircraft manufacturing.

As such, research in the field of global product development and the engineering processes for ETO products is still nascent. In this paper we intend to contribute to this field of research through proposing a preliminary framework that can be used to identify and structure the different requirements ETO and MTO products pose for globally distributed engineering processes.

### 4. Making the Distinction between ETO and MTO

The Order Penetration Point (OPP) is used to distinguish between different types of production environments [12]. It separates the part of the chain which responds directly to customer demand from the part which relies on forecasts [20]. Referring to the OPP, the following types of production environments are most frequently cited: “make-to-stock” (MTS), “assemble-to-order” (ATO), “make-to-order” (MTO) and “engineer-to-order” (ETO) environments (cp. Figure 1).

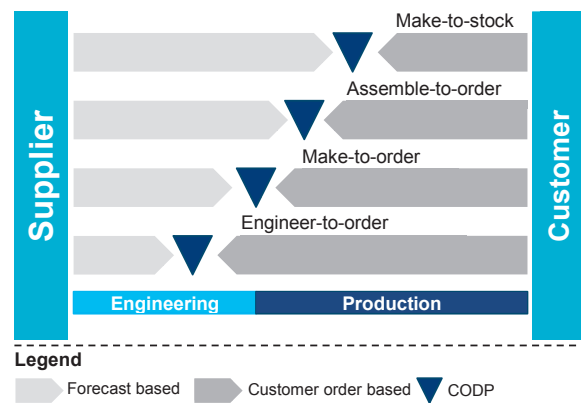


Fig. 1: The Order Penetration Point (based on [12])

On one extreme of the scale, MTS products can be found since their specifications are predefined long before the customer makes the decision to order. MTS products are often relatively simple and can be produced at low costs. Customers desire to acquire them in short lead times and manufacturers produce to stock according to demand forecasts [21]. Pre-manufactured parts and components are assembled according to customer specifications in the case that an ATO-strategy is being followed. In the case of MTO, products are often configured with the aid of a configurator (which contains a large set of pre-defined parameters and attributes that the customer can choose from) and then manufactured according to the selected configuration. ETO products are located at the other extreme of the scale with the highest uncertainties in terms of product specifications. The OPP of the ETO supply chain is located in the design phase since engineering changes based on an individual customer order are highly common in this type of production environment [13].

MTO can often be characterized by highly sophisticated products, small lot sizes, long lead times and sometimes high levels of customization [22]. However, in the case of MTO, the customer still has to select his desired product design within a pre-defined solution space. The engineering design and specification is generally completed before the customer order is received. This differs from the situation with ETO products, which have to be customized according to customer specifications (within order fulfilment) through the execution of engineering activities [9]. The necessary degree of customization can vary considerably: from a mere customer specific extension of the product parameter range to the complete development of a new product according to customer requirements.

The majority of ETO manufacturers does not exclusively produce goods requiring customer specific engineering changes. Instead, they often generate the largest share in revenues with MTO products. Nevertheless, the capability to engineer according to customer specifications is often an order winner in the MTO sector (e.g. an elevator manufacturer wins the tender for all the elevators within an office complex due to his capability to engineer the special elevator required for the lobby). While profit margins in the ETO business have been high in the past, today customers are no longer willing to pay high price premiums [12].

Both MTO and ETO value chains with their corresponding interfaces to the customer are shown in Figure 2. The MTO value chain consists of the four phases: product development, sales, production & logistics, and delivery. Within the product development phase, new products, sub-assemblies and components are planned and developed. In an MTO environment, the sales process is generally initiated through the request for a quotation from a customer. The product is configured according to customer specifications often with the aid of special configuration software. It can either be the sales department or the customer who executes the configuration. The customer interactions are limited to the sales (request for quote, quote, order) and delivery phase (delivery).

