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Similarity-based Product Configuration

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Abstract

In times of increasing market fragmentation, the ability to offer customized products at competitive prices is a crucial success factor for companies in mechanical engineering. Therefore, considering the benefits and expenses of product variants during the configuration process is a significant challenge. However, there is currently no systematic approach that would result in a product configuration that is similar to both, the internal standard variants and the customer requirements.

This paper introduces a methodology facing this challenge. The methodology allows companies to determine the "optimal configuration" of a product based on similarities between a new product variant and existing variants.

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Keywords: Configuration management; Order processing; Similarity analysis

1. Introduction

Particularly companies in the field of mechanical engineering face the challenge of providing customized products at competitive prices, while the market is increasingly fragmented into small niches [1, 2, 3]. Due to higher customer orientation, companies are forced to meet customer requirements despite small numbers and regardless of the resulting higher internal product complexity and process variance. However, in many companies there is a lack of transparency concerning product variety and the costs and benefits related to it. Recognizing the benefits and expenses of product variants during the configuration process is a significant challenge for companies in mechanical engineering. In the early phase of quotations, most of the costs are determined, but the real costs are usually not known. Moreover, there is currently no systematic approach that would result in a product variant that is similar to both, the internal standard variants and the customer requirements. Analyzing the sales process of many companies in this field leads to the conclusion that they try to satisfy customer requirements at any price instead of offering standard or slightly modified variants to the customer that would cause much less internal effort. As a result, exotic product variants are often sold unprofitably, since dissimilar products are more expensive than standard variants due to higher adjustment costs for their development.

Many companies, especially from the automotive industry, try to cope with the mentioned problems by structuring their products by means of modular product platforms [4, 5, 6]. Today the implementation of a product configuration system enables them to configure products from a given set of standard components. However, companies from the field of mechanical engineering face the challenge that the customer intervention (Customer Decoupling Point) takes place earlier in the order fulfillment process than in other branches. As a result, a significant portion of new features or components is determined directly by the customer.

At this early stage in the order fulfillment process mainly three divisions are involved: sales, product management and development. The coordination between the divisions is based on the personal background and knowledge of the employees

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and on defined processes. Today there is no concept that enables sales to offer products to the customer, that cause minimum internal effort while it satisfies the customer requirements as well as possible. This paper addresses the configuration process in mechanical engineering and delivers a new approach for the visualization of the product variance in order to support transparency and the control of the quotation process.

The paper is organized as follows: After having presented the problem in Section 1, Section 2 gives a short overview of relevant aspects in the field of product configuration management and similarity analysis. Section 3 deals with related work and the definition of the research gap. In Section 4 the methodology for the similarity-based configuration management is presented. The last section provides the conclusions of this paper.

2. Basic information and definitions

For a better understanding of this paper some definitions need to be clarified in the following section before presenting the methodology.

2.1. Product configuration management

A widespread definition of configuration is given by Mittal and Frayman. They describe configuration "as a special kind of design activity with the key features of the designed artefact being assembled from a set of predefined components that can only be connected in certain ways" [7]. Bongulielmi defines the major difference between the construction and the configuration of a new product variant by the nature of the solution space. While the construction is characterized by an open solution space during the development process, the solution space of the configuration process is limited by the structures and components from which the products can be combined [8]. According to an established differentiation four different types of order processing can be distinguished. The differentiation between the types is along the value chain and the influence of the customer requirements (Customer Decoupling Point) is crucial for typing [9]. The four types Engineer-to-Order, Make-to-Order, Assemble-to-Order and Make-to-Stock are shown in Figure 1.

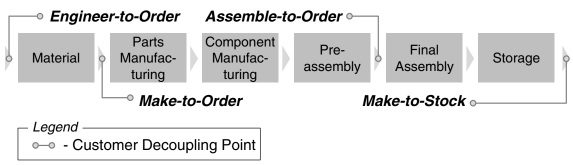


Fig. 1. Order fulfillment process and different customer decoupling points [8].

Products in mechanical engineering, which are focused in this paper, usually belong to the field of Make-to-Order. Due to the basic idea of the paper (development of product variants based on existing orders) the object region is also extended to the field of Engineer-to-Order. In mechanical engineering variant configuration constitutes about 80% of a typical order, while the remaining 20% need to be constructed according to the customer requirements.

Configuration management systems can be divided into three groups based on the configuration knowledge: rule-based, model-based and case-based [10]. Due to the core idea of this paper the analysis of existing approaches in Section 3 is limited to case- or similarity-based approaches. Case-based configurators are based on the investigation of existing configurations and their characteristics in order to draw conclusions for a new product variant. These conclusions can be derived based on similarity analysis, which is presented in the next sub-section.

