A Conceptual Framework for Stage Configuration

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Abstract.
Increased competition for creating best business cases in the ETO and capital goods industry forces companies to provide increased variety of product configurations to match diverse operating conditions, while simultaneously reducing the cost of supply. The ETO and capital goods industry is further characterized by rapid new technology introductions, constantly setting new standards in product performance and by an external environment with frequently shifting local regulations. To remain competitive in this volatile and unpredictable situation, this paper suggests a conceptual framework enabling companies to align new product development with sales order processes in a step-wise approach using product configuration. This alignment supports a five-stage approach in committing order specifications, thereby postponing configuration decisions according to the maturity of the sales order. Moreover, the stage-wise postponement enables the management of product specifications on different aggregation levels. The committed level of specifications, targets the relevant decision-making processes in product configuration without needless over-specification of the product. The stages are 1) qualifying a sales opportunity, 2) recommending an optimal solution, 3) signing the sales offer and performing supply chain planning, 4) releasing the order for production and completing customer specific design, 5) executing production, transportation and service operations.

Keywords: Staged Configuration, Conceptual Framework, ETO, Capital Goods

1 Introduction

Tendering and transparent bidding schemas increase competition in the Engineer-To-Order (ETO) and capital good industry. This is the result of decreased sales prices, greater expectations to product performance, as well as the demanded flexibility to adapt product offerings to customer unique and diverse requirements. This forces companies to quickly offer an increased number of variants early during new product development, and provide engineered solutions outside the standard solution space to match specific operating conditions and improve the customers' business case [1]. Providing more product variants while reducing cost has been researched by numerous scholars in the domain of mass customization. Mass customization is a business strategy enabling manufacturers to customize product offerings to individual customer requirements at a cost near mass production [2]. In this context, business processes must be robust towards product variety and directly linked to the information generated through product selection, usually implemented using product configurators, as all information used in the subsequent processes are derived from the configuration process. In addition, the integration between configurators and the subsequent processes can have great influence on the efficiency of these processes [3].

Although mass customization was originally intended for the consumer market, the enablers of mass customization have gradually been applied in other markets as well, including capital goods and ETO oriented markets [4]. However, since most traditional configuration approaches are aimed at mass customization, they do not necessarily fit the needs of ETO and capital goods companies [5]. For instance, in ETO companies, product requirements may be gradually determined over time, implying that not all variables can be decided in an early configuration process [6]. Furthermore, in ETO supply chains, availability, sourcing, local regulations etc. may influence the configuration processes, which is also not supported in traditional product configurators [7].

To solve these challenges, Brunoe [8] developed the concept of multi-level configuration to address the management of stage-wise postponing decisions in product configuration for complex ETO business and manufacturing processes. Zeng [9] introduced the concept of staged postponement of committing order specifications. The concept supports a gradual commitment of product features and order attributes during the order delivery process. This enables gradual decision making in the value chain without creating excess and uncertain product information. Through a sales configurator prototype, Kristianto et al. [6] suggest a concept for a system-level product configurator for ETO supply chains, thereby stage-wise automating the connection between the design of a global product structure, value chain processes, and ETO design activities. Czarnecki et al. [10] propose the concept of stage configuration through cardinality-based feature modelling. In this concept, feature models have dedicated configuration choices, which specified, results in new feature models prepared for further configuration until a finished variant is achieved.

The above-mentioned research deal with specific domains within complex ETO product configuration and are thereby limited in terms of a consolidated concept, that can be applied to manage and adapt product configuration in the ETO and capital goods industry. Thus, the purpose of this paper is to address the research question; How can product configuration decisions be divided into stages to increase the support of ETO and capital goods business processes, thereby enabling stage configuration?

2 Method

To address the research question and thereby define the concept of stage configuration, empirical requirements must be captured and organized to frame an abstract approach for performing stage-wise product configuration in the ETO and capital goods industry. To collect such requirements, this paper applies a requirement engineering methodology proposed by Pandey [11], in a Danish case company, see adapted methodology in figure 1. The company produce capital goods for the energy sector with great diversity in market reach and the capability to configure a wide range of products to accommodate local regulations, diverse operating conditions, market fluctuation etc. The company must further be flexible to react to individual customer requirements outside the standard solution space.

