Collaborative Customization Strategy for Complex Products – Prospects for Engineer-to-Order and Customize-to-Order Production Scenarios

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Abstract. To compete in globalized business environments, manufacturing firms, especially small and medium enterprises (SMEs), need to be collaborative with respect to their total product life cycle. In this research, a focus on complex products is proposed and a new approach to structure collaboration in design and operational activities is suggested. A complete framework and guidelines for collaborative product design, development and manufacturing is proposed with respect to two product development scenarios: Engineer-to-Order (ETO) and Customize-to-Order (CTO). The ETO scenario, which is project-based, and the CTO scenario, which is platform-based, are employed to respond to individualized and market driven production strategies respectively. The CTO scenario is developed using the platform-based product family concept, following a new approach that uses a product configurator and white boxes to assure sustainable customization. The research also explains how the transition from ETO to CTO can be implemented, aiming at improving the customization level and profitability of SMEs. The overall results, lessons learned and future research directions conclude the paper.

Keywords: Business collaboration, product design and engineering, collaborative bill-of-materials (BOM), engineer-to-order (ETO), customize-to-order (CTO).

1 Introduction

The business potential resulting from collaborative environments is receiving more attention from industrial organizations than ever before [1]. Today's market competition is forcing companies, especially small and medium enterprises (SMEs), to be collaborative in order to differentiate their products and gain advantage over larger firms globally. The increasing level of product variety, shorter product life cycle, unpredictable demand levels, unprecedented number of features and user-selected preferences are exerting extra pressure on SMEs. To cope with this situation, geographically scattered design teams are needed to work collaboratively on a virtual basis [2]. This collaboration can be enhanced by intra and inter-enterprise participants to work together from any geographic location.

Collaboration can start early in finding the immediate business opportunities and end up with taking advantage of those opportunities successfully. The business opportunities are ultimately the demand for specific products or product families which need to be designed and manufactured according to the customers' specifications and required features. In a networked business environment, the partners collaborate in the early conceptual phase of product development, where the necessary design and engineering are done with the objective of manufacturing the target product. During the conceptual design phase, the business partners communicate with each other and iterate various design options before choosing the best one. The conceptual design phase is followed by the detailed design and engineering stages, where the required design features are reviewed in terms of capacity, lead-time and costs.

The presented research defines the basic steps in developing both the ETO and CTO production scenarios in a collaborative business environment and also proposes a new approach to the customization of complex products based on transition strategy from ETO to CTO scenarios. In the ETO scenario, the customer suggests an idea/concept, time frame and budget, which are not just an updating of an existing solution but require specific functionalities. For complex products, the most challenging activity in this approach is to manage the long lead time. In ETO, detailed cost calculation and order specific engineering services are required.

On the other hand, in a CTO scenario, the development of a platform-based product family (PBPF) creates the possibility to offer the customer a wide variety of products with competitive costs. In this scenario, the product platform concept and a detailed business plan are needed to allow the business partners to comfortably decide the investment in such project. This research work proposes a CTO strategy, including all the methodological aspects, to manage the life cycle for such a PBPF and makes clear the differences and evolution paths from ETO to CTO strategies.

The rest of the paper is organized as follows: Section 2 presents a review of the existing literature on business collaboration with respect to product design and engineering, while Section 3 highlights the collaborative definition of BOM, which is necessary to structure the planning and control of operations. Section 4 and Section 5 present the scope of business collaboration in ETO and CTO production scenarios respectively. The transition of business scenario from ETO to CTO according to market opportunity is illustrated in Section 6. The basic outcomes from this research are discussed and concluded with future research directions in Section 7.

2 Literature Review

The growing concern with customer-tailored products creates tremendous challenges for product manufacturers in terms of costing and profitability. To achieve the solution for such challenges, manufacturing firms are focused on the joint development of product and process strategies for specific market needs [3]. This business strategy allows the identifying of ways to reduce the development cost and time for target products through sharing knowledge and resources. Distributed design, engineering and manufacturing provide the expected value chain integration among business partners, which opens new opportunities for collaborative work improvement [4].

Collaborative product development supports design innovation and increased productivity [5]. Moreover, design collaboration facilitates complicated interactions among multidisciplinary and globally distributed design teams through cooperation, coordination and communication [6]. Enhanced customization is enabled by business collaboration, where partners share their valuable knowledge and resources to be competitive in the market segment [7]. This strategic vision requires a distributed information network among partner organizations in order to facilitate up-to-date product and process architecture throughout the product's lifecycle.