Product innovations and improvements enable them to keep up with their competitors and to remain attractive in the eyes of the customer. Product development implies both the development of radically new products as well as the adaptation of products (either radical or incremental) already in the market. In this paper, the product development and engineering processes representative for the mechanical engineering sector (cp. [25]) are treated as the object of investigation. Product development processes common for other industries (e.g. information technologies, pharmaceuticals, chemicals) may highly differ and can be regarded as out of scope.

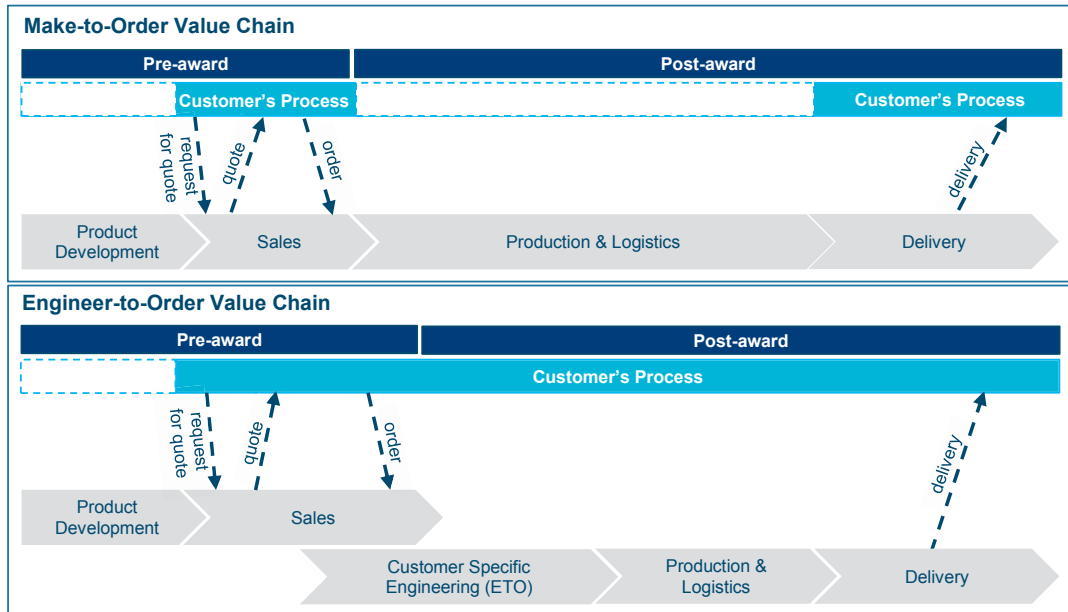


Fig. 2: MTO and ETO value chains

Compared to the MTO processes, the ETO value chain consists of an additional process: the customer specific engineering. In this phase, the design activities for a specific customer order are carried out. These can range from the engineering of small product changes to the design of a completely new product. Depending on the degree of engineering needed, the execution of the customer specific engineering can require many interactions with both internal and external stakeholders [23]. Customer specifications have to be discussed and analyzed between sales, engineering and the customer. The suppliers that are capable of carrying out the required engineering changes must also be identified, and production has to evaluate if the industrialization of the new ETO design is feasible. Finally, the aspects of the ETO design which should be integrated into the current standard have to be assessed jointly with product development.

## 5. Global Product Development in Engineering

To remain successful in the long run, the development of new products as well as the improvement of existing products is of utmost importance for manufacturing companies [24].

Many current best-practices in product development only consider the conventional development process, where the development activities take place “off-line”.

This is the development process typical for companies following an MTO strategy. As already addressed in the previous section, product development activities following the conventional approach are usually not attached to a specific customer order and are based on market forecasts. They are generally completed before the product is offered to the market. ETO products on the other hand require “online” or “contract” development processes, which allow for customer specific engineering [4].

ETO products can either be developed fully “online” or customer specific engineering changes can be made “online” to products previously developed in a conventional development process. “Online” development processes require many iterations and interactions involving various internal and external stakeholders and are often handled by a project management approach [4].

