DEVELOPMENT OF A CONFIGURE-TO-ORDER-BASED PROCESS FOR THE IMPLEMENTATION OF MODULAR PRODUCT ARCHITECTURES: A CASE STUDY

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ABSTRACT

As todays' global market trends lead to an increasing demand for individualised products, manufacturers need to cope with a high degree of internal and external variety, which has a severe impact on complexity and therefore -costs. When implementing modular product architectures, it becomes obvious, that the actual Engineer-to-Order (ETO) processes cannot cope with the requirements of such a product architecture. It is crucial to develop a complying Configure-to-Order (CTO) process in order to make full use of its suppled benefits. As there is no existing approach about how to methodically change an existing ETO process into an adequate CTO process, we intend to fill this gap with this paper by showing an approach for the development of a CTO process for modular product architectures. Furthermore, we show the application and evaluation of this approach in a case study with a special equipment manufacturer (SME), that is already implementing modular architectures.

Keywords: Configure-to-order, Organizational processes, Process modelling, Product architecture, Modularisation

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1 INTRODUCTION

Today's versatile, global markets create a continuously increasing competition within the sector of production companies, leading to a permanent race about decreased product life cycles. To cope with this situation, suppliers and end-product manufacturers rely increasingly on product specialisation, which directly intensifies the demand for customised machine systems. As a result, the attention to special equipment manufacturers with specifically designed Engineer-to-Order (ETO) process structures is on the rise (VDMA, 2014).

As the required customisation inhibits almost completely all internal standardisation and optimisation possibilities for the manufacturers, a large variant diversity is produced. In most cases, those individually designed product variants possess a high degree of complexity and component diversity, while being manufactured in only very small batch sizes. This combination creates a large diversity within business processes and results in an increase of costs in all product life phases (Ehrlenspiel *et al.*, 2005). Managing these variants is one of the key task in order to ensure a proper competitive advantage. A possible solution to reduce the internal variety and thus, costs, while keeping the external variety towards the customer as high as possible, supplies the concept of modular product architectures (Krause & Gebhardt, 2018).

Seidenschwarz points out the strong interconnection between module and process engineering when (partly) standardising complex products and emphasises the importance of their parallel development (Seidenschwarz, 2012). With modular architectures developed, the actually used ETO-processes are not suitable any more in order to meet the customers' demands efficiently and economically, as they do not allow the utilization of all benefits provided by the concept of modularisation. The goal hereby is the development of a Configure-to-Order-based (CTO) process structure, that meets the requirements of a modular product architecture.

In this paper, we develop a systematic for the design of CTO-based processes especially for special equipment manufacturers based upon the pertinent literature. The main goal is to define a methodical approach for the transformation of existing ETO-process structures towards a CTO-based process without creating a loss in the flexibility and adaptability of the customers' needs. Furthermore, we show the results by conducting an empirical case study at a German special equipment manufacturer.

2 STATE OF THE ART

In the following, a short overview of the state of the art concerning the methods of modularisation is presented. According to Salvador, modular product architectures are determined by five gradual dimensions: decoupling, functional binding, interface standardisation, commonality and combinability. The degree of these dimensions therefore characterises a single product's degree of modularity, enabling the assessment of it´s product structure (Salvador, 2007). There are several advantages when using modular kits, such as the reduction of internal variety and complexity due to variant-oriented design without decreasing the offered product range. Furthermore, when using similar modules, full advantage of economies of scale can be taken. On the other hand, limited product differentiation and oversizing can be cited as disadvantages (Hackl & Krause 2016).

There are several approaches to modularisation and modular product architectures to be examined, such as the work by Simpson *et al*. on developing product platforms, the Modular Function Deployment by Erixon and the Integrated PKT-Approach by Krause, which has been developed on the basis of previous ones (Simpson *et al*. 2006, Erixon 1998, Krause & Gebhardt 2018). This latest and most comprehensive approach contains a library of methods, which can be adapted individually to the actual task.

As much information there is about modular product architectures in the relevant literature, there are only a few phrases about the needed adjustments to develop corresponding business processes. As already mentioned in the introduction, an implementation of such a module-based configuration process is essential for an effective production with minimum lead times, maximum output, minimal risk and maximum quality. As this paper is about developing a suitable process, an overview of the currently described processes is given in the following.

