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Shafiee, Sara; Schäffer , Eike; Hvam, Lars

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Complexity of Configurators Relative to Types of Outputs

Sara Shafiee[1] and **Eike Schäffer** and **Lars Hvam**

Abstract.[1] Industrial gained and potential benefits of configurators are explored and researched to great extent in the literature. Moreover, configurators generate most of the needed documents automatically, which can be an effective solution to reduce the number of manual tasks. The generated documents include variety of customized knowledge such as BOM (bills of materials) or 2D and 3D figures. However, the influence of number and type of generated documents on the complexity of configurator has not been addressed in the literature. This paper aims to study the popular generated documents from configurators in an engineering company. Moreover, this study analyses the influence of different types of the generated documents on configurators' complexity. The research method is survey-based followed with interviews where the unit of analysis is based on operating configurators within an engineering company.

1 INTRODUCTION

Configurator projects in engineer to order (ETO) contexts fall into the category of IT projects with high level of complexity [1]. Owing to the increasing concerns about customer needs in the current competitive market, the identification and incorporation of customer requirements into product configuration designs have raised the interest of both researchers and practitioners [1], [2]. Product configurators include a knowledge base with information about product features, product structure, production processes, costs and prices [3], [4], empowering the companies by simulating the work that normally carried out by product experts, such as sales staff and engineers. Configurators are used to support design activities throughout the customization process in which a set of components and connections are pre-defined and constraints are used to prevent infeasible configurations [5]–[7].

Several studies report the gained benefits from the use of product configurators in engineering-oriented companies in the literature [8]. Configurators can bring substantial benefits, such as shorter lead times for generating quotations, fewer errors, increased ability to meet customers' requirements regarding product functionality, use of fewer resources, optimized product designs, co-creation and product innovation, less routine work and improved on-time delivery [9]–[16].

On the other hand, many companies also experience great difficulties in realizing such benefits within reasonable investment on configurators, which in many cases makes them abandon such projects [17]. Some of these challenges can be mentioned such as product modelling [18], documentation in configuration systems [19], system design and development [20][21], configuration process [1], analysis of benefits, risks, failures and impacts [8], [17].

Configurators used to support the engineering processes are considered more complex [19], [22] due to the expected documents and outputs from system. Besides, Configurators are mainly popular due to the automatic generation of the documents such as BOM, CAD (computer-aided design) 2D or 3D drawings, sales summaries, full quotations and others. However, there are no literature to compare the level of complexity in configurators related to the types of generated outputs from the system. Normally, the scope of the configurator is strongly related to the expected outputs from the system.

In this paper, the complexity of the configurator is calculated based on the number of inputs, attributes and constrains coded inside the system. By analysing the complexity in terms of types of the outputs, this research will provide a better understanding of the influence of the outputs and generated documents on the complexity of the configurators. Complexity of configurators influences the performance of the whole system as well as the efforts and investments related to system development and maintenance. Nevertheless, companies sometimes strategically decide to increase complexities to achieve the benefits such as generating more values and documents out of one configurator. This paper therefore aims to provide a more precise understanding on the different output types influencing complexity of configurators by providing answers to the following research questions (RQs):

***RQ 1*:** What are the popular generated documents in ETO companies?

***RQ 2*:** What are the influences of different types of generated outputs on the complexity of the configurators?

To answers to the RQs, a survey followed with interviews is conducted. This includes analysis based on one company where the unit of analysis is based on operating configurators within the company. This company developed and implemented 159 configurators in operation. The structure of the paper is as follows. Chapter 2 discusses the previous related works, and chapter 3 explains the research method. Chapter 4 highlights the main results of the research, and chapter 5 discusses the results in relation to the RQs and presents the conclusion.

2 RELATED WORKS

This section aims to provide the background for the study. Section 2.1 discusses configurators and automation process, and Section 2.2 provides definition of configurators scoping process. Section 2.3 discusses the complexity of configurators and the available contributions to suggest different solutions for calculating the complexity.