The pace of globalization has changed the product development landscape dramatically. Whilst in the past product development has primarily been conducted in the

respective home markets, a trend towards globally distributed product development is emerging. Globally distributed product development can be described as a “single, coordinated product development operation that includes distributed teams in more than one country utilizing a fully digital and connected, collaborative product development process” [1]. The development of contemporary information technologies and concepts such as Concurrent Engineering, Collaborative Engineering and virtual teams are considered as enablers for globally distributed product development [26].

Companies have different motivations for going global with their product development. A key argument is to achieve lower costs, e.g. taking advantage of labor arbitrage, raw material prices or transportation costs [1,18]. Manufacturers maintain product development and engineering facilities in foreign markets to satisfy local market needs, e.g. access to market-specific knowledge and execution of local adaptations [17]. Another argument for a GPD network is the access to a broader range of technologies or capabilities, e.g. to gain access to international knowledge centres and different technology or process innovations [1,18].

Managing globally distributed product development and engineering processes means coping with a large variety of complex challenges. Cultural and language barriers have to be overcome since engineers with different backgrounds and mindsets are working together. Even agreeing on a time for joint meetings can be demanding, when working on a common development project scattered over different time zones. Many companies, particularly those that have grown through mergers and acquisitions, apply different processes and IT systems at different locations. For the joint development of products, leading systems and processes must be determined, and methods for information transfer between different systems must be defined. In different regions material- and component suppliers also experience divergent needs for offering customer specific products. For instance, customer requirements can depend on climatic conditions, cultural preferences, or the development stage of a region, thus suppliers are often not able to deliver the same quality around the globe and some components might not even be universally available.

## 6. Case Study Companies

This section gives a short outline of the three case study companies. The companies all belong to the mechanical engineering sector and manufacture both MTO and ETO products. They are headquartered in Central Europe (Austria, Germany, Switzerland) and have engineering operations at more than two global locations.

### *Company A*

Company A is a leading manufacturer of elevators, here represented by its competence center for high-performance elevators. More than half of the elevators sold by the competence center require customer specific engineering. The customer specific engineering changes are not carried out by product development. Instead, a special department is responsible for the execution of customer specific engineering changes.

### *Company B*

Company B is a leading global manufacturer specializing in construction equipment, here represented by its asphalt mixing plants division. Around 20-30% of the plants sold require customer specific engineering. The department of product development is carrying out both the general product development as well as the customer specific engineering. The three main product development facilities are located in Switzerland, Germany and Italy. Product development is also performed in China, Brazil and India.

### *Company C*

Company C is a leading global manufacturer of ropeways. The company sells approximately 120 ropeways per year, and all ropeways require customer specific engineering to at least a minor extent, though this is often only a single, clearly identified assembly group (e.g. vehicle, pillars). Hence, the rest of the assembly groups can be treated as MTO within this case study. The department of product development is executing both the general product development as well as the customer specific engineering. The two leading product development facilities are located in Austria and Switzerland. Product development is also done in Germany, Italy, France, Canada and USA.

## 7. Findings and Discussion

From our review of the literature and the exploratory case studies, our findings show that product development and engineering processes for MTO and ETO products do in fact differ. Such differences provide the trigger for the different requirements ETO and MTO products pose on their globally distributed engineering processes. We propose a preliminary framework in which to structure these requirements according to their organizational and technological dimensions (Figure 3).

### *Organizational Requirements*

As depicted in Figure 2 the *Process Design* of the MTO value chain (based on the four phases product development, sales, production & logistics, and delivery), is fairly linear. In the ETO value chain however, the additional phase of customer specific engineering is prone to create a variety of process iterations and loops. A vast number of interactions between various departments is required to bring ETO products to market. A case study participant described these interactions as a “ping pong” game being played between sales, engineering and production with the goal to define product specifications correctly and to ensure that a customer specific product can be manufactured.