Generally, business processes can be divided by the means of their degree of product development, completion and customer orientation during design and production. At this point, Kilger and Stadler classify anticipative and reactive processes as shown in the following Figure 1.

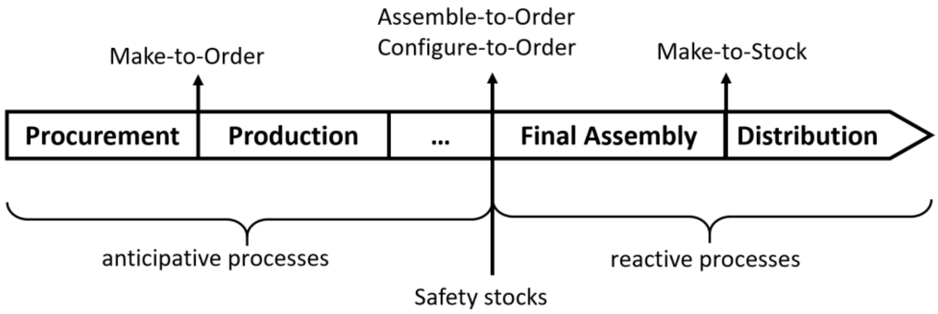

Figure 1: Business processes (following Kilger & Stadler, 2012)

As purely anticipative processes, *Make-To-Order (MTO)* processes contain the special variant of *Engineer-to-Order (ETO)* processes, describing customer-individualised product development, design and manufacturing. The opposing process form is called *Make-to-Stock (MTS)*, where already produced goods (mostly bulk-items) are stored until being ordered by a potential customer. In between those above-mentioned process forms, the *Assemble-to-Order (ATO)* and *Configure-to-Order (CTO)* processes are equally anticipative as reactive, differing only in the degree of module completion, as with CTO-processes the modules are just designed, whereas with ATO-processes they are already built (Kratochvil & Carson, 2005).

When developing modular product architectures, the simultaneous engineering of CTO-processes in the environment of complexity-cost oriented variety management is crucial, enabling customer-specific solutions with improved economies of scale (Zhang *et al*. 2004).

Having analysed the relevant literature, it appeared that only limited information about the detailed CTO-process makeup is supplied. Only the ORACLE company provides suitable instructions for developing such a business process within the Oracle Configure-To-Order Process Guide (Oracle, 2017). Key parts of their described process flow are a forecast-based module design with a module specific *Bill of Manufacturing (BOM)* as well as a module specific, department-overarching and combined flow of concurrent operations *(Bill of Operations, BOO)*. When receiving a corresponding customer's order, the BOO and BOM are selected, modules are combined and the product is handed over. A continuous control and adjustment system is of greatest importance in order to monitor target and actual states and counteract if necessary (Oracle, 2017). As this system is designed for software development, it can only be used as a foundation for developing suitable adaptions in order to meet the requirements of special equipment manufacturers in combination with variant-oriented modular design.

When analysing and developing business processes, using visualisations seems to be the most suitable method. Within the literature, several process visualisation approaches can be found and are opposed by Beckmann and Krause (Beckmann & Krause, 2013). Next to strongly process-oriented and linear models, such as the Procedural Landscape by Wagner (Wagner, 2007), Beckmann and Krause provide with the Methods for Process Visualisation (MPV) a tool, that allows the display of complex processes. This MPV-method shows major advantages to the visual analysis of process flows, as especially non-linear linkages between process steps, considering simultaneously the relevant departments, interest groups as well as the implicit and explicit business knowledge. It´s key steps are to assign at first a triggering event to each process step, which is described comprehensively regarding its required knowledge (implicit and explicit), tools (e.g. CAE-Software), partial steps, involved individuals as well as their authorities. Furthermore, appearing problems and conflicts can be allocated directly to where they occur. Every process step triggers an action (e.g. mechanical engineering), which is followed by the corresponding item (e.g. system engineering completed) while listing concurrently the required database or documentation documents (Beckmann & Krause, 2013). According to the MPV-method, which is applied for this contribution, each of the steps are represented by linked graphical icons, similar to technical flow charts, allowing considerably more detailed, accurate and intuitive process descriptions.

There are lots of different methods and processes supporting the development of modular product architectures, which are already implemented into the business structure of a wide range of businesses. As it has been shown above, the importance of a suiting CTO-based process, complying with the modular architecture, is crucial to make full use of its supplied benefits. Developing such a CTO-based process and suppling a suitable, methodical procedure to support the transition from ETO to CTO-processes is a gap which this paper tries to fill.

