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Improved Performance and Quality of Configurators by Receiving Real-Time Information from Suppliers

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Abstract. Companies providing customized products are increasingly applying configurators in order to support the sales and design activities. Yet, especially for engineer-to-order (ETO) companies such activities are often divided across different organizations, where throughout the configuration process product specification has to be retrieved across the supply chains. Therefore, it is required that relevant information from suppliers is included in the configuration process, either as sub-models or by integrating configurators across the supply chains. This study investigates the challenges associated with including suppliers' product specifications as sub-models and how these can be addressed by integrating configurators across supply chains to receive real-time information from suppliers. Based on established literature on the illustrated technical integration of configurators across the supply chains, this paper contributes with empirical evidence on the overall impact of its implementation. The results presented are based on a case study in an ETO company where it is supported that the complexity of the configuration models can be significantly reduced as well as the time devoted for the modelling and maintaining the systems. Furthermore, with the ability of receiving accurate and up-to-date information from suppliers, the quality of the specifications can be improved, which leads to reduced cost of the overall design.

1 INTRODUCTION

The ability to provide customized products has become more important across a wide range of industries [1]. To effectively guide communication with the customers and increase the quality of the product specifications, configurators are being applied to greater extent when defining product variants within the chosen scope of variety [2]. Such systems utilize formally expressed product architectures, i.e. knowledge bases, consisting of a set of components, their relationships, and constrains to prevent infeasible designs [3].

In engineer-to-order companies (ETO) the supply chains can be characterized by being tailored and complex [4], where manufacturing tends to be vertical integrated, including both internal manufacturing processes and outsourced supply [5]. Furthermore, the dynamic and segregated character of the early sales and engineering processes limits the availability of design information and increases the uncertainty of project's profitability [6]. As a result to this there is a high dependency of receiving information across the supply chains in the early sales design phases.

To address the complexity and the vertical integrated supply chains in ETO companies, the configurator's knowledge base needs to cover up to date product information related to the companies' own designs and of outsourced components/modules from suppliers. By including the suppliers' information as sub-models in the configurators there are some limitations, as the information are often confidential and sensitive for sharing outside the companies. Therefore, critical design detail and cost structures, which are often considered as confidential information, are not shared from the suppliers' side. This can result in insufficient level of detailed information being provided that can affect the overall quality of the configuration. Furthermore, rapidly changing components and modules supplied internally or externally drastically increase the effort for maintaining the configurator's knowledge base. This increases the risk of operating with outdated prices and variant designs and thereby decreasing the overall quality of the systems and the generated output. This underlines that centralized knowledge base is not desired, which emphasis the need of having distributed configurators across the supply chains [7].

The recent advancement of cyber-physical systems has enabled a closer integration of supply chains relationships [8], allowing for efficient ways of information management across multiple organizations. However, to make such an e-business environment possible, the established knowledge base needs to account for high degree of tailoring and dependency from suppliers [9]. Academia has proposed a technical approach that enables real-time information sharing across the supply chain by integrating configurators [7]. However, it's successful implementation and the actual impact from receiving the information directly from suppliers in the configuration processes has not been addressed in previous literature.

This paper aims to capture that research opportunity by analysing the overall impact from establishing the supplier integration to retrieve more accurate and up-to-date information across the supply chains in ETO companies. This includes description of the gained benefits, the challenges companies are faced within the process and directions for further improvements. Aligned with the focus of the research, the following propositions have been developed.

Propositions 1: By integrating configurators across supply chains, the complexity in terms of business rules, tables, parts and values of the configurator model, and consequently the modelling and development effort can be reduced.

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Propositions 2: By integrating configurators across the supply chains, the quality of the product specifications in terms of increased accuracy, more detailed and up-to-date, can be improved.

Propositions 3: The more detailed specifications from the supplier make it possible to improve the overall designs, which lead to cost optimization both for the component in focus and for other related components.

Aiming to investigate the impact of integrating configurators across the supply chains, a case study is introduced in an ETO company, which has established this integration with one of their supplier. The company operates globally and provides their customers with highly engineered and complex products and is thought to be a good representative of other ETO companies. The results of the case study are based on the in-depth interviews with the configuration engineers and managers at the case company as well as related supplier.