In the complex product development process collaborative design and manufacturing also have influence over the customer order decoupling point, in the case of both ETO and CTO scenarios [8]. It provides practical benefit for achieving true customization through individualized product and/or offering product variants [9]. The demand for more personalized products forces manufacturing companies to evolve from an ETO to CTO production scenario to gain wider market segments. In order to be successful in collaboration for both ETO and CTO scenarios, the network partners need to ensure integration among engineering data management (EDM), product data management (PDM), product information management (PIM), technical document management (TDM), and technical information management (TIM) [10].

3 Collaborative Definition of BOM

In collaborative product design, engineering and manufacturing in the network, the most critical aspect is to create a BOM of the target product. The development of the BOM can be started as soon as the conceptual design is done and can be expanded or updated according to further design improvement. Usually, in the early stages of a new product design and engineering, the network partners' design teams create the first BOM, which is also known as product structure or engineering BOM.

The detailed level of the final BOM is confirmed after securitizing the multiple BOMs created and iterated within the partner organizations. Along with the component hierarchy, the detailed BOM usually contains a component hierarchy along with the required interfacing and materials. This BOM helps to allocate essential tooling, and defines the manufacturing processes that include routing, scheduling, and resource planning. This ensures an identical view of the target product and process definition among the cross-functional design teams of the network partners. It also contributes to promoting true collaborative engineering in the early stages of design, and optimizing the work between design and manufacturing.

The definition of the BOM is critical for all operations after the product design, including collaborative budgeting, operations planning and control. During the BOM definition, component suppliers can be searched for by browsing partners or giving search criteria and comparing with potential partners. In such an environment, the collaborative partners might develop their own substructures, thus maintaining their own BOM data in the same context.

The definition of collaborative BOM (CBOM) can be stated as the structure of components that are designed and developed among distributed partner organizations with the objective to assemble to the end product. This CBOM guides the individual partners in essential planning in terms of operational routings, parts sequences, product coding, selection of potential supplier, etc., as presented in Figure 1. The ICT-based CBOM also supports the required modification of the operational sequences and/or production routings in real time according to the production requirements. This real time information update is made visible to the other partners with a view to adjusting their production processes if needed. The semantic model for CBOM as displayed in Figure 1 saves on production quantity and cost along with the description of the product/operation/part, too. This information management approach to the product structure enables the defining and creating of high level production batches comfortably within the collaborative business network.

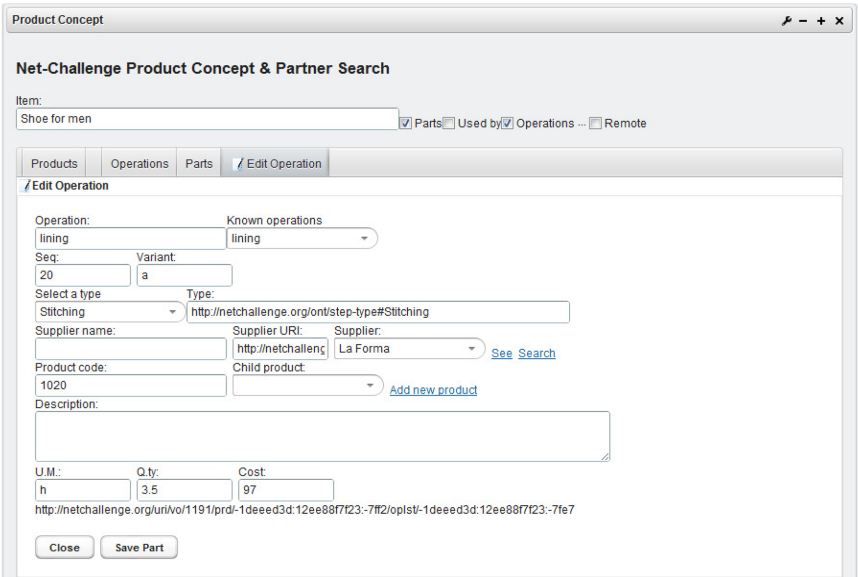

Fig. 1. Display of manufacturing operations of an example collaborative BOM.