3 DEVELOPING A CTO PROCESS: THE METHOD

The systematical procedure for the development of a CTO-based process is shown in Figure 2:

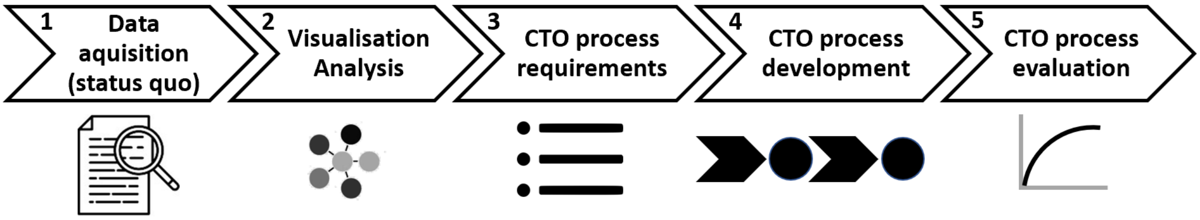

Figure 2: Flow chart of CTO-process development approach

The first step is to acquire all relevant data about the current process' status quo. According to Rubin & Rubin, a combination of qualitative and quantitative data is regarded as a sufficiently accurate data base for any analysis (Rubin & Rubin, 2005). Those data can be gathered via recorded process and performance data (hard facts) as well as expert interviews and questionnaires in order to collect qualitative data (soft facts). As a second step, the status quo is to be analysed and visualised via a suitable method, which has been determined to be the described MPV in order to derive the required needs for action. With these data as a basis, the third step is to derive suitable requirements for the new CTO-process, which can be clustered into four different categories: **general, company driven, process driven and module driven**. During the fourth step, the new CTO-Process can be developed according to these requirements and displayed graphically via the MPV. The last step is to evaluate the effects of the new process by either mapping a complete cycle, simulating various cycles or using extrapolations.

4 CASE STUDY

4.1 Case introduction

The case study for developing a CTO-based process has been conducted in cooperation with a German special equipment manufacturer SME. Figure 3 shows its main module-based laser welding system.

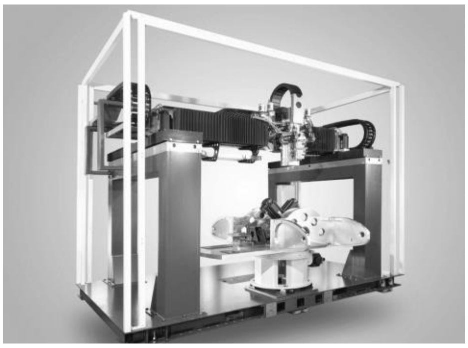

Figure 3: Product example of a laser welding system

With its high degree of product complexity and customer orientation, a corresponding CTO-based process provides an adequate solution to improve product quality, delivery times, cost structures and reusability.
To analyse the process' status quo at the SME, expert interviews as well as project-specified accumulated data were used. The expert interview was developed according to Rubin & Rubin's specifications with questions oriented towards the information required by the MPV. The questionnaire refers to the following key issues: tasks of the regarded department, classification into the business process, pre- and post-positioned project steps, hierarchical structures, process coordination, data- and knowledge-management (implicit and explicit), tools used within the process step, KPIs, releasing procedures and already detected improvement potentials. The in total 14 expert interviews were

conducted over a period of two weeks with the respective heads of sections. The required quantitative data was gathered by analysing the project-related data acquisitions of 21 completed projects from the past, showing exactly which employee spent what amount of time on each project during which process step, classified by the current SME-specific product life phases. These are sales, project management, engineering, manufacturing, assembly, automation, start-up, service and development. This data is mainly to be used in order to determine the cycle times for each life phase and their share of the overall cost and material volume. In the course of the visualisation, it appeared during the procedure, that the actual state of the MPV-method is not fully suitable for the underlying task. Especially the large amount of cross-connections, communication and iteration steps between individual departments as well as a considerable amount of if-then conditions would lead to an unclear and confusing display of multiple connection layers in the visualisation. To solve these problems, the adaptions to the MPV (shown in Figure 4) were proposed:

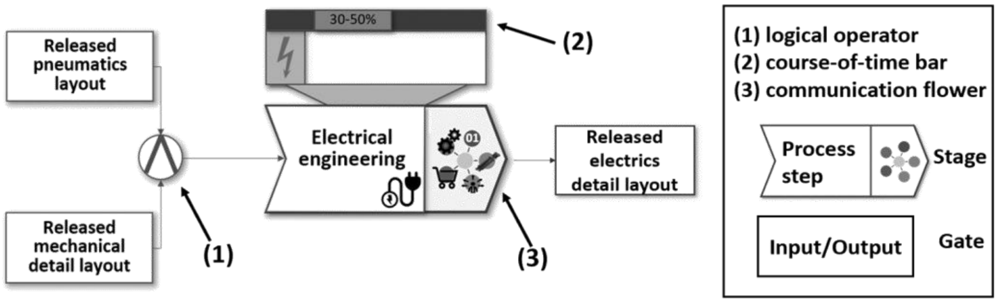

Figure 4: Modifications (1-3) to the MPV

The *logical operators* (1) are to simplify the existing visualisation when considering if-then conditions and are used analogous to Bool's logical operators. Figure 4 shows the condition of both the release of pneumatical and mechanical layouts in order to trigger the electrical engineering. The introduced *course-of-time-bar* (2) shows the amount of time and the respective process step's categorization into the overall project process throughout a percentage bar chart. In this way, critical process paths in terms of duration or overlapping can be identified at first glance. The *department-specific process "flower"* (3) shows interactions between individual departments by using separate icons with a high recognition factor for each department, e.g. *gears* for mechanical engineering. The example illustrated in figure 4 displays the exchange between the electrical engineering department (icon: *cable* and *plug*) with the mechanical engineering, automation, pneumatics, project management and procurement. This development avoids the need for a visually confusing multi-layer linkage system.

4.2 Process development results

For clarity reasons, a one-pager of the current value-added chain's process situation is presented in Figure 5 before explaining the relevant details.

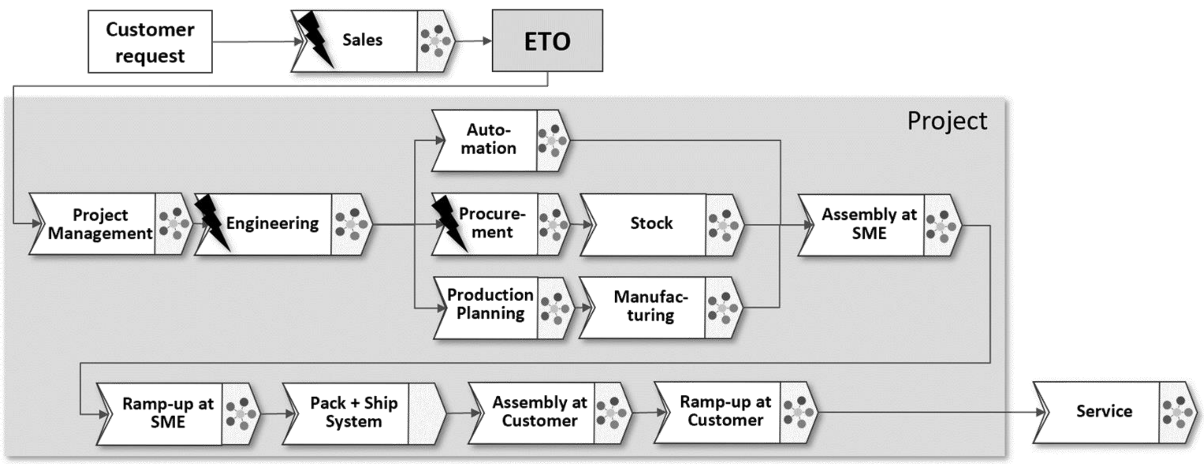

Figure 5: One-pager of value-added chain's status quo at SME including the issue points (marked by a flash)

With the current ETO-situation, whenever there is a proposal request, the sales department hands a specified quotation over to the potential customer. After the order confirmation, the head of projects instructs the heads of sections, such as engineering, manufacturing, automation, assembly and ramp-up during the kick-off meeting. Afterwards, the actual product development begins on the basis of the quoted layout. Having completed the engineering part, the subsequent plans are being sent to the automation, procurement and production planning department, leading to an independent manufacturing of soft- and hardware while consulting the engineering department if necessary. After finishing manufacturing and procurement, all parts are being transferred from the warehouse to the assembly, where the whole system is set up at the SME for pre-acceptance from the customer. The next step is to disassemble, pack, and ship the system for reinstallation and final acceptance at the customer's place, signalling the end of the project. Maintenance services are offered subsequently as separate projects.