The paper is organized as follows. First, relevant literature is reviewed to identify the key constructs of the research model. In the next section the results in connection with the propositions and the managerial implications are presented. Finally, the main findings are discussed and concluded, and directions for further studies are elaborated.

2 LITTERATURE REVIEW

In this section the related literature is explored. The theoretical foundation for this article consists of configurators' main benefits and challenges and integrative information technologies in supply chains.

2.1 Configurators benefits and challenges

Configurators 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 [3]. The main technical component of the configurator is the knowledge base, which includes a database where the different components and their instances are stored along with the configuration logic representing constrains how different components can be combined [10].

Configurators have been considered as one of the key success factors in order to achieve the benefits from the mass customization approach [11], [12]. The main benefits of using configurators can be listed in terms of reduced lead times, improved quality of product specifications, preservation of knowledge, use of fewer resources, optimization of product designs, less routine work, improved certainty of delivery, reduced time for training new employees and increased customer satisfaction [13]–[15].

Even though configurators have proven to be beneficial and provide various benefits, there are some challenges concerned with utilizing such a system. The main challenges can be described in terms of supporting the customer in the customization process where the configuration process should be simple and short [10]. As a result of insufficient tools and methods, it can be difficult to guarantee consistency, completeness and formal documentation of the models and the long term management of interfaces and data can as well be a challenge [16]. Structuring and modelling product information [17], product characteristics, customer relations and long time span of the projects, and product complexity are also considered as one of the main challenges especially in ETO companies [18]. Lack of documentation which can lead to confusion about the variation possibilities [16], [19] and finally acceptance of the systems and change management as employees might see the implementation of the configurators as a threat to their job security [20] has also been named in relations to the challenges related to configurators.

2.2 Integrated information technologies across supply chains

Supply chain management involves the activities concerned with flow information and the transformation of raw materials to the end users [21]. In order to develop an integrated supply chain, a detailed top down approach is important, however successful achievement of integrated supply chain is more likely to happen through bottom up approach through a number of stages as shown in Figure 1 [22].

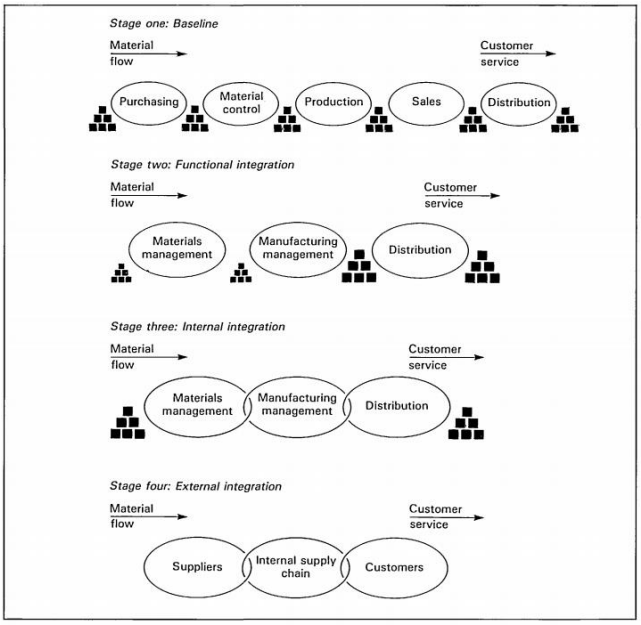

Figure 1. Achieve integrated supply chain [22]

There are a number of research that have explored the hypothesis "the higher the degree of integration across the supply chain, the better a firm performs" [22]–[27]. Ragatz et al. [28] identify the linked information systems applicability as a key success factor for integrating suppliers into the new product, process or service development process. Tallon et al. [29] point out that any positive impact of IT comes from its ability to coordinate value adding activities. A linkage between integrative IT and supply chain is a key aspect of supply chain integration. Stroeken [30] examines the link between IT and supply chain innovation in six industry sectors in order to show the importance of IT to develop the process oriented structure of the supply chain needed for the integration [30].