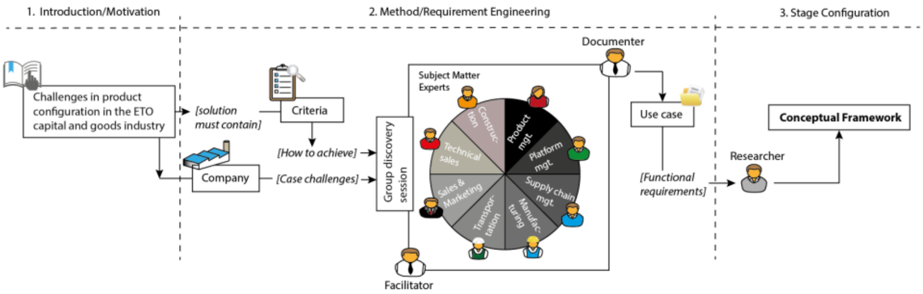

Fig. 1. Requirement Engineering using Group Discovery Sessions

To do so, the company wants to adapt a stage-wise approach to product configuration, enabling the supply chain to operate on different specification levels according to the maturity of the sales order. Further, the company pursues this implementation through the employment of the following main criteria; 1) step-wise committing product specifications, 2) flexibility for adapting and changing product specifications, 3) autonomous interlinkage between product configuration and supply chain processes, 4) management of complex engineering knowledge, and 5) configuration of non-standard solutions. Requirement engineering is a facilitated and systematic approach, where subject matter experts join in face-to-face discussions with the purpose of consolidating requirements towards a business initiative [11]. The business initiative originates from the mentioned criteria. Subject matter experts are stakeholders, which are either impacted by or will influence the new business initiative. In this research, the discussions were divided into group discovery sessions with themes defined by senior configuration specialists, senior supply chain specialists, and chief specialists in product management, joined by different key stakeholders from the entire organization.

3 Conceptual Framework for Stage Configuration

In Fig 2, the framework for staged configuration proposed in this paper is illustrated. The framework facilitates a stage-wise commitment of product specifications throughout the sales order process, aligning it with stages in solution space modelling for new product development. The left-hand side of the framework denotes the relevant business processes and the x-axis denotes the time. At the top of Fig 2, the stages of solution space modelling, i.e. the development of product family models and implementation in a configuration system, are presented with corresponding gates for the stage-gate approach to new product development [12]. At the bottom, the stages in the sales order process are presented with timings for committing product specifications. Both the stages in solution space modeling and the sales order process loop between business processes until a "go" decision can be made. In each stage, information is transferred to the configurator and distributed to be applied in later stages. The timing of the sales order stages indicates when they can happen at the earliest.

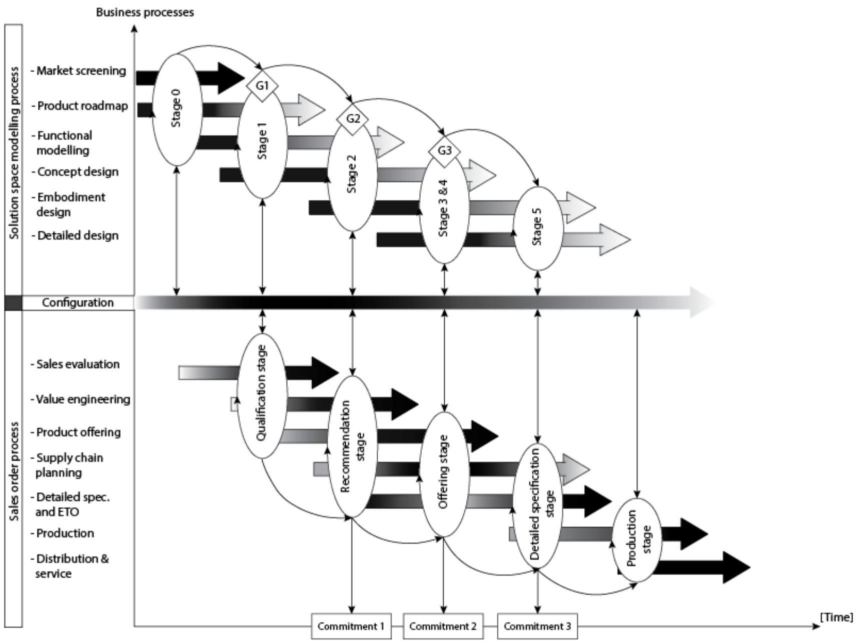

Fig. 2. Stage Configuration Conceptual Framework.

