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Published in:
Proceedings of the 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

Link to article, DOI:
10.1109/IEEM.2015.7385953

Publication date:
2016

Document Version
Peer reviewed version

Utilizing Product Configuration Systems for Supporting the Critical Parts of the Engineering Processes

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Abstract – **Engineering-To-Order (ETO) companies have to respond to increasing demands to provide highly customized and complex products with high quality at competitive prices. In order to respond to those challenges ETO companies have started to implement product configuration systems (PCS) to increase efficiency of the specification processes. As a result to complex products and processes in ETO companies, PCS are usually gradually implemented where only subsets of the products are included to support specific processes. However, a systematic way to identify and evaluate the products and the processes to be supported with the PCSs is not described in the current literature. This paper aims to pursue that research opportunity by presenting a framework, which aims to identifying the critical parts of the engineering processes in order to identify where it most beneficial to implement a PCSs and how to prioritize the future PCSs projects.**

Keywords – **Engineering-To-Order (ETO) companies, product configuration system (PCS), process improvements, critical parts of the engineering processes**

I. INTRODUCTION

In order to respond to fast changing business environment and increasing demands from customers Engineering-To-Order (ETO) companies are increasingly applying product configuration systems (PCSs) in order to increase the efficiency of the sales and engineering processes.

PCSs are used to support design activities throughout the customization process, where a set of components along with their connections are pre-defined and where constrains are used to prevent infeasible configurations [1]. PCSs have proven to provide various benefits in terms of shorter lead-time, on time delivery, improved quality of the product specifications, less routine work and increased customer satisfaction [2]. As the most important decisions regarding products capability and cost are taken in the early phases of the sales and engineering processes [3], PCS have also proven to help the companies to improve that decision making process [4]. Furthermore, PCSs are tools that ETO companies can use to increase the sale of more standardized products and thereby helping companies to have more control of their product variety offered to the market [5].

Due to the complexity of the processes and the products in the ETO companies, PCSs are normally used to only support a specific part of the sales and engineering processes or a subset of the product family Hence, there is a need for guidelines to recognize the critical engineering processes in order to identify where it is most beneficial to apply a PCS in such an environment. In this paper the aim is to answer these questions by proposing a framework to identify the critical engineering processes and evaluate different alternatives in order to find the most beneficial specification processes to be supported with a PCS in order to prioritize the future PCSs projects.

The research methodology in this paper is structured in two phases. The first phase is dedicated to the development of the framework, which is based on both literature and experience from working with PCSs in ETO companies. The second phase is concerned with the testing of the framework. For that purpose a project team was formed, in an industrial ETO company operating in the building industry, including two researchers from the Technical University of Denmark and experts from the company.

II. LITERATURE REVIEW

The literature review is focused on the specification processes in ETO companies along with the benefits and the challenges in ETO companies that have implemented PCSs.

ETO companies can be defined where the re-engineering of the product is done after receiving the order and before the production [6]. Due to the fact that the products are often large and complex systems, where the products are custom designed for each customer, the sales process is much more intensive in ETO companies [5]. Haug et al. [7] describe products in ETO companies in turns of where a design is made on a high level of abstraction in the sales phase and a detailed design is carried out after the customer has accepted the quotation. Examples from the literature support that normally PCSs are only used for a design on a high level of abstraction in ETO companies, because it is extremely time consuming to define the solution space on a detailed level [7]. Paunu and Mäkipää [8] acknowledge that design configurators can be used to automate the engineering order process and thereby decreasing the lead-time for product quotations and moving ETO companies closer towards mass customization.

The main benefits ETO companies can expect when implementing a PCS are described as the following; improved fit with a customer's unique needs, increased efficiency due to lower inventory levels throughout the distribution channel, ability to raise the price of a good or a service, improved ability to analyze opportunities due to continues dialogue with the customers and increased efficiency of the business processes [9][10]. The main challenges for ETO companies when implementing a PCS are listed in terms of product characteristics, customer relations and long time span of the projects [9]. In order to overcome these challenges, it is suggested that modules are decoupled from each other and thereby make it possible to configure products in a structure that has not been previously defined but fulfils all requirements, finally it is suggested to configure products on multiple level of abstraction [9][11].

For ETO companies that want to utilize a PCS in order to support the sales and engineering processes, there is a need for more structured approach to break down the overall processes so the most critical processes can be identified and analyzed. This will help to identify the greatest potential for utilizing a PCS.