Mukhopadhyay and Kekre [31] quantify both strategical and operational impacts for Electronic Integration which leads to efficient procurement processes. The strategic benefits concerning the supplier and the operational benefits are in respect to both parties, or the suppliers and the customers. It should though be

noted that the operational benefits are generated by Electronic Data Interchange (EDI) through reengineering of the internal processes of an organization, unlike strategic benefits, which result from changes in the buyer-supplier trading relationship [31]. A supply chain strategy recognizes that integrated business processes create value for the companies' customers if these processes reach beyond the boundaries of the firm by drawing suppliers and customers into the value creation process [22], [32]. Vickery at al. [33] explain this linkage as the relationship between where one value activity is performed and the cost or performance of another is then introduced as the core purpose of supply chain integration as optimizing linkages amongst value activities.

IT development can lead to process innovation, or more broadly, supply chain integration, followed by cheaper, more diverse and customer-specific products. By considering organizations and markets, information processes makes the economic role of computers clearer [34]. To be successful, firms need to be able to adopt to computers as part of a system or cluster for reinforcing organizational changes [35]. Additionally, the extent clients achieve real time, or direct access to information maintained by service providers constitutes a goal of customization efforts efficiently and economically attainable through newly developed Internet-based technologies [36]. Suppliers utilize information specific to client requirements for global optimization of plans and adaptive execution of processes and these clients integrating logistics applications, enable suppliers to plan capacities for peak periods and exhibit requisite scalability of operations [9].

Configurators have been proven to be useful in distributed supply chains, where information from sub suppliers are retrieved in the configuration processes. Ardissono et al. [7] express the development of configuration services which offers personalized user interactions and distributed configuration and services in the supply chain. In Figure 2, the architecture for configurators setup integrated to the suppliers is demonstrated. The approach suggested is thought to support further cooperation, where the exchange of orders, publishing of product catalogues and the billing processes is supported in the supply chain [7].

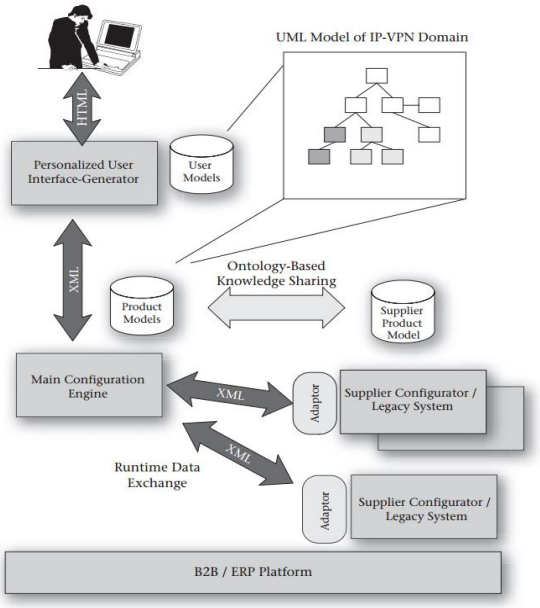

Figure 2. Architecture overview [7]

2.3 Summary of the literature

Based on the current literature in the field, the research highlights the importance of achieving greater integrations across the supply chains where IT plays a key role. Furthermore, for companies providing customized products, there is a need for having up-to-date information across the supply chains. Therefore, by integrating configurators across the supply chains, it allows companies to further integrate the flow of information and at the same time solve some of the main challenges concerned with mass customization and configurators. However, the impact from increased integration across the supply chains by enabling interactions of configurators across the supply chains has not been addressed previously in the literature.

3 CASE STUDY

3.1 Background information

The case company introduced in the study has a world leading position in providing cement plants and equipment for the minerals and cement industry. The company has utilized configurators since 1999 and has currently 136 operational configurators[2], which support the specification processes in the sales and the engineering at the company. The configuration setup at the case company has been addressed in previous researches where Hvam [37] describe the benefits and Orsvarn and Bennick [38] provide explanation of the overall configurations setup, integrations, output and the benefits. Even though, the company has been very successful in applying configurators to support their specification processes in the past, receiving up-to-date and accurate information from suppliers to use in the overall configuration process has proven to be a challenge.