It is to be noticed that apart from the step "pack and ship system" all steps are marked by the communication flower, meaning that a large amount of communication is needed between departments due the high process complexity and individuality. The lack of a standardised communication structure is a clear disadvantage, as it is a major source for missing, mismatching or insufficient communication, leading to a deficient use of department synergies.

A major problem resulting from the communication issue can be seen during the quotation phase. Due to the proposed systems being highly individual and customer specific, combined with its high complexity and the small time window between proposal request and required proposal delivery, the sales department mostly relies on their experience about how to encounter the customer's request without being able to properly crosscheck technical details with the relevant departments. This leads frequently to unexpected situations when the final detailing is performed during the engineering phase, binding monetary, personnel and material resources.

A second issue noticed during the analysis is located within the procurement process. In fact, there are three different engineering departments (mechanical, pneumatic, electrical), deriving three different bills of manufacturing. It appeared, that overlapping or doubled component requests within those bills are not uncommon, leading to ordering unnecessary parts.

The last issue to be mentioned is the serial structure of the engineering processes. As shown in Figure 6, the pneumatic department relies on the detail layout provided by the mechanical engineering. With pneumatic construction completion and the following electrical engineering, all schemes need to be sent back to the mechanical engineering, where the final layout gets updated. The need for optimisation becomes apparent, as this process structure requires a lot of coordination effort and therefore is quite time-consuming.

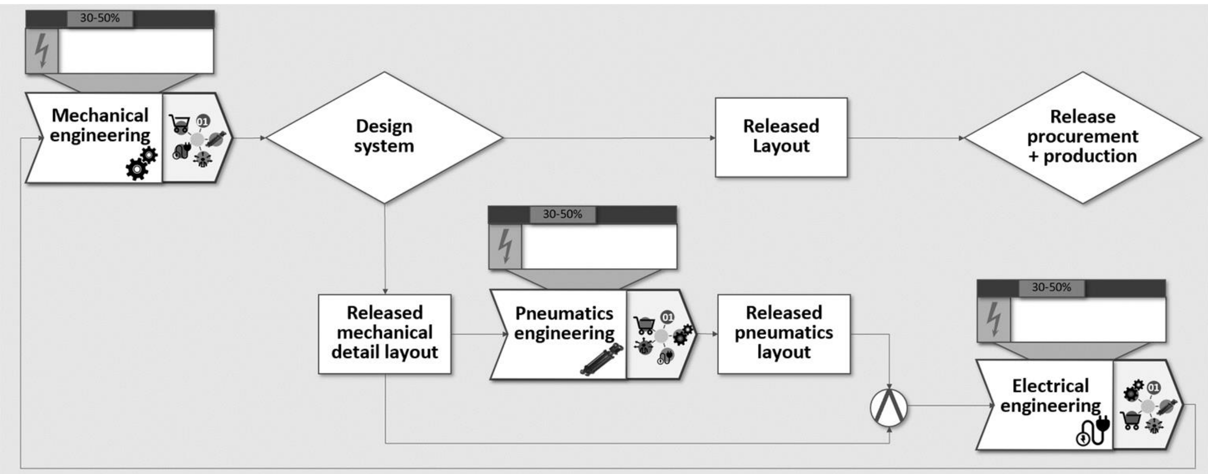

Figure 6: Serial structure of engineering processes

Based on the above-mentioned critical process paths, noticed issues and the persistent literature, requirements for the new process can be derived. In general, a modular-kit supporting, pure CTO-process is not suitable for the market position of a special equipment manufacturer due to the diverse customer requests, which do not allow an overall standardisation. As experience has shown, machine systems with a configuration depth of 100% (completely composable by modular kit) are not viable. In consequence, the goal is to develop a Configure-to-Order-based Engineer-to-Order-process, which aims to adapt the process for the adaption of variant oriented engineered modules according the relevant customers' needs. Nevertheless, process structures for both a CTO and an ETO are to be defined. The requirements for such process structures can be divided into general, company-driven, process-driven and module-driven requirements.

