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Bottom-up Component Rationalisation using a Dynamic Sharing Matrix

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Abstract

Today, many companies spend a lot of resources developing and delivering products tailored to customers' needs. This strategy of product proliferation has a huge effect on the complexity of the companies' product portfolios, with an aspect of this being the management of the supply chain and inventory of the components used in the products. This paper addresses this challenge by proposing a tool to reduce the number of component variants used in the product portfolio by creating an overview and proposing possible replacement components. The tool has been developed with smaller components in mind, as these are often overlooked as being insignificant, even though they can pose significant challenges for inventory management and cause delays in lead time if not in stock. The general approach for the method is to gather the available data from within a company, and then start by analysing one type of component by setting up the matrices described to find possible replacement components. The process can then be expanded to other types of components, gradually, to increase the effect within the company. The process has been employed in an engineer-to-order company that makes district heating units with a high degree of customisation. The focus here was put on different brass components, like tees and other fittings, which we classify as smaller components. This work has drastically improved the overview of brass components within the company to help in the development of new products. The process is, at the time of this writing, still in progress, but initial estimates suggest that about 40% of the variants of brass components can be eliminated or replaced by other components, without affecting the functionality of the products being sold.

Keywords: Component rationalisation, bottom-up, complexity reduction, product portfolio mapping, sharing matrix,

1 Introduction

Various strategies of product proliferation have become widespread in recent years within industry, with customers being able to order products tailored to their preferences. This increases the variance and complexity of the companies' products, which effects the proliferation of inventories of the purchased and semi-finished parts (Forza & Salvador, 2002). A long-term solution to this challenge could be a thorough analysis of the company, its products and processes, with the goal of developing new, efficient and future proof product architectures, as described in (Mortensen et al., 2012) using the principles of modularisation, also described in (Erixon, 1998). These approaches, however, require a large amount of time and resources to perform and implement, and they give little advice on what to do in the short term and how to handle existing products during the development of new architectures.

An approach that can yield results within a smaller time span refers to when companies address this challenge of product complexity by performing conventional stock keeping unit (SKU) rationalisations. This can be quite effective in make-to-stock (MTS) companies, but the techniques are not as effective in make-to-order (MTO) companies, as they focus more on product manufacturing and distribution costs rather than product development, marketing and aftermarket service costs (Meeker et al., 2009).

In MTO companies, products are often configured with the aid of a configurator, who provides predetermined rules that the customer can choose from; however, in engineer-to-order (ETO) companies, the uncertainties regarding product specifications are even higher, as the products are customised to customer needs through engineering activities (Willner et al., 2014). These uncertainties constantly generate new variants, which creates product portfolio complexity. This, in turn, creates difficulties in the execution of supply chain processes related to product development, supply, manufacture, delivery and support (Closs et al., 2008).

Due to the practice of postponing production to the actual time of the order, the number of SKUs that must be kept in stock are naturally lower in MTO and ETO companies. The inventory of components/raw materials to be used in the products, however, are not affected, and due to the uncertainties mentioned above, the management of this inventory will likely be more complex. This larger complexity and variety are unwanted, as having fewer components reduces the risk of forecast errors, which means that the safety stock of multi-use components can be smaller than the sum of the safety stock of the covered specialised components (Boysen & Scholl, 2009). This leads to reduced inventory cost and reduces the risk of components with long delivery times not in stock on the production site when needed during production.

This paper addresses the following questions: "How can we reduce the complexity of the portfolio of existing components?" and, "How can we select the right components for removal or replacement?" These questions can be addressed by providing a tool to assist in finding and selecting compatible components within the existing portfolio to move volume from low-runner to high-runner components. Applying this can also serve as a first step in the process of implementing a more radical product architecture development project via the provision of guidance regarding which components to keep for the new architecture, and can provide some immediate benefits for in the current product portfolio during architecture development process.