3.1 Qualification stage

The purpose of the qualification stage is to enable the user of the sales configurator to explore and communicate with customers on opportunities to co-create a profitable business case without having detailed knowledge of product specifications. Requirements to the product do not need to be translated to product functionalities by the customer. Instead, the customer focus on defining the boundaries for the opportunity and operating variables. Due to the high-level modelling of the solution space, the qualification stage provides an agile and fast response to key stakeholders and customers when competitiveness in tender rounds must be assessed and prioritized. Further, an engagement from both the customer and the company can be accepted without making any commitments, thereby using the configurator solely as a co-creation platform. The business processes involved are 1) Sales evaluation: Sales engineers use the configurator to access information provided from stage 0 and 1 in solution space modelling. Through the configurator, sales opportunities can be evaluated and communicated with key accounts to further investigate the fit with market and account strategies, and to clarify main risk through a risk assessment. 2) Value engineering: When the objectives and requirements are defined for an opportunity, a preliminary recommendation can be presented using the configurator. The recommendation is based on main characteristics from the solution space, performance of the configuration, cost and operating assumptions. Because the sales order process is in a very early stage, this information is somewhat uncertain. There is uncertainty in the performance of the product, the cost, and the variables defining the operating environment. 3) Product offering: Based on the recommended configuration, sales engineers seek to optimize scope and increase the value of the opportunity by offering a non-binding business case or indicative offer, with a minimum acceptable contribution margin. By assessing the offer, it should be considered if a solution outside the standard solution space provides a better business case.

3.2 Recommendation stage

From an initial business case assessment, the customer and the company can decide to engage in further exploration of the optimal configuration, either by joining forces in tendering rounds, suppling an end-customer, or through further negotiation in a traditional B2B sales process. At this stage, value engineers can calculate the optimal configuration in detail by applying a more mature solution space, consisting of main characteristics and constraints. In order to only include relevant configurations in the calculations, the customer can further constrain the solution space by defining requirements for acceptable performance measures, investments cost, local product regulation etc. The cost of the recommended configuration is gathered from the manufacturing footprint established in Sales and Operation Planning (S&OP) and managed by supply chain planning. Not all product characteristics need to be committed in this stage. If a characteristic does not have a significant effect on product performance, cost, or is crucial in securing capacity at vendors or production sites, it can be postponed for later specification and thereby mitigate uncertainties.

The involved business processes are 1) Value engineering: In the recommendation stage, the level of detail increases as the sales order process matures. At this stage, the solution space is elaborated with additional standard and customer unique product characteristics and functionalities. This enables value engineers to reduce uncertainty and through the configurator perform simulations to optimize how multiple configurations interact and operate, resulting in one final recommendation. 2) Product offering: Due to volatile and fluctuating market conditions, the customer is often conservative in committing a complete configuration and will have to postpone some specification decisions in order to preserve the possibility to adjust the configuration according to both future technical development and changing local regulations. However, because the optimal configuration was elicited in the value engineering process, the customer can commit characteristics with high impact on performance and cost, and postpone the specification of options and auxiliary systems to be decided in the next stage, thereby mitigating future unforeseen restrictions and possibilities. 3) Supply chain planning: The sales offer and the partly specified configuration will be included in the sales forecast. From the forecast assessment, the sales forecast enters S&OP. The output is a batch-based allocation of production on a regional level, with corresponding production slots, lead-times and committed product characteristics. The indicative/binding configuration created in value engineering is part of the batch allocation and subject to further processing and specification as the sales offer mature. 4) Detailed specification and

ETO: The recommendation proposed in the value engineering process can deviate from the standard product program and recommend a non-standard solution. If a non-standard solution is recommended, the company must perform feasibility studies on alternative designs and create a compatible solution, which fulfill general specifications. Based on the design, cost estimations must be added to the non-binding offer.

3.3 Offering stage

With an accepted configuration from the recommendation stage, consisting of committed main product characteristics, the purpose of the offering stage is to move the sales offer towards an unconditional signed order through negotiations with the customer. To do so, the customer must further configure the configuration to include more characteristics and options. This must be performed to secure exact cost calculation, detailed capacity allocations and lead time commitments. Although the configuration must be specified in further details, characteristics and options with less influence on product cost and performance can be step-wisely postponed throughout the supply chain planning process. This postponement provides the customer with the flexibility to commit options in a step-wise manner according to supply chain constraints on lead times, inventory, and capacity.