General requirements:
- *Integration into existing process:* guarantee business stability; higher employee acceptance
- *Transforming implicit to explicit knowledge:* avoid know-how loss in case of employee change

Company-driven requirements:
- *Generate project-nature adequate calculation basis:* separate standard or development projects

Process-driven requirements:
- *Enable IT-Integration and software support:* mistake, complexity and cost reduction
- *Establishment of documentation and operation standard:* easing later problem reconstruction
- *Establishment of intervention possibilities:* enable changes within project and process itself

Module-driven requirements:
- *Enable controlled and standardised change management:* control variance development
- *Check product availability:* determine repeating modules, preproduce during low occupancy rates

In accordance to the derived requirements, the new CTO-based ETO-process was developed on the basis of a stage-gate process and is displayed in Figure 7.

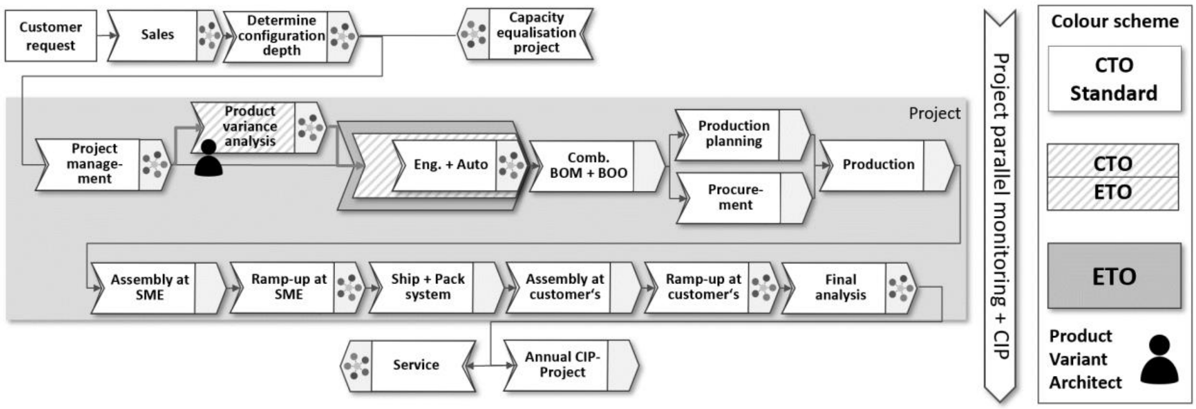

Figure 7: One-pager of value-added chain of developed CTO-process

The first step is to properly define the project type as either occupancy compensation or a customer-specific project. When receiving the triggering event *customer's request for proposal*, the sales department decides on the configuration depth for this process and therefore determines the corresponding process path. Having successfully acquired the order, the project is transferred during a kick-off meeting towards the project management. Corresponding standardised documents and processes have been established at the SME. From this point on, the project progress is determined by the configuration depth. The main difference can be noticed throughout the engineering stage. The effort that has to be contributed there is visualised by the size of the process arrow icon, as it is smallest when using the pure CTO-process and only choosing, assembling and checking suitable modules for the underlying application. For the most likely CTO-based ETO-process path, the engineering effort depends on the number of modules to adapt, but is still smaller then with a completely new engineering concept. At this point, the main expense is created by the interface-adequate variance generation of modules, which is mainly to be regulated by the newly created position *"product variant architect"* (marked by icon in Fig. 7) in the process step *product variance analysis*, whose task is to plan schematically the module adaption and coordinate their parallel mechanical, electrical and pneumatical development in order to avoid exceeding variance generation.

Having finished the engineering stage, the mechanical engineering department derives a collective bill of manufacturing (BOM) as well as a collective bill of operations (BOO) for the following manufacturing and assembly steps, which are sent to the procurement and production planning department at the same time. This results in a proper use of economies of scale, as the required raw material can be purchased at once. The manufacturing, assembly, pre-acceptance at the SME, packaging and shipping and re-installation are the last steps before concluding each project with a final project analysis. During this stage, all appeared issues throughout the project are collected and documented. Another developed measure is to permanently monitor current project's processes via an adapted Scrum method (according to Sutherland & Schwaber, 2016) in order to be able to interact if necessary, ensuring a continuous improvement process (CIP), concerning the product family itself as well as the process. Once a year, all during the final project analysis documented problems are collected, clustered, prioritised and analysed to guarantee a continuous Lessons-learned flow. When comparing the newly developed CTO-ETO-process with the existing ETO-process, the significantly reduced amount of *communication flowers* in the *one-pager visualisation* becomes visible, a result of the introduced standardised documentation and coordination processes.