2 Research Approach

A method for rationalising sub-components within a product portfolio is proposed. The method has been tested in a global company that has approximately 3,000 highly customisable variants serving different markets, with significantly different requirements depending on region and country. The company's products are divided into seven different product assembly lines and more than 15 different product families. The components targeted by this analysis are shared between all families, which means that all families must be considered to show the bigger picture.

Considering the internal validity, the researcher has full access to detailed data from the company. Quantitative data has been gathered from the company's enterprise resource planning (ERP) system and computer aided design (CAD) library, and qualitative data has been gathered from un- and semi-structured interviews with key employees and managers from the sales, engineering and purchase departments. Furthermore, un- and semi-structured interviews have been performed to evaluate and provide feedback to the proposed method, and to directly involve and engage the organisation in the research. The interviews ranged from prepared sessions with one or two employees to gather specific information on company products or processes to more unformal "talks at the coffee machine" from which the amount of useful information gathered must not be underestimated.

The study has been carried out over a period of about six months in 2021 as part of a PhD project partly financed by the partner company.

3 State of the Art

This paper contributes to research and industry with a method for rationalising sub-components inside a company's product portfolio by means of the dynamic sharing matrix. A literature review has been performed with a focus on finding and investigating existing methods for reducing a component portfolio to reduce complexity, gather inspiration and establish state of the art performance. The literature review has been performed online using DTU-Findit, Web-Of-Science and Scopus with keywords, such as 'rationalise product program', 'simplify component assortment', 'product portfolio complexity reduction' and 'component variety optimisation'. Additionally, the list of references for each article is used to identify the related bibliography. Listed below are some of the approaches that were found in the literature for getting an overview of or rationalising components. The selection of approaches has been based on the criteria that they are concerned with the component use and variety within product portfolios and how to optimise this.

3.1 Mathematical Quantitative Models

Several writers have contributed with different approaches consisting of mathematical models as tools for providing answers with regard to component commonality and variety optimisation, or in some cases, product family development. Heese and Swaminathan (2006) developed a model to select components to maximise the profit for a company with two products sold to two market segments with different valuations of quality. Gupta and Krishnan (1999) describe a model with the purpose of deciding which components to replace in a portfolio and which suppliers should supply the components, all based on a quantitative ranking of component functionality. The model is, however, limited to a case where components that enable different functional capabilities do not interact with each other. Boysen and Scholl (2009) proposed a framework based on a two-stage graph approach to solve commonality problems based on products and required features. However, their approach was only implemented theoretically in a computational study, and not in an industrial case.

Moving up a level to product family development, which is also, in most aspects, related to component selection, Bajaras and Agard (2014) propose a methodology to create product families using fuzzy logic. The output from the model is a family of products based on features where direct component-level development has not been included. Corbett and Rosen (2004) also applied a mathematical model for platform commonization, especially with regard to interfaces and component compatibility.

While these models might be logically and/or mathematically elegant, they are all based on gathered or developed data. Generally, better raw data will naturally provide better results. In practical cases, gathering enough high quality, accurate and quantifiable data is often both challenging and time consuming, if not impossible; and, according to (Askhøj & Mortensen, 2020), this is especially true in small companies where data are not available.

3.2 Existing Tools for Component Analysis and Mapping

3.2.1 Product Family Master Plan

The Product Family Master Plan (PFMP), which is described in (Harlou & Mortensen, 2006; Mortensen et al., 2012) is a well proven tool used to get an overview of a product family, and thereby, to some extent, its components. The main shortcomings of the PFMP, with regard to balancing the depth (detailing of included products) and width (number of included products) of the investigation, while also considering the size of the resulting overview, comes down to the scoping.

If the tool is used for the development of a new product architecture, it might be sufficient to include the old product family for redevelopment in the model with its major components, and then abstract from the smaller insignificant components to avoid making the PFMP too complex. However, if the goal of the investigation is to rationalise not only the major components, but also the smaller components, naturally, they must also be included in the model, which adds a significant amount of complexity. This might still be possible to manage, if only one product family is within scope, as the number of products is relatively limited.