III. FRAMEWORK DEVELOPMENT

The framework consists of three steps. In the first step the operational objectives and the critical engineering processes are identified. In the second step the critical engineering processes are analyzed in order to determine the most promising scenarios and to determine the scope of the system. Finally, in the third step the future PCS projects can be prioritized. The individual steps of the framework and sub steps are listed below:

1) Identification of operational objectives and company critical engineering processes
    - Determining operational objectives
    - Identification of critical engineering processes
2) Analysis of the critical engineering processes
    - Analysis of the current processes
    - Performance analysis
    - Scenario generation and scoping of the system
    - Cost benefit and risk analysis
    - Selection of scenario
3) Selection and prioritization of the processes to be supported with a PCS

A. Identification of operational objectives and critical engineering process criteria

As stated in the literature, PCSs are often used to support only part of the engineering processes in order to make the PCS manageable in the development phase and to minimize the risk [12]. The first step is therefore to identify the operational objectives that should be reached by the implementation of the PCS and to identify the processes that are critical to the overall processes of the projects carried out at the company.

Operational objectives: Operational objectives for PCS project are often listed in terms of; reduction in lead time for product customization and document generation, less resource consumption for producing the product specifications, higher quality of the products specifications, higher independency from product experts and etc. [13].

Identification of critical engineering processes: In order for engineering processes to be labelled as a critical process, it has to have a remarkable contribution to the operational objectives. Aligned with this purpose, the following criteria can be used to identify the critical engineering processes: 1) the process is important to the overall quality, 2) time duration of the process has a great impact on the lead-time, 3) the process has a great impact on other processes (if changes are made that will have an impact on other processes which can result in rework), and finally 4) the process needs expertise knowledge that is not accessible to all employees at the company. Furthermore, Hvam et al [13] describes that the most important specification processes can by identified with regards to the output from the processes.

B. Analysis of the critical engineering processes

After identifying the critical engineering processes, the next step is to evaluate the potential of supporting those processes with a PCS. The following steps should be applied to each of the processes identified in the first step.

Analyses the current processes: Having a standard definition of the current processes is a fundamental step in order to identify how the current processes can be supported with a PCS. For this purpose flow charts are commonly used with Business Processes Modelling Notation (BPMN) to demonstrate the communication between different actors and the tasks performed by the individual actors [14]. Other approaches that are commonly used are IDEF0 where the processes is divided into 16 different modelling structures and each step is described by input, output, controls and mechanisms [15]. Value Stream Mapping (VSM) can also be used to identify opportunities for improving e.g. lead time by identifying waste and how it can be eliminated [16].

Performance analysis: Based on the objectives formulated in the first step the current performance is measured. GAP analysis can then be used in order to list the current performance, the targeted performance and the gap that has to be bridged [13].

Scenario generation: Based on the GAP analysis, scenarios are generated where PCS is used to support the future processes. The stakeholders and their necessities can be drawn through using process flowcharts and use case diagrams based on the Rational Unified Process (RUP) methods [17]. The scenarios demonstrate how a

PCS can be used to support the current processes to different extent.

Cost benefit and risk analysis: Cost Benefit Analysis (CBA) is carried out to compare the different scenarios. CBA is an effective method to compare different results from variety of actions [18]. The benefits are evaluated as how they contribute to the operational objectives listed in the GAP analysis. The risk factors should both include the risk associated with the development of the system and the implementation [13].

C. Selection and prioritization of engineering processes to be supported with PCS

Based on the cost benefit and risk analysis for each of the scenarios, the suggested PCS projects are evaluated according to the selected criteria for importance, payback time, strategic importance and risks. This evaluation gives the foundation to make the decision whether the company should implement PCSs and how to prioritize the future projects.

IV. CASE STUDY

The case study was done in collaboration with a construction company in the Nordic region where the proposed framework was tested. The results presented in this paper are based on material extracted from the company's internal databases, observation, workshops and regular meetings with experts at the company. The end result from this project was a PCS that could be implemented. However the focus here will only be on the initial stages or how to identify the processes to be supported with a PCS in order to evaluate the framework proposed in this article.

A. Identification of operational objectives and critical engineering process criteria

In order to identify the operational objectives and the critical engineering processes a workshop at the company were held where the main stakeholders could give their opinion.