The *Responsibilities* for the development of new MTO products are well defined within the case study companies and formalized product development processes exist. In Company A the department responsible for the definition of the new products is not in charge of the engineering changes required for ETO products: This responsibility lies with a different department solely focusing on the execution of engineering changes. Both departments are present at several globally distributed locations.

|                                    | Product Development (PD) and Engineering for MTO Products  | Product Development (PD) and Engineering for ETO Products  |
|------------------------------------|--|--|
| <b>Organizational Requirements</b> |  |  |
| <b>Process Design</b>              | <ul style="list-style-type: none"> <li>linear process</li> <li>PD consists of one phase: General Product Development</li> </ul>  | <ul style="list-style-type: none"> <li>many iterations and loops</li> <li>PD consists of two phases: General Product Development and Customer Specific Engineering</li> </ul>  |
| <b>Responsibilities</b>            | <ul style="list-style-type: none"> <li>one general PD responsibility</li> <li>formalized responsibilities</li> </ul>   | <ul style="list-style-type: none"> <li>in some cases: division of responsibility for general PD and customer specific engineering (Company A)</li> <li>less formalized responsibilities</li> </ul>   |
| <b>Internal Relationships</b>      | <ul style="list-style-type: none"> <li>linear process with clearly defined interfaces between departments</li> </ul>   | <ul style="list-style-type: none"> <li>feedback processes between sales, product development and production regarding engineering changes required</li> </ul>  |
| <b>External Relationships</b>      | <ul style="list-style-type: none"> <li>customer involved in product configuration</li> <li>pre-defined preferred suppliers and components</li> </ul>   | <ul style="list-style-type: none"> <li>in some cases: customer involved in definition of engineering specifications</li> <li>in some cases: identification of new suppliers and development of new supplier components required (Company A)</li> </ul> |
| <b>Technological Requirements</b>  |  |  |
| <b>Product Structures</b>          | <ul style="list-style-type: none"> <li>static (are initially defined and later on only long-term changes are executed)</li> </ul>  | <ul style="list-style-type: none"> <li>dynamic (customer-order specific requirements have to be integrated)</li> </ul>   |
| <b>IT Applications</b>             | <ul style="list-style-type: none"> <li>process automatization possible</li> <li>product configurator: fast and efficient configuration technically possible</li> <li>ERP system: suitable</li> </ul> | <ul style="list-style-type: none"> <li>manual support processes necessary</li> <li>product configurator: "free components" imply exception handling</li> <li>ERP system: limited suitability (Company C)</li> </ul>                                    |

Figure 3: Differences in product development and engineering for MTO and ETO products – A preliminary framework

The organizational and geographical separation of the two departments makes it difficult to feed engineering knowledge gained during customer specific engineering activities back to product development. As our findings from the case studies show, engineering processes for ETO products are often not highly formalized. When asked if globally valid process instructions on how to perform engineering changes to ETO products exist, a case study participant from the asphalt mixing company replied that the high-level process has been defined by the headquarter, but that within the boundaries of that process the individual global locations decide independently how to proceed.

Interfaces and deliverables between departments within a company are well defined for MTO processes through the previously mentioned formalized process instructions. On the other hand, *Internal Relationships* regarding ETO products between departments within a company are more likely based on tacit knowledge and informal exchanges of information. Obviously, tacit knowledge is a lot harder to exchange and apply in a globally distributed setting. A case study participant emphasized "If you have different engineering locations, you cannot just go down to the floor below you".

When discussing *External Relationships*, we distinguish between relationships with both the customer and the supplier. MTO products are configured within a predefined solution space jointly by the customer and a sales engineer. Engineering is usually not involved in the configuration process. In ETO, the participation of the customer in carrying out engineering changes is only sometimes required. For instance, the customers of Company B usually have an extensive technical background and are experts regarding the wear of their plants. Hence, they often support engineering

changes connected to product-wear with their previous experiences. However, it was identified that most customers of Company C are not very proficient in regards to the technical details of a ropeway. They are mainly concerned with the functionalities and aesthetics of the end product. Therefore, their degree of involvement is quite small. The content of customer requests for engineering changes also depends on the region. The requirements in regards to product-wear and maintenance for the Swiss and Brazilian customers of the asphalt plant manufacturer are extremely different. Brazilian customers are much more willing to change wear parts and filters on a regular basis if this leads to a lower price.