The tool, however, does become less usable if multiple product families are to be considered, especially if there is some amount of component sharing between product families. This will require a large width of analysis (many different products) and, at the same time, a large depth (high detailing of each product); as a result, this will simply become too big to create any sort of overview.

3.2.2 Product Commonality Index

There are several different product commonality indices that can be used for product family redesign. Thevenot and Simpson (2006) provide a comparison of six different commonality indices for products, components and production lines. A methodology for product family redesign is also proposed with four phases for scoping, data gathering and computation, analysis of computed data and then a redesign phase. A shortcoming, however, is that the redesign step does not provide much guidance, rather, it suggests, using the calculated commonalities from the indices, to redesign the product family. Additionally, there is the challenge of some of the indices being quite subjective, such as in the case of competing geometries, which can make the results less accurate. The commonality indices do, however, have a strong point in serving as a benchmark, making them tools that could be used to investigate commonality before and after a component rationalisation process.

3.2.3 Conventional Sharing Matrix Concepts

One relatively simple way of illustrating component usage and sharing is to make a matrix with components on one axis and product variants on the other. This can be inspired by the constraint table described in relation to the PFMP in Harlou and Mortensen’s (2006) study, where the table shows the usage of parts in different assemblies. When used in this context of showing usage or constraints between a selection of parts, and a relatively limited number of sub-assemblies, the table is quite useful. However, if the principle of the table was to be used for completed products in a whole product family, with all associated parts in a large matrix, it would become too large and would not be useful for making an overview. Another weakness is that the matrix or table can only provide an overview, not any input on what to do.

3.3 Value Engineering

The concept of value engineering is to develop or improve the value of products by achieving the required function at the lowest possible cost. The general relationship between these three elements is V = F/C, where V is the value, F is the function (meeting the demand of customers) and C is the cost of the product (PENG et al., 2017). According to Sharma and Belokar (2012), value engineering is an effective problem-solving technique and an essential process that uses function analysis, teamwork and team creativity to improve value.

A model for integrated value engineering is proposed in (Maisenbacher et al., 2014) using a Multiple-Domain-Matrix to gather and list requirements, functions and components, with the goal of deducing correlations between them and identifying where there is potential to improve value to achieve a set target cost. The model has then been further developed in (Behncke et al., 2014), with a matrix that also considers the assembly process, manufacture process and suppliers for the components.

Value engineering has also developed into the Design-to-Value approach, as described by the worldwide management consulting firm McKinsey & Company. They describe the methodology as focusing on optimising the market aspect of product lines from consumer preferences, along with benchmarking the company against competitors and leveraging supplier insights to optimise costs (Henrich et al., 2012). According to (McKinsey, 2015), successfully implementing a Design-to-Value approach can yield a dramatic performance improvement, along with a 10–40% reduction in product cost and a 15–50% reduction in time to market.

In relation to component rationalisation, being the topic for this paper, the goal of maximising value is well in line with the target of rationalisation. Therefore, while the objective is the same, what the value engineering methodologies described here lack is the actual input on what to do, rather than just providing a tool to visualise the current situation and help identify where to put in the effort.

3.4 State of the Art Conclusion

To sum up the state of the art, the most obvious gaps identified are related to three aspects. Aspect one is related to methods concerned with mapping or quantifying the current situation. This is beneficial for getting an overview or for comparing situations before and after changes, but fails to provide input on changing the situation. Aspect two is related to the requirements for the completeness of data. Mathematical tools or indexes require a complete and consistent set of data to provide reliable results, and this is often impossible to get in a company challenged by complexity. Aspect three refers to the scope of employing the approaches. For these tools to be useful, they must include an investigation of the company’s whole portfolio, which requires many resources and, if this is then completed, the result will be too large and complex to be used for anything.

4 Dynamic Sharing Matrix

With the shortcomings mentioned above, the Dynamic Sharing Matrix is proposed as a tool to assist the process of reducing complexity in a product portfolio by rationalising the components used in the products. The general idea is to use the data available in the company to create a selection of relatively small matrices to help identify substitute components that can be used to narrow the portfolio of components by shifting volume from many low-runner components to fewer high-runner components.