[1] Mechanical Engineering, Technical University of Denmark, email: sashaf@dtu.dk

2.1 Configurators and automation processes

The underlying IT structure of a configurator consists of configuration knowledge representation and reasoning, conflict detection and explanation, and finally an user interface [23]. Configurators can be applied as standalone software, as well as data-integrative and application-integrative systems [24]. Data-integrative configurators can be used to avoid data redundancies and application-integrative configurators allow for communication across different applications (e.g. computer-aided design (CAD) drawings can be generated based on the output of a configurator) [24].

In terms of data integration for configurators, common sources for master data can be found in enterprise resource planning (ERP) systems that often define a production-relevant view of the material. This is required for the assembly process, product data management (PDM) and product lifecycle management (PLM) systems, which are used to maintain production relevant data. Finally, product information management (PIM) systems are used to maintain sales-relevant data [25]. Different configurators can be integrated in terms of, for example, sales and engineering configurators [26]. At a higher level of aggregation, configurators can be integrated into suppliers systems to retrieve the required data from the configuration processes [27].

2.2 Scoping of configurators

Determining the scope of configurators is a knowledge management as one of the main challenge for industries and researchers [6], [28]. Moreover, clarifying the knowledge requirements for the entire project gives the team the opportunity to make intelligent decisions from the early phases of the project [29]. Furthermore, in the early phases of the configuration projects, the scope of the products sheds light on project goals and outputs, process objectives and requirements from involved stakeholders, IT architectural requirements as well as integrations and connectivity of the whole system, etc. [30].

One method of clustering the knowledge in configurators is to determine output knowledge according to stakeholder requirements and sub-categorize them step by step [6], [30]. Listing the sources and resources of the knowledge helps to group the knowledge and delegate the tasks to resources in an efficient manner to both increase the performance and decrease the risks of failures [31]. Depending on the resources, the knowledge might be explicit, and come from the company's internal documentation systems, or tacit, and come from domain experts [32]. However, in majority of the cases, the tacit and explicit knowledge are mixed and has to be clarified, condensed, standardized and visualized. In summary, the scoping and knowledge management process in configurators depends highly on the output documents expected by stakeholders to be generated from the system.

2.3 Complexity of configurators

Industrial companies are interested in calculating the complexities from different configurators and predicting the resource and time consumption required for developing and maintaining the configurator based on the system complexity [19]. The calculations not only clarify the required investments but also the expected gained return on investment from the configurator as well as future beneficial investments in development and maintenance.

Configurators are used to support the product or service configuration process. The configuring process consists of a set of activities that involve gathering information from customers and generating the required product specifications [26], [33]. The product configuration process can be divided into sales and technical configuration processes [34], [35]. The sales configuration process is concerned with identifying products that fulfil customers' needs and determining the main characteristics of the products [34]. The technical (engineering) configuration process, on the other hand, is concerned with generating documentation for the product based on the input gathered during the sales phase [34]. Another dimension of the configuration process is production configuration [35], [36]. Based on the coded data inside the configurator and the expected outcomes, these configurators have different levels of complexities. However, measuring the accurate level of complexity for the configurators is still challenging for companies.

To measure the complexity of configurators, Brown et al. [37] categorize them into three major components; (1) execution complexity, (2) parameter complexity, and (3) memory complexity. Execution complexity covers the complexity involved in performing the configuration actions that make up the configuration procedure and the memory complexity refers to the number of parameters that system manager must remember. In this paper, the parameter complexity is the most important, as it measures the complexity of providing configuration data to the configurator by users and external systems during a configuration procedure [19], [37]. Therefore, it was decided to focus on parameters complexity to determine the complexity of the configurators. In this article, the parameter complexity is determined based attributes and rules included in the configurators.

3 RESEARCH METHOOD

The chosen research method for this study is a within company survey followed by interviews. In this study, we analyzed only one company to get an in- depth knowledge about the configuration setup and to compare the complexity of the configurators within the same settings. This single company includes 159 different configurators. The same modelling paradigms are used for all the configurators in the company, which allows comparison of the complexity. The company therefore has an extensive experience from working with configurators. The case company introduced in the study has a world leading position in providing process plants and related equipment for industrial use. The example of the product types could be named as all the small products and technology used in cement plants from the chemical process to mechanical and electrical instruments. The company provides highly engineered products and engineering consultancy for both installation and maintenance. In summary, the case company is chosen because it:

- offers highly engineered and complex products;
- had frequently implemented configurator projects – including projects with frequent and more sporadic maintenance efforts;

- had a database including all the data regarding complexity of configurators, number and types of outputs generated from the configurators; and
- offered a unique level of access to project data.