The preferred components and materials for MTO products are usually defined long before a product is configured. The case studies conducted led us to the conclusion that the value-added achieved by a company internally is one of the key variables for determining to which degree suppliers are involved in the customer specific engineering required for ETO products. The ropeway manufacturer usually receives highly standardized materials and components (e.g. metal sheets) and executes engineering changes internally. Interactions with suppliers in regards to this matter are rare for the company. Nevertheless, the lift manufacturer requires suppliers to perform engineer changes. For highly customized products (e.g. panorama elevators) it might even be necessary to find new suppliers for customer specific components. Due to different levels of qualifications the lift manufacturer cooperates with suppliers in different regions differently. Suppliers in Switzerland often merely need a rough sketch and then carry out the detailed engineering on their own whereas suppliers in other countries need more support.

#### Technological Requirements

All three companies define *Product Structures* and the corresponding operational routings for their MTO products right after a new product with its variants has been developed. This knowledge is represented in product configurators and customers later select their preferred product variants within the predefined solution space. Since ETO products are developed to fulfill the specific requests of a particular customer, attributes describing these new variants remain to be defined and integrated into the existing product structures and operational routings at a later stage. All three companies experience difficulties when adding these so-called "free components" to their product structures. The lift manufacturer has to perform calculations manually when the dimensions of free components exceed certain limits. The search for and reuse of previously developed ETO solutions still has opportunities for improvement. The producer of asphalt mixing plants reports that engineers mostly use their memory and past experiences in order to recollect what has been engineered previously. However, when ETO processes become increasingly globally distributed, this tacit knowledge becomes less accessible and more capable IT solutions and processes to support knowledge formalization are needed.

Conventional *IT applications* are designed to process static process structures and operational routings. The lift manufacturer processes MTO products in a highly automated way. Layout drawings, purchase orders and operational

routings are derived from the product configuration with very minor manual effort required. On the other hand, the required effort for processing ETO products is considerably higher. ERP systems used in production usually require fixed product structures and operational routings. The ropeway manufacturer has found a remarkable work-around to keep lead times at a minimum by splitting up the product into 60 clearly defined modules which can be released one by one into production.

## 8. Conclusion and Research Agenda

This paper shows how the requirements that MTO and ETO products pose on globally distributed engineering processes differ. We identified the following differences along the organizational dimension: (1) ETO processes contain more iterations and loops than MTO processes and require more detailed feedback processes, (2) responsibilities for product development and customer specific engineering may be split up between different departments, and (3) the involvement of customer and supplier in the engineering process is more relevant for ETO products. The following differences can be highlighted along the technological dimension: (1) product structures for ETO products tend to be dynamic, and (2) full automation of ETO processes is often not feasible. These differences are to a large extent triggered by the customer specific engineering activities characteristic of ETO products. ETO processes are highly knowledge intensive and are often built on tacit knowledge. This knowledge can be anchored both inside and outside of company boundaries. Both technologies and organization are important enablers for making this tacit knowledge accessible. While eliciting this type of knowledge locally already proves to be challenging, the challenge becomes even greater on the global scale. The following questions still remain to be explored: How do ETO companies set up and manage their global engineering processes? How are engineering operations allocated globally? Do ETO typologies influence the suitability of a specific global engineering process for a certain type of ETO company? To shed light on these questions we intend to proceed with the multiple case study research. We plan to include additional companies in our study in order to gain a better overview of the field. We strive to identify patterns describing how ETO companies that possess different characteristics employ different types of global engineering processes. In this context, we will also try to determine the defining characteristics that distinguish ETO companies amongst each other. Further, we intend to identify best practices in the area of global engineering, which can serve ETO companies as general guidelines for improving globally distributed engineering processes.

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