4.1 Scoping and Applicability

Finding the information needed to develop the Dynamic Sharing Matrix is an essential part of the process. First, there are considerations about the scope of the investigation. Generally, the method is developed to consider the entire selection of product variants within the portfolio, but only one category of components at a time. The keyword to this scoping is bottom-up. Figure 1 shows a simplified example of a product portfolio with product families, variants and components. Taking a traditional top-down approach could be to investigate only one product family at a time, but as seen in Figure 1, this can lead to a failure to consider many components. If there was no sharing of components between variants and families, this might not be a problem, but if there is sharing, the incomplete analysis can lead to wrong decisions.

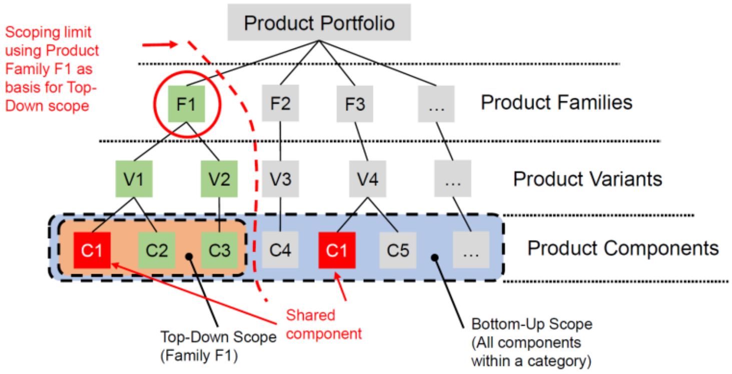


Figure 1. Illustration of a product portfolio structure explaining the reasoning for usage of the bottom-up approach. Starting from the top the different product families are denoted by 'F', different product variants by 'V' and difference product components by 'C'.

Consider, for instance, a scenario where a top-down analysis is done based on F1 and where V4 is selling in large volumes, but V1 is not. The top-down analysis would suggest eliminating C1 and C2, but this would be wrong, as C1 is used in high volume due to V4.

This calls for the bottom-up approach to be used. The principle here is to take one type of component and investigate its use independently of the product variants it is used in. They can then set the direction on what to eliminate, and these results can additionally suggest the elimination of product variants. The resulting scope of a bottom-up approach is illustrated by the blue area in Figure 1.

Having determined that it is beneficial to take a bottom-up approach when performing the investigation, another important part of the scoping is the question of determining which components to look at. This requires the consideration of the product portfolio, its products and components. A product consists of components of different sizes, functionalities and complexities. Some components (we call these main components) are directly related to the functionality of the product and, therefore, directly related to customer requirements, while other smaller components (we call these supporting components) are only there to support the functionality of the more significant components. Examples of these supporting components are pipes, hoses, fittings, wires, nuts, bolts, etc.

The Dynamic Sharing Matrix is developed with the supporting components in mind, as the matrix should be able to assist in finding replacement components that can comply with the same requirements. The main components are typically more directly related to the functionality of the products, meaning that they are more difficult to replace while maintaining functionality. The organisation also tends to put more focus on managing the main components, due to their higher cost and relevance for the products' specifications. The supporting components, on the other hand, are smaller and less significant, meaning that they are often overlooked even though they are still important for the products, are used in large numbers and consist of many variants. This can add a significant amount of complexity in inventory cost and management, and can result in extended delivery times of finished products if components are not in stock.

4.2 Matrix Tool and Example

To support the understanding of the tool, a theoretical example has been provided, as shown in Figure 2, Figure 3 and Figure 4. The matrix contains a selection of product variants, and one type of component. Additionally, the sales number of the product variants and usage volume of components are listed. Some requirements and specifications have also been included, along with a visual representation of each component and variant, which will be relevant when determining the possible actions in Figure 4.