The involved business processes are 1) Product offering: The configurable solution space now includes options and technical system attributes. The technical attributes define the product design to a level where it is possible to commit a final offer and a signed contract. The final offer does not have to include all product characteristics, but options requiring long lead-times must be committed together with main characteristics to comply with delivery constraints. 2) Supply chain planning: Before the company can sign an offer, decisions must be made regarding from where the product should be sourced. This is performed as the first step in the Master Production Scheduling process, where capacity slots occupied by the sales forecast is converted into sales orders with actual configurations. Production is allocated to factories based on minimizing the cost across the company´s delivery portfolio, while obeying lead time and inventory constraints. 3) Detailed specification and ETO: Beside allocating production and preparing capacity for the sales order, the design must be further matured in order to commit the exact cost of the configuration into the offer. The information needed contain 3D documentation of the main product structure, product and production drawings, design documentations, and material creation.

3.4 Detailed specification stage

The purpose of the detailed specification stage is to enable the customer to postpone the last product specification just in time before approval for production. By doing so, the company can limit themselves to only maintain and create variants which are going to be produced, including BoMs, design, and information enabling manufacturing. Timing is crucial in this stage, as a too late commitment will delay the delivery date. The customer gains benefits in postponing product options just in time, and the company gains benefits in avoiding managing frequent change to the configuration.

The involved business processes are 1) Supply chain planning: Following a signed order, the detailed master planning activities have resulted in a preferred factory to source from, with corresponding and adjusted lead-times. The lead-times trigger a forced decision on whether the sales order should be approved for producing and purchasing materials or it should be postponed e.g. due to non-fulfilled contractional obligations. If the order is approved for production, a purchase requisition is generated to the factory for purchasing the materials. The product must be completely specified and configured before approving it for production. 2) Detailed specification and ETO: Before approving the sales order for production, the final design including 3D documentations and design drawings must be finalized. To achieve this, the final product variant is configured in the PLM system, generating the final related design and production BoMs. The BoMs are added to the product modules, developed in stage 3 and 4, and transferred to the factories where the BoMs are selected for production. 3) Production: When the sales order is approved for production, planned orders are converted into production and purchasing orders, depending on the make/buy setup. From these orders, the factory makes production scheduling and prepares the necessary adjustment to routings for non-standard solutions, updating relevant information in the Manufacturing Execution System.

3.5 Production stage

1) Production: It is not possible for the customer to make further specifications of the product in the production stage. The production processes focus on executing production and purchasing orders created in the detailed design stage. After completing production, the product in stored as finished goods inventory and from there transported to the delivery destination. Documenting the specification as-produced enables the possibility to create configuration transparency throughout the value chain. 2) Distribution and service: The vendor selected for delivering the needed materials also defines which spare parts should be managed in the service business. For capital goods, which typically include service agreements, it is not favorable to divide the purchase of the same material number on multiple vendors, because that may require more inventory, different tooling, different interfaces to other components and extensive complexity in planning regular maintenance. The vendor selection is also crucial for configuring the transport solution and determining which transport equipment is needed.

4 Conclusion and Future Work

In this paper, we present a conceptual framework for stage configuration. The framework is created based on data from a case study performed at a large capital goods company and is therefore specific to the setup of that company. The framework aligns solution space modelling in stage-gate new product development, with sales order processes by using a product configurator to facilitate the information flow between the two domains. Compared to previous research, this framework integrates the development of ETO and standard product design with value chain processes using product configuration, thereby enabling a stage-wise postponement of configuration decisions. This is further managed under the conditions of long order horizons, with frequent changes in product specifications, and extensive complexity in product architecture. By applying this conceptual framework, companies will gain benefits from specification flexibility, transparency in order uncertainties, and the capability to manage product configurations without creating excess amounts of unnecessary information impacting and demanding resources throughout the entire organization.

The framework is still conceptual and requires further research to investigate how to operationalize each stage in different contexts and industries. We suggest that the main topics of future research in stage configuration should focus on the following questions: 1) How does decisions in both the sales order process and the solution space modelling process impact each other? 2) How can partly and aggregated product specifications be applied in detailed values chain processes? 3) How can a configurator be applied to optimize the match between the operating environment and the recommended solution? 4) How can solutions outside the standard solution space be an integrated part of standard stage configuration?

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