Operational objectives: The most important objectives were regarding lead-time per design, resource consumption, redesigns per project, quality of the overall design and the production planning, and finally elimination of rework that can occur either in on-going production or after the production.

Identification of critical engineering processes: The engineering processes that were identified as critical processes in terms of achieving the operational objectives and areas where PCSs could potentially help to improve their efficiency were; the processes of carrying out designs with regards to the acoustics, energy consumption, indoor climate, ventilation, heat supply insulation and consumption water.

B. Analysis of the critical engineering processes

In order to demonstrate this step, the processes of making the acoustic calculations will be used as an example. However it should be noted that the same procedure was also applied to all of the identified critical engineering processes.

Analyses the current processes: The analysis of the current processes revealed complex processes where several redesigned loops could be identified. A simplified version of the process is described in this section and visualized in Figure I. The main stakeholders concerned with the acoustic designs were the Project Leader of Design (PLoD), architects, structural engineers, acoustic engineer and the Project Leader of Production (PLoP).

The PLoD, is responsible for the overall design, receives the customer requests and assigns tasks to architects and structural engineers. The architects are responsible for making the overall design and the 3D models while the structural engineers for the structural design and making relevant calculations. The acoustic engineer verifies the design and makes suggestions for improvements if needed and sends them to the PLoD. After the PLoD receives the recommendations he/she either decides to use them or not. If the recommendations are rejected the design is sent to the PLoP. The main reasons for PLoD for rejecting the acoustic recommendations are due to cost or time constrains of the overall project. By rejecting recommendation, the risk of the project not fulfilling the requirements increases, which could lead to having to rework the acoustic aspects later in the process. Finally, the PLoP figures out the operational times and production cost for the given design. Based on those factors and the timeframe for the project, it is decided whether or not adjustments are needed. If adjustments are made without consulting with the acoustic engineering it might jeopardize the acoustic quality of the construction. In the construction phase an acoustic measurements are made to secure that the acoustic requirements are fulfilled. If it is realized that the requirements are not fulfilled a rework process is initiated as is demonstrated with red color in Figure I. The later that defects are realized the more expensive it is to correct them.

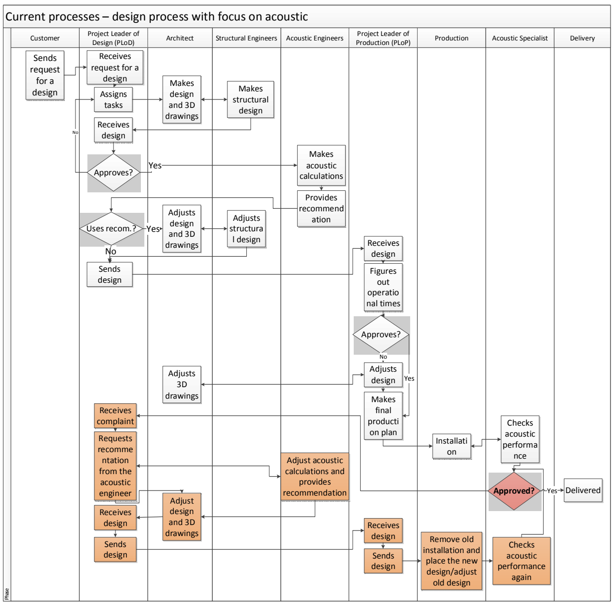

Fig. 1. Analysis of the current process: acoustic design processes in construction.

Performance analysis: Based on the operational objectives from the first step the operational objectives for the processes were set and the current performances were measured. Based on that, the GAP that needs to be bridge could be identified. The results from the performance analysis are demonstrated in Table I.