4 Business Collaboration in the ETO Scenario

The basic concept of the ETO production scenario is to develop and manufacture one-of-a-kind products, where the customer expectations for an individual product are fulfilled. The motivation behind the ETO scenario is to develop and manufacture a custom-made product collaboratively, where Virtual Organization (VO) partners participate in the complete product development process starting from the conceptual design phase to the final product design and development phase. The collaboration enables partners to fulfill more challenging business opportunities such as sharing costly resources, time consuming workloads, fatal risks and replying faster to customer requests. This approach is project-based, where the individual customer order is initiated after consulting with the customer in terms of his/her desires, emotional needs and requirements of the end product.

In this approach, the partners collaborate to define the product concept and quotation and form a VO after the customer order confirmation. After forming the VO, the VO enters the operation phase, where the customer order is deployed to the involved partners, followed by detailed product engineering and detailed collaborative planning. The required product specification, drawings and BOM are done at the product engineering sub-phase, while in detailed collaborative planning essential routings for the production processes are defined in order to achieve the confirmed delivery date of the final product. In this sub-phase, required calculation for the delivery lead time is performed. After confirming the delivery date, the process continues with the production execution and monitoring. In the production execution process, any abnormality or unforeseen events in the operational processes are monitored and managed in order to avoid unnecessary problems or risks.

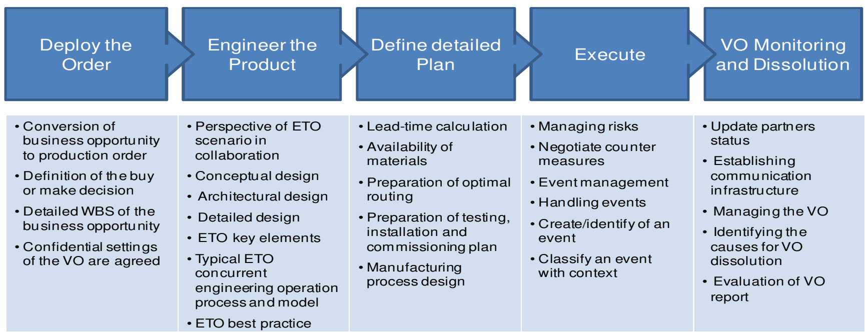

Fig. 2. High level operational sequence of collaborative ETO scenario.

Figure 2 presents the high level phases of the ETO VO Operation. In this phase, the VO partners monitor the production process and update the operational activities. A communication infrastructure is established in order to manage the entire VO. During this phase, possible causes for dissolving the VO are identified and a time frame is confirmed for dissolution. When the objective of developing collaboratively a one-of-a-kind product is achieved, the next stage is dissolving the VO as it was developed temporarily within a predefined timeframe. Before dissolving the VO, overall evaluation reports are sent to the collaborative partners.

5 Business Collaboration in the CTO Scenario

The result of the CTO production scenario is the collaborative development of a product platform, from where a stream of product variants can be specified and manufactured efficiently and economically, as required to meet customers' expectations. The main idea is to create a family based product platform, defining the common sets of components or modules to be used for delivering different product variants [11]. The platform offers cost efficient and enhanced customization features by adding and/or replacing customized components and/or modules within it. The variants created on the platform should be optimized from the manufacturing and logistics point of view and it should not be possible to generate incompatible combinations of parameters. The possibility to define special requirements for some components or functionalities (white spots) provides enlarged customization possibilities.

During the formation of the collaborative VO, the platform concept is developed and the high level design and the main rules are agreed. The role of the VO partners is to support the agreed interfaces and propose features and options that will fulfill the market needs. The product platform can be considered ready when the price, lead-time, high-level BOM and routing list can be generated automatically from the model. The business model of the platform is also agreed during the VO formation phase. The high level structure of the collaborative CTO VO operation is presented in Figure 3.

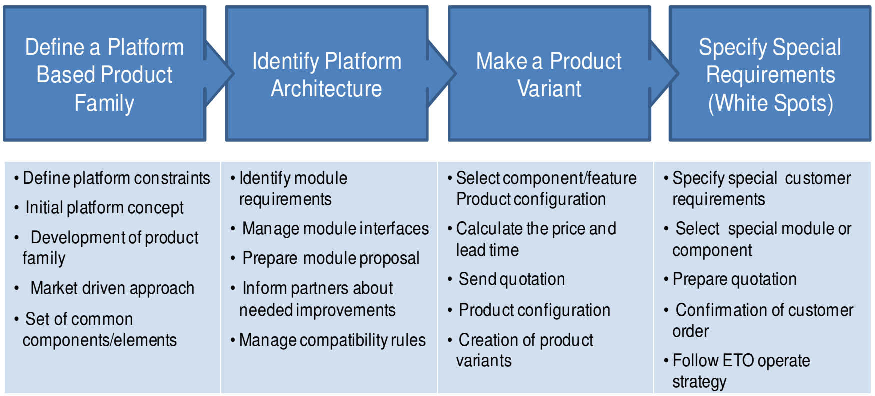

Fig. 3. High level operational sequences of collaborative CTO scenario.