The case company has a great number of suppliers providing it with customized products to be used in the overall design. Therefore, there is a close dependency of receiving relevant product information and prices from suppliers in the configuration process. In many cases products are sourced from several suppliers and it has to be considered which supplier is the most suitable one for a particular project. The initial strategy for past years was to include high-level product specifications from each supplier in form of sub-models, modelled and maintained directly in the configuration system. This additional responsibility requires a regular follow up activity with the suppliers to ensure the correctness and validity of the product specifications. There are several challenges reported using this approach, as the knowledge is not available in-house it can be difficult to access and validate it. Furthermore, with no mechanism in place for the required supplier updates to be communicated, the company has to compromise on the overall configuration quality and generated specification outputs.

In order to overcome these challenges, the company has made an integration to one of their gear supplier's configurator via API web services as suggested by [7]. Through this integration, information can be retrieved directly during the configuration process, thereby leaving the modelling and maintenance task to their suppliers. Through that the suppliers can obtain the

[2] A configurator is defined as model based expert system with it is own knowledge base and inference engine.

confidentiality of sensitive product data while increasing the level of details and optimization and ensuring up-to-date provided specifications.

In this chapter, first the procedure to include the suppliers' information before the supplier integration and the main limitations to those procedures will be elaborated. Secondly, the technical setup and the protocols will be explained in order to give more understanding of the overall technical setup for this specific case. Thirdly, the impact from integrating the configurators across the supply chains will be explained in relation with the propositions. Finally, the suppliers' incentives for providing the integrations and the main organizational challenges with establishing the setup will be addressed.

3.2 The prior documentation of the suppliers' information

To include the suppliers' information in the internal configurators used at the case company, three different methods have been used over the years. The method selected to document the supplier's information each time depends on the product complexity and the availability of the product information. Following is a brief description of those methods.

- The first method includes making a list of all possible configuration of the supplied product. In cases where highly complex product with great number of possible configurations, it will become impossible to map down all different configurations. Therefore, a limited number of possible combinations of the products and pre-calculated ranges of values are included in the configurator for the product.
- The second method includes building a configuration model based on the supplier's documentation, which allows covering all different configurations even for complex products. However, the main limitations can be traced to the knowledge not being available for the programmers, which makes it difficult to access and validate the models. Furthermore, changes over the time are not always communicated, which can result in invalid or inaccurate configurations of obsolete supplier designs.
- Finally, the third method is to integrate with .DLL[3] files provided by the supplier. The .DDL files can contain both codes and data, which enables that the program division into separate modules. Therefore, the .DDL files from the suppliers can be incorporated into the configuration system as separate components of the program. In these cases, where .DDL files are used, it has to be assured that in case of any changes, the supplier will send an updated file to the company. Furthermore, the suppliers are in most cases not willing to share company critical information. Therefore, these files are often missing product related information concerning the sensitive aspect of the design and the overall cost structure.

Even though, these approaches have been used at the company to include the suppliers' information, they are not without limitations. The main limitation is the insufficient level of detail of the included product specification and its availability in an up-to-date form. In order to overcome these limitations, the suppliers could be contacted every time an input or a proposal from them is required. However, that would delay the overall process, as the lead-time for receiving input or proposal can take weeks. Furthermore, this requires resources being available both at the company and the supplier to request and send the information. This scenario is therefore regarded being unfeasible or impractical. With the current technological progress, an alternative approach to receive up-to-date and accurate products' information from suppliers is to establish integration that allows data exchange in automatic and efficient way. Here, the case company has decided to connect its internal configurator via API web services to the supplier's configurator. During the configuration process input parameters configured in prior steps are sent to the supplier's configurator, which calculates possible solutions within the given criteria in 0,1 - 0,2 seconds and send back the requested product specifications. This setup enables the company to use the correct and up-to-date designs. Besides, suppliers have the ability to optimize the design for the particular customer requirements with a greater level of detail, instead of using a fixed range of pre-calculated calculations. The technical setup used in this case study is further described in next section.