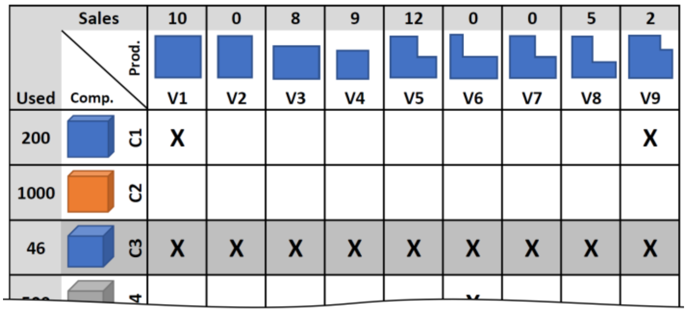


Figure 2. A snapshot of the base matrix. This example is based on component C3, and contains all the product variants that contain component C3. The usage of other components in these units are also included, denoted by 'X'. The full matrix can be seen in Figure 4.

The term 'dynamic' comes from the way the matrix is created. The content of the matrix, shown in Figure 2, is dynamic in the sense that it is taken from a complete matrix with all product variants on the horizontal axis, and one type of component on the vertical axis. This component is then taken as a basis, meaning that the target of the generated matrix is to remove this component from the portfolio. When this component is selected, all product variants not containing this component are removed to form this dynamic matrix, which has a more usable size and format. This process is then supposed to be repeated for all the components that are to be removed from the portfolio.

The matrix in Figure 2 shows the current situation with component C3 as a basis, which is highlighted by the grey colour of the row. This means that the matrix shows all the product variants that use component C3, and the other components of the same type. The component C3 is used as the basis for the matrix, as the objective is to remove component C3 from the portfolio due to low volume.

The matrix in Figure 3 provide an overview of the options for replacing the components based on a comparison of requirements from the product variants with the specifications for the component variants. The tool compares the requirements determined by the product that the component is used in and compares it with what the components are capable of handling. If the component specifications match or exceed the requirements of the product, the combination is given as 'Y' in the matrix, indicating a possible substitute.

In this example, the requirements/specifications used are 'maximum temperature', 'maximum pressure' and whether it is a 'high-wear-environment' related to requirements for the material of the components. In this case, the 'high-wear-environment' requires 'material A'. These properties should be selected based on how they can be used qualitatively, and another important consideration can be the availability of data. Therefore, in cases where data is difficult to gather, the selected data might just be what is available.

Apart from providing an overview of possible substitutes, the matrix in Figure 3 also provides two different suggestions for substitutes. The first suggestion is based on cost, meaning that the component that matches the requirements and has the smallest cost is suggested. The second suggestion is based on volume, which means the matrix suggests the compatible component that is currently most frequently used. The highlighted possibilities and suggestions should then be able to assist the employee in decision making.

*High wear -> Mat A					Specs.	V1	V2	V3	V4	V5	V6	V7	V8	V9
					Max. T	80	80	80	80	80	70	110	110	70
					H. Wear	Yes	No	No	Yes	Yes	No	Yes	No	No
					Max P.	120	120	130	110	80	60	150	140	100
					Sales	10	0	8	9	12	0	0	5	2
Max T.	Max P.	Mat.	Cost.	Used	Comp. \ Prod.	V1	V2	V3	V4	V5	V6	V7	V8	V9
100	130	A	90	200	C1	Y	Y	Y	Y	Y	Y	-	-	Y
100	100	B	80	1000	C2	-	-	-	-	-	Y	-	-	Y
120	120	B	130	800	C10	-	Y	-	-	-	Y	-	-	Y
					Suggestion (Lowest Cost):	C1	C4	C4	C1	C1	C5	C9	C4	C2
					Suggestion (Highest Volume):	C6	C6	C4	C6	C6	C6	C9	C4	C6

Figure 3. A snapshot of the option matrix. This highlights which components can be used as substitutes for each product variant based on specifications and requirements. Possible matches are denoted by 'Y'. The matrix also makes suggestions for compatible substitutes based on the lowest cost and highest volume.