In detail, every project's first step is to collate the customer specification sheet with the company's catalogue of module services. This catalogue is a library of all existing modules, their description, specifications, conditions and interfaces and is used to determine the configuration depth for deriving the adequate process path. This is either ETO for completely new applications, CTO for completely configurable applications, or, most likely, CTO-based ETO for adaptive configuration projects.

A further development which has been made is the lessons-learned box, which is shown in Figure 8.

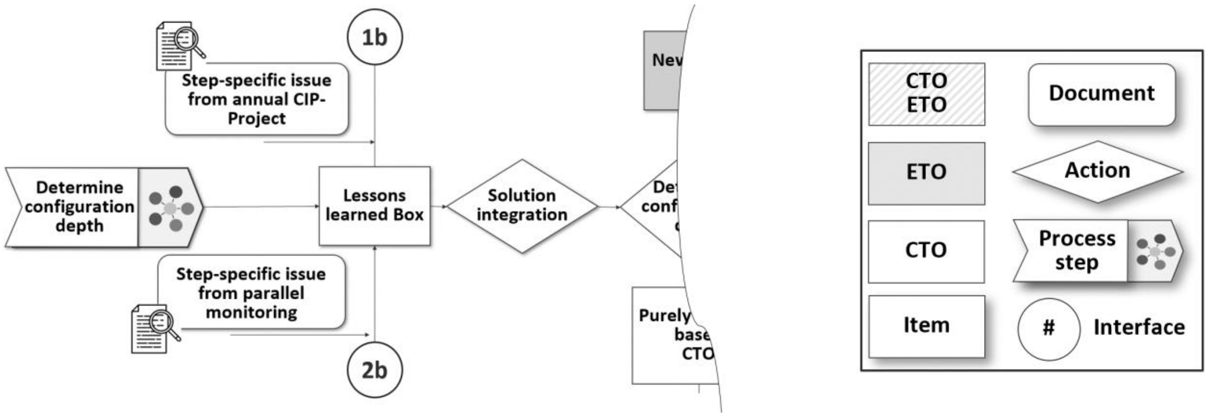

Figure 8: Lessons-learned box as excerpt of the detailed step "Determine configuration depth"

This is an interface located previous to every process step, where intervention measures from the final project analysis (1) and the parallel CIP (2) can be integrated. The letters (a-z) assign the occurred improvement potential directly to the subsequent department, such as (a) for the sales department, (b) for the configuration step and so on. As these intervention means originate from the final project analysis as well as the annual review project (Figure 9).

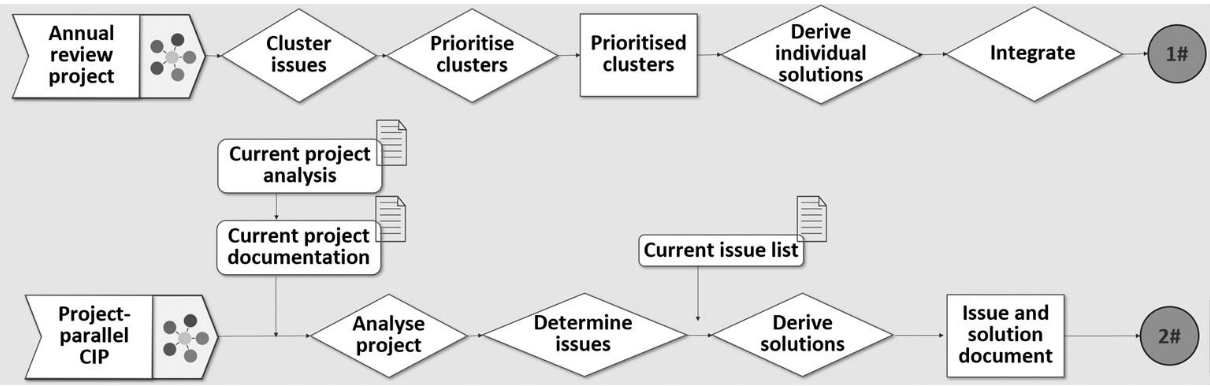

Figure 9: Annual review process and project parallel CIP process

Each project is checked critically after completion by the project manager in correspondence with the product variant architect to analyse all improvement potential and document their origin and effects on the project process in the standardised process document. Those sheets are then used during the annual review project in order to cluster the occurred problems by causation principles, prioritising them and