From Figure 3, it can be seen that the CTO scenario starts with the detailed development of a product platform, which is the prerequisite to successfully configure a product variant in accordance with a customer enquiry. The second phase of the CTO life cycle is to identify the platform architecture. This phase starts with the generic concept of the product platform architecture. The most important and time-consuming phase during the platform architecture definition is the interface management among the modules. The interfaces may have technical (dimensions), feature-based (material or color) or non-tangible relations (drivers). The platform can be initially designed as feature or component-based.

The consecutive stage after indentifying the platform architecture is to make a product variant. This phase starts with the identification of specific customer requirements to create a customized product variant.

The last phase of the CTO life cycle is the specification of special requirements (white spots). In this phase, special requirements from the prospective customers are collected. In order to fulfill such special requirements, the VO broker (initiating partner) consults with the collaborative partners for developing a specific module or component termed as 'white spot' that could satisfy such unique customer requirements. If there is a possibility to produce the specific module or white spot, the broker proceeds by defining the necessary price, lead-time, etc., with a view to preparing the updated quotation.

The proposed approach is revealed to be very powerful, as it can be implemented from an IT point of view with a product configurator, with the capability to manage white spot.

6 Transition from ETO to CTO Scenario

In this section, the scope and usability of the transition from ETO to CTO scenarios is demonstrated with respect to business potential and fulfilling customers' needs. In general, the ETO scenario is customer-driven or project-based, where a specific type of product or product group is developed in terms of unique design and specification. The CTO scenario is market-driven, as it responds to a broad business opportunity and customers are given the possibility to customize an existing solution and the output is a stream of products resulting from a configuration process with optional white spots.

Most SMEs do not have a strong product strategy and structured approach to product customization. Inconsequence, they become dependent on subcontracting and often are forced to compete on price. European SMEs have strong technical skills and are able to follow an ETO strategy more easily than a CTO one. It is therefore considered an important need to make a transition from ETO to CTO scenarios, which allows SMEs to enable and to manage overall competitiveness and sustainability. The detailed transition from ETO to CTO is presented in Figure 4.

In Figure 4, it can be observed that when a business opportunity is identified, the business partners need to check out its possible consequences. If the identified opportunity is highly customized, the business partners need to follow the ETO production scenario. In this approach, the collaborative partners form a specific VO with the objective of developing and delivering a custom-made or one-of-a-kind product. After forming the VO the next available step is to operate the VO in terms of detailed designing, engineering, scheduling, routing and manufacturing the expected product. When the specific customer requirements are fulfilled through VO operation the last step is to dissolving the VO. At this stage, the partners are evaluated with respect to fulfilling the business targets as set during the VO formation.

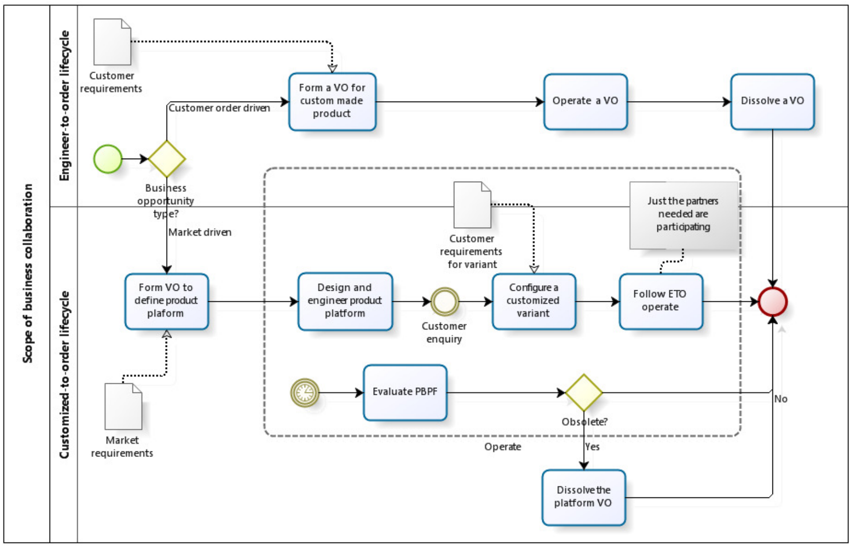

Fig. 4. Generic scope of the VO life cycle in a collaborative business environment.