This leads to the results matrix in Figure 4, which shows the decisions made for each component in this fictive case. Each elimination or replacement is denoted by a different letter to increase clarity and, in case of replacement, the new component to be used is shown with the letter followed by '*'. For example, component 'C3' in product variant 'V1' denoted by 'A' is replaced with component 'C6', denoted by 'A*'. An alternative to replacing the component is to just eliminate the product variant in the case of low or no sales. This has been done for product variant 'V2', 'V6' and 'V7', and is illustrated by the orange columns and no '*' added to the letters as the component is removed not substituted.

*High wear -> Mat A					Specs.	V1	V2	V3	V4	V5	V6	V7	V8	V9
					Max. T	80	80	80	80	80	70	110	110	70
					H. Wear	Yes	No	No	Yes	Yes	No	Yes	No	No
					Max P.	120	120	130	110	80	60	150	140	100
					Sales	10	0	8	9	12	0	0	5	2
Max T.	Max P.	Mat.	Cost.	Used	Comp. \ Prod.	V1	V2	V3	V4	V5	V6	V7	V8	V9
100	130	A	90	200	C1	X								X
100	100	B	80	1000	C2									I*
120	155	A	120	46	C3	A	B	C	D	E	F	G	H	I
120	150	C	85	500	C4			C*			F		H*	
80	80	D	50	0	C5						F			
100	120	A	100	2000	C6	A*			D*	E*				
100	120	A	105	12	C7					X				
100	115	E	85	623	C8									
120	200	A	110	289	C9							G		
120	120	B	130	800	C10			X				G		

Figure 4. The results matrix. The selected replacements are shown with a different letter for each component. The red letters are the original component and the letters followed by '*' are the substitutes. Orange columns denote the fact that the product variant has been eliminated.

The Dynamic Sharing Matrix is a tool used to assist the process of reducing the variety of components within a product portfolio, and can provide some input with regard to how components can be replaced. A strength of the method is that it can be used with the data that is available, even though it is not complete; however, better data of course yields better results. The tool also makes it possible to start investigating one type of component, and then expands gradually to more types of components.

5 Industrial Case

The approach has been used in the case company mentioned in the Research Approach section. The focus of the component rationalisation was placed on brass components used in the company's district heating units based on a request from management. Generally, there were two expected outcomes of the process. One was to reduce the number of components in the portfolio to simplify inventory management, and the other was to provide better overview of which components to use, and not use, when developing new products. Bottom-up scoping was used, as described earlier, with each type of component investigated, independent of the product families that they were used in. The brass components primarily included different types of fittings, like tees, angles, crosses and other adaptors, but also smaller components, like plugs and union nuts. An example highlighting some of the variance creating complexity for the tee-pieces is shown in Figure 5.

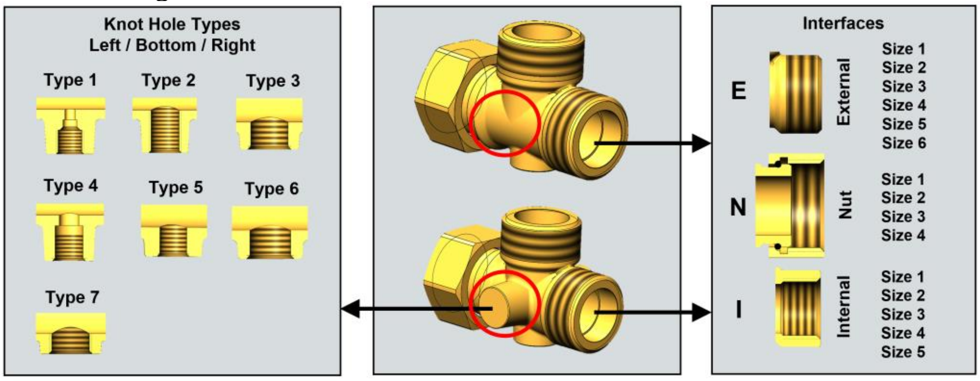
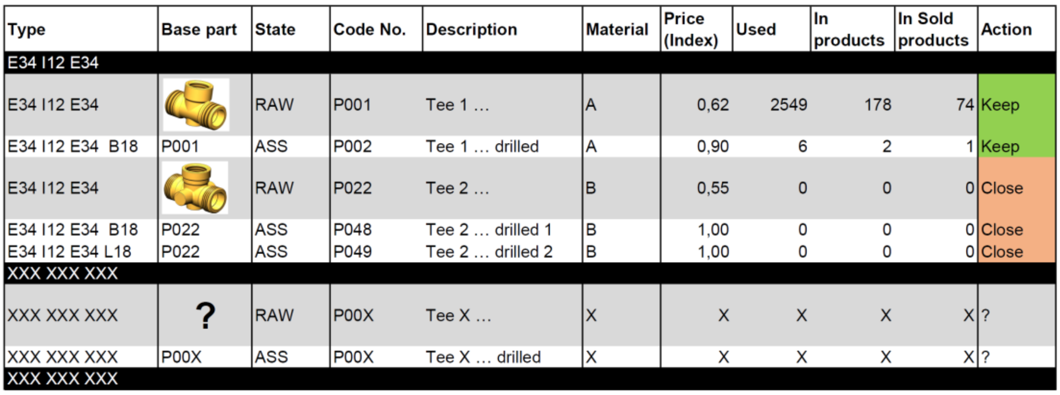