3.3 The technical setup and the protocols at the case company

The case company and the supplier both had operational configurators used for internal operation to support the sales and engineering processes. The technical setup allows the configurators at both companies to interact (business-to-business communication) in order to retrieve real-time and accurate product configuration from the supplier. In Figure 3, the setup of the supplier integration in the case company is demonstrated. The company has currently established integration with one of their suppliers but has planned to expand the numbers of suppliers in close future as is shown on the figure below. By expanding the number of suppliers it both allows expansion of the parts that can be configured via the integration and also by including number of suppliers providing the same product the most desirable supplier can be found each time in automatic way, which is done manually today.

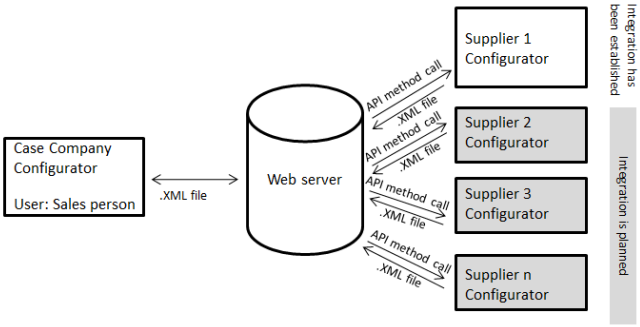

Figure 3. The technical setup at the case company: the supplier integration via API web services

[3] Dynamic link library (DDL)

3.3.1 *The setup for transferring data from one system to another system*

Confidential data are transferred across the companies and therefore special security methods are required. In this specific case, the confidential part is limited to the pricing logic as different product designs are already accessible for customers in product catalogues. Therefore, by establishing the integration the supplier does not have to revile the logic behind the pricing as only the final price for the specific configurations are reviled. In order to reduce the risk from the supplier's site of sharing confidential information, several methods have been established. Those method are not only limited to the prices but to the overall access of the information that can be gathered from the supplier's configurator.

In order to prevent spying collection, data tracking and men in the middle attack, a third party is not used for transferring the data and the data communication is directly established between the two companies. The case company has special access rights to the supplier's server, which can be used without identification after login. The initial login therefore only enables persons having access to the configurators at the case company to access the supplier's configurator as the server is not accessible without the login. In addition at the case company, the access rights are not shared with the whole company as it is only available for the employees, which needs to work with the specific configuration/product model. These security methods should therefore protect the supplier from misusages of the integration both from the case company and from other external threats.

3.3.2 *Input and output parameters*

The data exchange between the case company and the supplier is done via .XML files. The case company sends 20 design parameters (such as min/max torque, what the reduction should be in the gearbox, gear factors), which are defined in the previous steps of the configuration process. The request is to find a design within these parameters, where the supplier's configurator, based on their logic and business rules, find all possible design solutions, which can be around 100 and the prices for the different designs. It is highly unlikely that the supplier's configurator will not be able to find feasible solution. However, if that situation comes up either parameters have to be changed in the configuration at the case company or the supplier has to be contacted. The design solutions are sorted according to prices (from lowest to highest) and sent back on an .XML format via the web API web services. For this specific product, the prices are most important and therefore the cheapest solution is automatically selected by the case company's configurator. It should though be noted that other parameters can be used to sort after, such as in terms of quality, lead-time etc. The information retrieved from the supplier is then used in the further steps of the configuration as the dimensioning of the product, will affect the overall design under configuration at the case company.

3.4 The impact from integrating configurators across the supply chains

3.4.1 *Reduced complexity of the configuration model*

The configurator models operated at the case company contain a number of sub-models that in turn include parts and modules bought from suppliers (as described in section 3.2). Outsourcing these sub-models, the complexity of the configuration model has been reduced. By reducing the complexity, in terms of business rules, tables, parts and values, of the configurators' models, the development and maintenance effort can simultaneously be reduced as the supplier's configurator is accessed in the configuration process. The supplier therefore becomes responsible of developing and maintaining his own products' information. In Table 1, it is summarized how the supplier integration affects the complexity of one of the configurator's model operated at the case company and the impact is has on the development time.