The questioner was emailed to the company and the interview sessions was planned. In order to get the full understanding of all 159 configurators, the research team was supported through a project manager for one week to gather and evaluate the required data. The data was gathered from both internals systems at the company, documentations, and through survey and interviews, verified by the project manager. The configuration team also gave presentations and knowledge about the development and maintenance of the configurators at the case company.

The configurator were grouped according to specification processes they supported; sales, sales and engineering, and engineering. A limitation of the data is that the majority of the configurators are used to support the engineering processes (75%), and sales and engineering processes (19%) while there are few configurators used to support only sales processes (3%) and finally configurators used to support other processes (such as manufacturing or marketing process) are (2%). Figure 1 illustrates the percentage of different types of configurators at the case company.

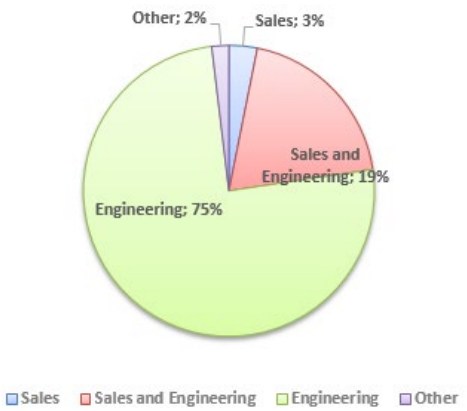

Figure 1. Percentage of types of configuration system in use at the company

4 RESULTS

In this chapter the main result from the survey are presented aligned with both the RQs introduce in the paper.

Within the first section, different types of the outputs generated from different configurators were elaborated at the case company. Some of the configurators generate more than four different documents. The generated documents have a vast range of varieties including sales and production (Prod.) Bills of Materials (BOM), 2D and 3D CAD documents, quotations and etc. The group that has been called 'other' belongs to the documents which has been generated from the other internal home-made IT systems at the case company. The different types of outputs as well as the most popular ones are analyzed (RQ 1). The second section elaborates the influence of different types of generated outputs on the complexity of the configurators (RQ 2).

4.1 Types of generated documents for the configurators

This chapter analyses different types of output documents from configurators at the case company and studies how frequent they were used. First, we extracted different generated outputs at the case company and group them. Second, the number of configurators related to each group of documents has been measured. Figure 2 shows the percentage outputs generated from configurators at the case company.

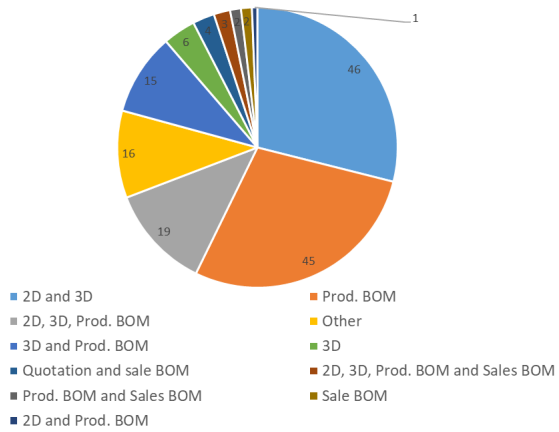

Figure 2. Percentage of different types of outputs generated from configurators at the company

As can be seen in figure 2, there are many configurators generating 2D and 3D CAD documents as well as the production BOM. Based on the numbers on the figure 2, the configurators generating 2D and 3D plus production BOM are in the next level and belong to the configurators that generates three different documents. The figure demonstrates that the most popular documents are 3D and 2D CAD drawings. After CAD drawing documents, production and sales BOM are the most popular documents to be generated automatically from the configurator at the case company.

4.2 Complexity measurement in relation to the types of generated documents

Table 1 illustrates the complexity parameters of the configurators relevant to different types of generated documents. As it is demonstrated in table 1, the total complexity is calculated for different types or mixed of different outputs.