Figure 5. Overview of the tee's, which was one of the types of components investigated for rationalisation.

Differences include different thread diameters, along with different interfaces and types of holes drilled, or not drilled, in the side of the components. Component data was collected from the company's ERP system (provided by the company SAP) and where available, images were found in the company's CAD file library.

First, a spreadsheet of code numbers within the company, containing about 20,000 lines, was manually sorted to identify the subcomponents to investigate. This could then be used as basis for pulling out a list of cost prices for the components, and another for quantity of components used in a selected period. The period selected was from January 2020 to May 2021, due to a migration of ERP-systems in late 2019. Based on the spreadsheet of code numbers, another spreadsheet containing the BOMs for the company's product variants with over 500,000 lines was extracted. This BOM-spreadsheet could then be matched with sales data and component code numbers to provide information on how many different products each component was used in and how many of these products were achieving sales.

To gain benefits from the work as soon as possible, preliminary versions of overview spreadsheets were quickly handed over to the design department containing the described information about the components. These spreadsheets also contained markings of components that seemed at risk of being eliminated. This allowed the engineers to, from this point, start designing new products and product variants using high-runner components, and at the same time, avoid components marked for elimination, which would find their way into new products. A small part of the spreadsheet is shown in Figure 6. The general feedback from the engineers and designers was very positive, with the overviews not only making it easier to avoid selecting low-runner components, but also providing an overview of components within the portfolio that they previously had not had. A project engineer in the company stated: 'I use the spreadsheets every day and they are a great help in my daily tasks. They give a systematic overview of components that I can use when developing products'.



Type	Base part	State	Code No.	Description	Material	Price (Index)	Used	In products	In Sold products	Action
E34 I12 E34										
E34 I12 E34		RAW	P001	Tee 1 …	A	0,62	2549	178	74	Keep
E34 I12 E34 B18	P001	ASS	P002	Tee 1 … drilled	A	0,90	6	2	1	Keep
E34 I12 E34		RAW	P022	Tee 2 …	B	0,55	0	0	0	Close
E34 I12 E34 B18	P022	ASS	P048	Tee 2 … drilled 1	B	1,00	0	0	0	Close
E34 I12 E34 L18	P022	ASS	P049	Tee 2 … drilled 2	B	1,00	0	0	0	Close
XXX XXX XXX										
XXX XXX XXX	?	RAW	P00X	Tee X …	X	X	X	X	X	?
XXX XXX XXX	P00X	ASS	P00X	Tee X … drilled	X	X	X	X	X	?
XXX XXX XXX										

Figure 6. A snapshot example of the overview used for easing the selection of components for future products.