finally develop individual solutions and intervention methods, which are then documented and introduced into new projects via the corresponding lessons-learned-interface (marked via a-z).
The process evaluation (step 5 of the development method) was conducted by extrapolation and analogy approaches on the basis of expert opinions, as long cycle times render a complete cycle monitoring unattractive. The evaluation plan consists of analysing the cycle time reduction due to parallel engineering and more non-variant parts by extrapolating the workload within the three described process paths during the relevant steps, based on gathered project-relevant data. This data is also used to consider the reduction of post-ramp-up error costs and multiple-order costs as a result of standardised and re-usable modules. As a third aspect, the improvement on an early detection of project deviations is regarded via a normalised project graph.
Having conducted the evaluation, a cycle time reduction of four weeks in average can be shown, which is assumed to be improved by increasing module configurability, as the pure CTO-process shows a workload reduction of 80% compared to the current process. The post-ramp-up error costs are calculated to diminish the overall project costs by around 5% (assuming a configuration depth of 60%). Furthermore, the fluctuation margin, which describes the allowed project cost and time fluctuation window around the normalised process graph, is assumed to be reduced by 30%, leading to an earlier deviation detection and therefore impacting significantly the intervention costs.

5 DISCUSSION

During the development of the Configure-to-Order based Engineer-to-Order process, the process development procedure appeared to perform quite promising and was continuously adapted to the company specific requirements. Especially the needs of a special equipment manufacturer were integrated and finally lead to a suitable method for the development of a CTO-based ETO-process structure, which does not yet exist in the pertinent literature. During the first step (data acquisition), it became obvious, that the recorded project data showed several inconsistent parts which had to be normalized in order to make use of these data. The second step (visualisation) worked out well, but the MPV-visualisation tool had to be expanded as shown above in order to display complex structures adequately. The in step 3 derived requirements supplied a suitable base for the development of the new CTO-based ETO-process and covered all appearing issues. The fourth step, (development) required next to the process adaptions further adaptions to the organisational structure. Especially the introduction of the product variant architect as an organisational expansion with the main task of overseeing the development and changes to the current and future modular architecture shows the need for an interlinked development of process and organisation architecture. During the last step (evaluation), it appeared quite difficult to get reliable results, as only the implementation of the new CTO-based process would allow the complete mapping of a project cycle as a data basis for an adequate evaluation. Due to the long time needed for the integration and the project cycles, extrapolations had to be chosen in order to pre-evaluate the developed process.

6 CONCLUSION AND OUTLOOK

As a conclusion it is to be noted, that a pure CTO-process is not suitable for the needs of a special equipment manufacturer, as the flexible adaptation of customer needs would be eliminated. This led to the development of the CTO-based ETO-process, which compensates for that need.
Regarding the gathered results, it is to be stated, that especially the determination of the process path that should be used (on the basis of the configuration depth) is considerably time-consuming, especially with highly complex products such as laser machine systems. Secondly, when developing the modular product architecture with the above noted modularisation methods, a module adaption (which is crucial for the developed CTO-based ETO-process) results in a work-intensive manual component rearrangement, showing the strong need for a software-based solution. This software should be able to integrate the modularisation methods, relying on one consistent database. It should as well contain an interface to a dynamic configuration software, that transfers the SME-intern modular architecture via customer-relevant properties to the individual application while deriving the adequate project process (CTO/CTO-ETO/ETO). Especially this connection between a configuration software and the software structure which incorporates modularisation methods is of great interest, as it enables a consistent, intuitive manufacturer-to-customer knowledge transfer while reducing manual configuration efforts and therefore corresponding errors. Furthermore, it has been shown that the modular kit efficiency can be

increased by improving module configurability. One way to cope with this demand is to map recent product configurations and their deviations from the modular standard via the configuration software to analyse them afterwards when setting up a second generation of modules. This second generation can then contain the gathered information about customer needs, leading to a higher degree of standardisation and therefore a better configurability. Such a software could also provide an analysis of product configuration sales numbers. With this tool, low-performing product-market shares can be exited in order to reduce the overall complexity.

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