According to table 1, figure 3 is demonstrated to visualize the data in table 1. This data shows that the number of configurators and types of generated documents and the sum of the complexity but we cannot understand the level of complexity for each group of documents. Hence, we calculate the numbers (No.) in table 2.

Table 1. Complexity measurement in relation to the types of generated documents from configurators

Generated documents	Number of configurators	No. Rules	No. Attributes	No. Input Fields	Total complexity
Prod. BOM and Sales BOM	2	1568	2599	627	4793
2D, 3D, Prod. BOM	19	635	1122	180	1937
2D and 3D	46	538	798	215	1551
Other	16	352	454	573	1379
3D	6	483	343	236	1062
Sale BOM	2	240	310	448	998
Prod. BOM	45	334	381	191	906
Quotation and sale BOM	4	210	307	293	810
3D and Prod. BOM	15	278	303	125	706
2D, 3D, Prod. BOM and Sales BOM	3	228	257	146	562
2D and Prod. BOM	1	33	32	27	92

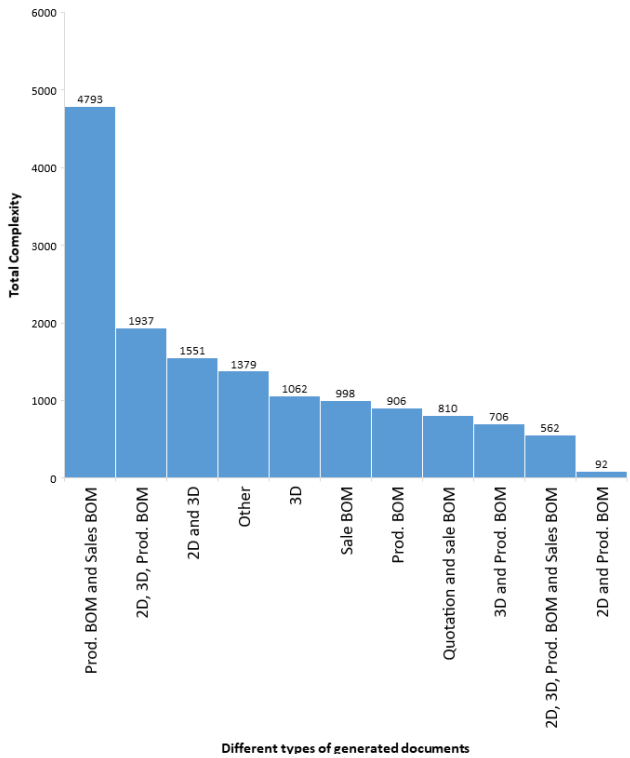

Figure 3. Complexity measurement in relation to the types of generated documents from configurators

Table 2 and accordingly figure 4 demonstrate the average of complexity for each document categories generated from configurators. The reason for generating table 2 and figure 4 is to illustrate the average complexity as cumulative numbers of attributes and rules for different types of documents.

Table 2. The average of complexity per generated documents types for one configurator at the case company

Generated documents	Average of complexity
Prod. BOM and Sales BOM	2396.5
Sale BOM	499
Quotation and sale BOM	202.5
2D, 3D, Prod. BOM and Sales BOM	187.3
3D	177
2D, 3D, Prod. BOM	102
2D and Prod. BOM	92
Other	86.2
3D and Prod. BOM	47.1
2D and 3D	33.7
Prod. BOM	20.1

As demonstrated in figure 4, the average of complexity is the highest when the configurator generates the group of documents of production and sales BOM and in the next level is the Sales BOM. In the third level of the most complex configurators are the ones generating the quotations and sales BOM. Afterwards, the documents generated from CAD such as 2D and 3D documents are located. Thereafter, the numbers shows that BOM documents create the highest amount of complexity in the configurator, while 2D and 3D documents create less complexity in the structure of the configurator. Moreover, 2D and 3D documents and also production and sales BOMs are the most popular documents generated from the configurator at the case company due to the time and resources saved due to this automation.