The elimination process is still in the works, as it requires final approval from engineers and management, and more importantly, it requires time spent by employees performing daily work, which can prove difficult to find in a busy company environment.

5.1 Quantitative Results

As mentioned above, the process of closing part numbers is still ongoing, meaning that the exact number of eliminated components is not known. In Table 1, however, the quantitative results from the identification phase are listed. These numbers are of cause estimates, but do provide some insight to the level of reductions possible. Types can, for instance, be tees or angles, but they are anonymised for confidentiality.

The numbers for variants to be closed covers different levels of complexity of removal, with some variants being obsolete (not used at all) and others being more difficult to eliminate, as they are used in active products. For Type 8, for instance, about 74% of the 132 components are either unused, or rarely used, allowing for relatively easy removal; the remaining 26% will require more effort.

Table 1. Number of currently existing variants of nine different types of brass components and the expected number that can be eliminated. Component types are anonymised, as it is company sensitive data.

Component Type	No. of Variants	Variants to be closed	Percentage reduction
1	474	200	42%
2	92	54	59%
3	187	80	43%
4	40	22	55%
5	62	10	16%
6	46	15	33%
7	39	5	13%
8	258	132	51%
9	53	20	38%
TOTAL	**1251**	**538**	**43%**

In general, it seems that about 40% of component variants should be possible to remove, suggesting that the company is currently dealing with more complexity than necessary. When discussing this highly unnecessary number of variants with employees, it seems that the main reasons for the many components are historical, with variants coming from old products and the company being incapable of eliminating old components when developing new products.

6 Discussion and Conclusion

We propose a tool to assist in the process of reducing the number of components in a product portfolio to be used in industry. The tool is made with the supporting components in mind to allow employees to make the right decision when eliminating or substituting components.

The main contribution consists of the Dynamic Sharing Matrix, or rather, the three matrices described in the paper, along with input on how to gather the data from within an organisation required to create and fill out the matrices. Currently, the matrices are still on a conceptual level, with the matrices having been developed manually in Microsoft Excel, along with most of the data processing. Regarding the collection, insertion and updating of data, this is, by nature, quite a manual process. We would argue that this is, at the present time, the largest weakness of the tool and the proposed approach, as it requires a significant amount of both time and discipline from the people adopting the model to a company's product and component portfolio. Ideally, the model should be linked to a company's ERP/CAD/product data management (PDM) system directly. This would allow for data to be updated automatically, meaning that decisions can be made based on live data, rather than a snapshot, and that the effects of changes can been seen instantly in the data used for the matrices.

An important goal for the tools developed is that they should be usable in industry. A frequent challenge in real cases is, as mentioned earlier, not only to get access to data, but to get access to high quality and complete data. We have, therefore, focused on presenting tools that should be able to provide 'the best results possible' with 'the best data available'. At the same time, the creation of the dynamic sharing matrices can, if all product variants have been found and listed, be done gradually for one type of component at a time, to gradually introduce improvements in the company. However, the downside of this is that the guidelines and suggestions must be less specific due to large variations in the type and amount of data available in companies, which then requires more discipline from the people making the overviews and the decisions within the company.

Multiple aspects of this approach have been tested in an industrial company producing district heating units. The company is characterised as an ETO company that struggles with managing inventory of supporting components. This results in an unnecessary large inventory of components, but also extended delivery times for customer products, due to long delivery times of components that are not in stock. The procedure is still in process in the company, but we have received a lot of positive feedback regarding the insights into the component portfolio that the process has provided. With regards to reducing the number of components, the process is expected to yield a reduction of about 43% for the components within the scope of the operation.

For further work, it could be beneficial to evaluate the results of the operation within the company when it is 100% complete. Additionally, there could be potential for improving the tools by further testing them in other companies with different kinds of products, portfolios and production strategies. We mentioned earlier that the early versions of the matrices were created manually in Microsoft Excel, which does take some time and effort. Furthermore, it could be interesting to take the concepts and develop software tools to be able to quickly setup the matrices from raw data or be able to take data directly from the ERP, CAD or PDM systems.

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