Table 1 Summary of reduction of complexity in the configuration at the case company

Characteristics of the configurator	Before the supplier's integration	After the supplier's integration
Business rules	86	0
Tables	13	0
Parts	17	1
Values	18.836	20
Development time of the system	8+ days	2 days
Specialist time spent on the development	8+ days	0 days

3.4.2 *Improved quality of the specifications in terms of updated and more detailed product information*

An important aspect of the proposed approach is improved quality of the products' specification as they are based on real-time, optimized and more detailed information. This secures a valid solution, right dimensioning of the product under question and exact and up-to-date prices are used in the overall configuration process.

For the product provided by the supplier addressed in this case study that is gears, the numbers of possible configurations for a product are 25-26 millions. When having so many possible combinations, it is not feasible to include them all by using Excel sheets or preliminary databases as it will take too long time to look up and affect the time it takes to start up the configurators. Therefore, for the product in question in this case study only 20 different configurations were included (out of 25-26 millions) in the configurators before the integration. As a result to this, the company was not using the most optimal design of the supplier's product (as feasible solution is selected based on limited number of configurations). The solution that was chosen was always scaled up to the predefined range, which means that surrounding systems also needed to be scaled up. As if one part of the design is over dimensioned other parts have to be adjusted accordingly, which will cause a snowball effects in the overall design. In Figure 4 this is demonstrated where the blue line represent the predefined configuration that would have been selected prior to the supplier integration and the red line represent the exact configuration, which can be selected as a result to more detailed information retrieved after the supplier integration was established. The product' dimensions for this specific product are determined based on required kilo watts (kW).

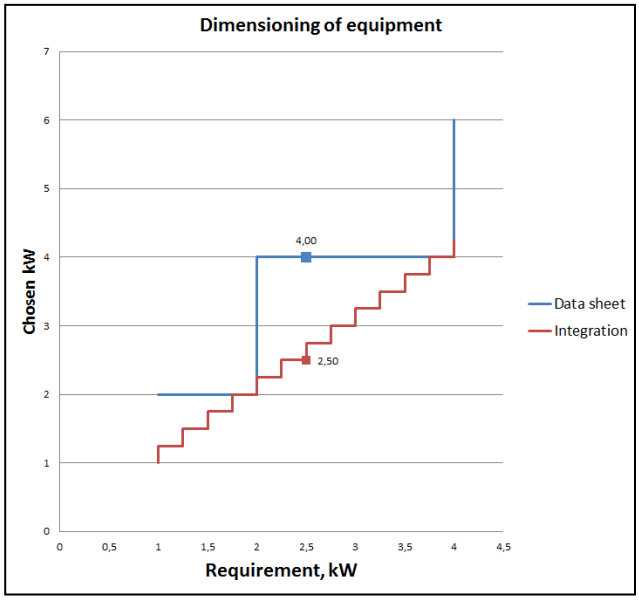

Figure 4 Dimensioning intervals of the equipment before and after the supplier integration

Having the precise dimensions of the supplier's product in the configuration process has proven to improve the accuracy of the generated specifications and reduce over-dimensioned surrounding systems. Therefore, the company has archived both immediate and in-direct cost savings as a result to more detailed product information. The immediate cost saving, for the example presented in Figure 4, is the difference between the 4,00 kW and 2,50 kW gear while the in-direct cost savings represent the related systems, or the frame as the gear is positioned on and again the platform area, weight of supporting building and etc. It is estimated that the company saves up to 20% in material cost in the overall design by having more detail information in the design phase.

3.5 Supplier incentive for providing integration

From a supplier perspective this approach provides additional benefits as it allows the supplier to protect sensitive product information, as these are considered as a secure black box in the configuration process. The supplier also saves resources for generating and sending proposals to their clients and thereby drastically reducing lead-times across the supply chains. Finally, the supplier hopes to increase their business share in long term with the case company as when this integration has been established it can easily be expanded to include additional products provided by the supplier.

3.6 Challenges with the approach

The main challenges can be related to legal barriers from both parties and to identifying suppliers that have the capabilities for the suggested collaboration with respect to operating with configurators.