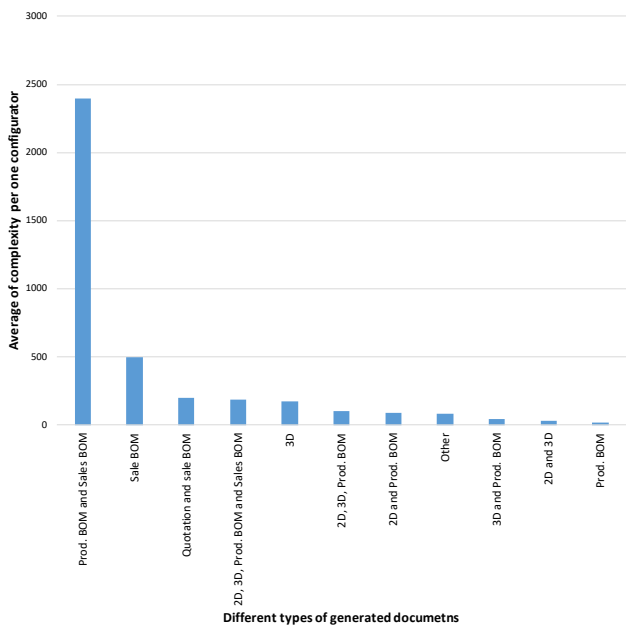

Figure 4. The average of complexity per generated documents types for one configurator at the case company

5 DISSCUSSIONS AND CONCLUSIONS

This study provides insights into the type of generated documents in an engineering company and the influence on the complexity of the configurator. The complexity is analysed based on parameters, which consists of cumulative numbers of attributes and rules. First, we extracted different generated outputs at the case company and group them. Second, the number of configurators related to each group of documents has been calculated. Thereafter, the complexity is calculated based on the number of attributes and rules in the configurator.

In the literature, it is discussed how configurators are used to support the engineering processes are considered more complex [19], [22] due to the expected documents and outputs from system. However, the literature does not explain what are the most popular documents generated from the configurator and how these documents influence the complexity of the configurators. The results provided in the present article aim to contribute to the field of configurators' complexity and the factors influencing them. In this article, we analysed the influence of the generated outputs from the system on configurators' complexity. This is an important topic not only for the research community but also for practitioners. The results show that a difference can be found in relation to the complexity by analysing different types of generated documents.

The first research question in this study aims to identify the most popular and common generated documents. The results demonstrates that 2D, 3D documents and BOMs are the most common generated documents which can be due to the benefits. Normally creating 2D and 3D drawing based on a specific configuration of the system is a time consuming task. Moreover, preparing the bills of material including details and prices based on a specific order is a teady task. Hence, generating these types of documents leads to considerable benefits for the company.

The second research question aims to analyse the relationship between the types of generated documents and the complexity of the configurators. Our analysis shows that the highest is the parameters complexity when the configurator generates the group of documents of production and sales BOM and in the next level is located the Sales BOM. In the third level of the most complex configurators are the ones generating the quotations and sales BOM. Then in lower levels of complexity, the documents generated from CAD such as 2D and 3D documents are located.

The results shows that the most popular are CAD drawing and BOMs while BOMs create the highest level of complexity in the configurator. The reason can be explained technically. While generating CAD documents from configurator, we integrate the system to the CAD and make sure that the names are mapped between the systems. However, creating BOMs requires lots of rules and attributes including the whole list and details of materials that can be millions. Thereafter, the rules for different calculations such as price calculations have to be considered. Therefore, it is rational to conclude that BOMs create very high complexity inside the configurator. Besides, automating the generation of BOMs reduces considerable amount of time and resources from industries.

The results can be very beneficial for strategic planning at ETO companies to decide on scoping of configurators. This research provide a good estimation to compare the complexity of the configurators with different generated outputs.

The result presented in the paper is based on answers from one case company. However, this large case company with 159 different configurator can represent most of the engineering companies. This is thought to provide a valuable insight as by studying one company an in-depth knowledge about the configuration setup could be accessed. More companies will be contacted in the future, which will allow cross functional comparison for the further studies. Considering and analyzing different influencing factors on the complexity level of the configurators and comparing the results can shed lights on potential practical obstacles during development and implementation of the configurators.

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