Also in Figure 4 it can be noted that when the business opportunity is assessed to be market-driven the business partners move forward to accept the CTO production scenario. The objective of adopting this scenario is to develop a platform-based product family from where a stream of product variants can be customized. To adopt the CTO approach according to market demand, the collaborative partners form the necessary VO with the view to defining the product platform. In the operational phase of the VO the necessary detailed design and engineering of the platform is done. At this stage, the possibility of the individual customer's need for a variant is checked out for configuration purposes. When there is a possibility to configure an individualized product within the CTO scenario, the ETO operational steps are followed.

This ETO operational strategy within the CTO environment requires partners experienced in the ETO scenario, which in any case is the most common for SMEs. This operating environment develops the possibility to define a new module or component (known as white spot) according to the customer needs. If the new module or component (white spot) attracts an increasing level of interest from potential customers it can be merged to the platform for future use. During the VO operational phase, the developed platform is evaluated with respect to its outcomes and might be dissolved when it is considered obsolete over time. After fulfilling the objective of platform-based product family (PBPF), the necessary steps are taken to dissolve the previously formed VO. During the VO dissolution process, generic assessment is done in terms of performance evaluation of the partners, assessing the general liabilities of the partners and terminating the contractual agreements. The performance evaluation and the knowledge achieved from forming and operating the VO is stored for future use that will allow the enrichment of the business community.

The presented transition scenario from ETO to CTO supports the collaborative partners in designing and developing their products according to market demands. From the analysis, it is clear that the product development strategy can be changed according to customers' requirements. If the customer asks for an individualized (one-of-a-kind) product, then the developmental strategy should be ETO-based. On the other hand, if the products are developed for the mass customized market, it has to be then the CTO approach, where the product variants are created from the basic platform. In business collaboration, the partners decide whether the production scenario is market-driven (CTO) or customer order-driven (ETO) depending on the future business opportunities. However, on some occasions, the CTO approach can be merged with the ETO scenario when there are options for the customer to tailor his/her choice of product. This combined approach supports business organizations in adjusting their production processes according to the level of customization offered by them.

7 Conclusions

Business collaboration creates ample opportunities for manufacturing firms to survive healthily in today's competitive markets. This collaboration can emerge by forming virtual organizations that might be shorter or longer term. The VO duration depends on the business opportunity type and the commitment from the partner organizations. These networked businesses are especially important for SMEs, where there are often shortages of available and valuable resources and knowledge, which are the deciding factors for business sustainability. There is also a lack of proper communication infrastructures among SMEs which might allow them to be collaborative and enjoy the benefits of collaboration. The success of business collaboration depends not only on suitable qualified partners but also on the proper selection of the right ICT tools necessary for seamless information processing and to act in dynamic business environments [12].

In this research the fundamental requirements for collaborative business environments are presented with respect to product design and development, starting from the conceptual design phase and ending with manufacturing and control processes. The collaborative definition of the BOM is presented as a key step in this business collaboration.

To enable the long-term sustainability of SMEs two scenarios for the development and delivery of custom-made and customized products were developed, namely the ETO and CTO scenarios. The transition from an ETO to a CTO scenario was developed in this study, to allow the competitive delivery of customized products by SMEs. The very common situation with developing customized products is that the number of final products with an individual BOM will increase dramatically. The proposed concept makes the component commonality higher and the manufacturing of the customized final product more cost efficient.

The presented approach was validated with pilot companies from the textile and footwear sectors. An extension of these research results can be implemented in other real life industrial case networks in order to verify and validate the approach. The outcomes from such case applications might reduce the limitations of the presented approach and can be useful to fine tune these research results.

Acknowledgements

The authors would like to acknowledge the co-funding of the European Commission in NMP priority of the Seventh RTD Framework Programme (2007-13) for the Net Challenge project (Innovative Networks of SMEs for Complex Products Manufacturing), Ref. CP-FP 229287-2. The authors also acknowledge the valuable collaboration provided by the project team during the research work.

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