For the companies addressed in this case study this is the new way of doing business, which needs the management and power to be able to execute it in a bigger scope so both parties can get some substantial gains from it. The main challenges can therefore be described in terms of organizational and not in terms of technical challenges. From the technical aspect, the whole programming was done in 2 days for the first time and afterwards for other integrations it was even less than 1 day, which highlights that the integration can be established without great effort.

4 DISCUSSIONS

The supplier integration used in the customization process where configurators are connected via API web services has proven to improve the overall process and provide substitutional benefits both for the case company and their supplier. This can be traced to accuracy of the suppliers' data, where more detailed and optimize information are provided, which are constantly up-to-date. This has enabled the case company to save up to 20% of the overall material cost in the overall design. Furthermore, the complexity of the configuration models can be reduced and the time consuming task of modelling and maintenance are delegated to the supplier. Finally, with this setup the supplier does not have to revile the actual logic behind the designs and the pricing strategy as the supplier's configurator is treated as a black box in the configuration process.

As the application of the configurators is constantly increasing, this integration to supplier's configurators becomes more realistic. That is since the requirement for making the integration is limited to the suppliers having operational configurators or willing to develop a configurator, which is capable of covering the required configurations. In addition to the integration that has been established at the case company four other suppliers have been identified that fulfil these requirements and have approved to participate in the project.

Further work at the case company with this approach will therefore include establishing the integration to greater number of suppliers, where comparisons capabilities of the configurator are used to identify the most suitable supplier. As for each product bought at the company there are several suppliers able to provide the product. For plant equipment, the aim is to have 2-3 suppliers for each of the products and the most favourable supplier each time will get the quote. The criterion for selecting the most desirable supplier has to be selected in the system for different products. In many cases the cheapest supplier would get the quote but it could also be lead-time, quality etc. The configurations retrieved from the suppliers are then sorted based on the selected criteria and the best one is selected by the system. This will automate the processes of comparing different suppliers' offers, which is done manually in the company today. For configurations on plant level there are preferred suppliers and therefore this cannot be applied in these cases. However, the comparison capabilities can be used to analyse the impact from changing the preferred suppliers to see the effect it has on prices, delivery-time etc.

The company has also made plans to increase the amount of documents retrieved from the suppliers in the configuration process. Therefore, further work will include making it possible to retrieve documents such as, 3D models and technical specifications as now only prices and dimensions of the product are received. Furthermore, currently the integration is only used to receive data as input in the configuration process, where the procurement will then contact the supplier to make the actual order purchase. In close future it is anticipated to automate that as well, so that the product can be requested from the supplier via the integration.

5 CONCLUSION

The present paper analyses the impact from having integrated configurators in the supply chains in an ETO company. The approach suggests the involvement of configurators that retrieve accurate sub-product information in real-time from suppliers during the customization process. The results indicate an improved quality of the product specifications and reduced complexity of the configurator model. Three propositions were developed to analyse the impact from integrating configurator across the supply chains to retrieve more accurate, detailed information and optimized in the configuration processes.

The first proposition investigates if by applying this approach the complexity of the configurator model can be reduced. The modelling and development effort proved to be reduced at the case company as they are not responsible for modelling the supplier's product information. Thereby the modelling and maintenance effort is moved to the supplier. The findings support this proposition as the complexity, which is defined in numbers of business rules, tables, parts and values is reduced to almost zero. This also effects the development time of the system which is reduced from 8+ days to 2 and the specialist time spent on the development has been reduced from 8+ to 0.

The second proposition questions if by integrating configurators across the supply chains, the quality of the specifications generated by the configurators will increase. The quality of the configurators model in this article is defined in terms of improved accuracy as the information retrieved via the supplier integration are optimized, more detailed and up-to-date. The findings support this as over dimensioning of different parts is not required as a result to improved quality of the products' specifications.

Finally, the third proposition is concerned with the improved quality of the specifications will lead to cost savings at the company. The result indicate that the company can save up to 20% of material cost as a result to immediate and in-direct savings gained from over dimensioning both the supplier's product and the surrounding systems. The results based on this study indicate that significant benefits can be gained from increased supply chains integrations in ETO companies where integrated configurators are distributed across the supply chains.

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