TABLE I
PERFORMANCE ANALYSIS FOR THE ACCOUSTIC PROCESS

Operational objectives	Target performance	Current performance	GAP
Lead time per design	Lead time for design around 10,5 months	On average 12 months - Great variation in lead time	Around 1,5 months – to be reduced by 12.5%
Resource consumption per design	1017 man-days	1062 man-days	45 man-days
Redesigns per project	0 loops	2-3 loops	2-3 loops
Quality of design in terms of acoustics	High	Low/High	None to great
Quality of the production planning	High	Low/High	None to great
Rework in an on-going production	0%	In around 15% of yearly projects	15%
Rework after production	0%	2 instances from the year 2008 (around 2.5% of projects in the time period 2008-2014)	2.5%

Scenario development: Two scenarios were developed. For both scenarios it was decided that the PCS should support 80% of the projects and the remaining projects were left to an acoustic engineer as they are too specialized to be included in the system. In the first scenario the PCS is used to provide an optimized design in terms of material cost that fulfils the acoustic requirements. In this scenario, the acoustic perspective can be taken into consideration in the early phases of the design processes and therefore the redesign loops can be eliminated while cost is reduced and quality is improved. Furthermore the acoustic knowledge is accessible to all of the company's employees at all stages of the design phase. In the second scenario, an extended version is made where the system also includes operational aspects in terms of time and costs. By doing so the threat of the design being changed in the production phase can be reduced as well as the cost of implementation and time can be optimized in order to provide further cost savings.

Cost benefit and risk analysis: The *benefits* are identified with regards to the contribution to the operational objectives. In Table II the expected benefits from implementing the PCS are summarized for the given scenarios.

TABLE II
PERFORMANCE ANALYSIS FOR THE ACCOUSTIC PROCESS

Operational objectives	Target performance	Scenario 1	Scenario 2
Lead time per design	Lead time for design around 10,5 months	On average 11 months	On average 10,5 months
Resource consumption per design	1017 man-days	1025 man-days	1017 man-days
Redesigns per project	0 loops	0-1 loop	0 loops
Quality of design in terms of acoustics	High	High	High
Quality of the production planning	High	Low/High	High
Rework in an on-going production	0%	0%	0%
Rework after production	0%	0%	0%

The estimated *cost* for the scenarios is divided to project cost and yearly running cost. The project cost consists of the development cost of the system as well as the investment cost of the software. For scenario 1 the project cost was estimated to be EUR 90,000 and for scenario 2 it was estimated to be EUR 150,000. The difference lies mainly in the more extensive data gathering that has to be performed in scenario 2. The cost savings were calculated from the savings in man-hours minus the yearly the running cost that includes maintenance of the system and licenses fee. The cost savings indicates that for scenario 1 the company could save 410,000 EUR and for scenario 2, 490,000 EUR on yearly base. The *risk* associated with the development of the system is mainly concerned with the data gathering, especially when it comes to cost factors as it varies between different projects. Furthermore there is a risk concerned with the structural engineers and architects will not base their designs on the output from the PCS. The risk factors in scenario 2 are the same is in scenario 1 but more extensive. That is due to the fact that more information is needed for the PCS, which increases the complexity of the data gathering and the software.

Selection of scenario: In the case of the acoustic configuration system it was decided to select scenario 1. The main reason was to minimize the risk and cost and later the system could be extended to scenario 2.

B. Selection and prioritization of the processes to be supported with PCS

Based on the analysis it was decided that the acoustic configuration system should be the first one to be implemented. The main reason for that decision is that the investment cost was rather low and the company wanted to increase the acoustic awareness at the company in order to eliminate the risk of re-work. From the analysis the most promising project that was recommended to be the next projects were to support the design of the ventilation and the heat supply.

V. DISCUSSION AND CONCLUSION

In ETO companies there is a great challenge when starting a PCS project in order to determine the processes that should be supported with a PCS. By analyzing the sales and engineering processes in order to find the most promising business case and to prioritize the future projects can therefore bring significant value to the companies. The development of the framework in this article is based on literature and from experiences gained from working the ETO companies such as: MAN Diesel, FLSmidth and CIMBRIA, which have all implemented and are currently using PCSs to increase the efficiency of their sales and engineering processes.

The proposed framework was applied in a construction company where it provided a systematic approach in the starting phases of the PCS project. The framework consists of three main steps. The first step is concerned with identification of operational objectives and company critical engineering processes. In the second step the critical engineering processes are analyzed. The final step is then concerned with selection and prioritization of the processes to be supported with a PCS.

The framework gave structured approach and valuable result that helped in the pre-steps when formulating the PCS projects at the company. However there are some limitations as the framework was only applied in only one ETO company. Nevertheless, the company is thought to be good representative for other ETO companies. In order to improve the framework, further work includes testing the framework in order ETO companies to achieve more generalization. Furthermore, a study of the direct advantages in terms of time and cost savings from applying the framework should be conducted in order support the findings of this research.

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