2.2. Similarity analysis

Similarity analysis is the analysis of a set of individual objects concerning the similarity in certain criteria and the classification of the individual objects into segments, which should be as similar as possible (homogenous) in relation to the criteria and as dissimilar as possible (heterogeneous) among themselves. "Similar" in the context of product design represents a broad range of potential commonality levels in the whole spectrum between "common" (identical in fit, form, and function) and "unique" (different part numbers) [11].

For the calculation of dissimilarities or distances between two objects several distance metrics can be used. In this paper the most common distance metric, the Euclidian distance, is employed. The Euclidian distance corresponds to the geometric distance, which makes it easy to interpret.

Distances between objects can be visualized in different ways, for example with dendrograms or multidimensional scaling. Multidimensional scaling is a family of statistical techniques for analyzing the structure of (dis)similarity data. Multidimensional scaling represents the data as distances among points in a geometric space of low dimensionality. This visualization can help to see patterns in the data that are not obvious from the data matrices [12].

In this paper multidimensional scaling is used in order to visualize the overall product variance and the distances between several products on different levels.

3. Related work

In the following section approaches in the field of product configuration management are examined concerning different criteria: the consideration of the market, customer requirements and product level, the focus on mechanical engineering, the similarity analysis of existing product orders, and the optimization of scale effects along the order fulfillment process.

There are several existing approaches for the matching between market segments and customer requirements [13-17]. The connection between customer requirements and product components is also addressed by many theories [3, 8, 18-21]. However, up to now there is no approach that integrates features and specifications on all three levels, the market level, the customer requirements level and the product level.

Similarity analysis is used in some cases in order to estimate costs of new products based on existing products [22, 23]. Furthermore, some approaches use similarity analysis in order to identify similar groups of customers [24], customer requirements [25, 26] or products [27-31]. The mentioned approaches make use of different solutions. Some approaches use dendrograms or metrics as an aid [27], other approaches focus on cladistics [30].

By looking at the relevant literature it becomes obvious, that some approaches fulfill important aspects of similarity-based product configuration, but no approach meets all requirements. Literature review does not provide a holistic approach, that considers both, the costs related to a new variant, and the former variants that have been constructed and produced in the past. Furthermore, the optimization of the internal economies of scale throughout the entire order fulfillment process is often neglected. Moreover, the existing approaches often do not address mechanical engineering with its specialties that have been mentioned before. A major factor influencing internal complexity are the existing product variants in the company, which is not focused in the approaches described before.

4. Methodology of the similarity-based configuration management

The following section is structured as follows. First, the methodology concept and framework is presented. Second, the description of customers and products by describing feature vectors is explained. The third part deals with the identification and visualization of similarities. In the fourth part the similarity-based configuration process is described in detail. The section ends with a case study.

4.1. Methodology concept and framework

During the early stage of the order fulfillment process usually three divisions of a company are involved in the process: sales, product management and development. Therefore, the methodology presented in this paper addresses all three view points on the process and combines them in one integrated approach. From sales perspective, customers can be described and allocated to a specific customer segment. Product management usually focuses on the customer requirements that constitute a product segment. The view point of the development department is characterized by modules and components that build a product.

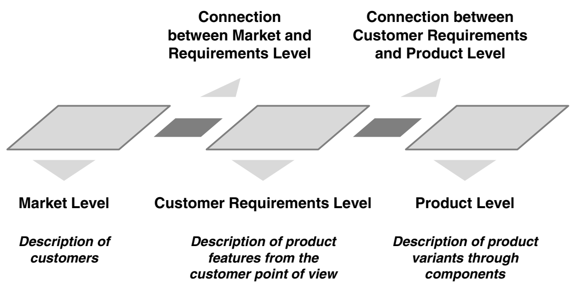


Fig. 2. Methodology framework.

The framework of this paper is presented in Figure 2. The level of product detail increases from sales to development, since the process starts with a general idea of the customer requirements and ends with a defined bill of materials.

4.2. Description of customers and products

Within the defined framework customers and products can be described on all three major levels using features and specifications. While the proceeding is equal in every use case, the used features can differ from company to company. On the market level customers are defined by general features such as price sensitivity, required quality, need for security or need for innovation. During the description the customer indicates his degree of fulfillment for the different features using the Likert scale. The specification is based on a rating scale, which consists of five steps. Every customer can be described by an n-dimensional vector, where n is the number of features (see Figure 3).

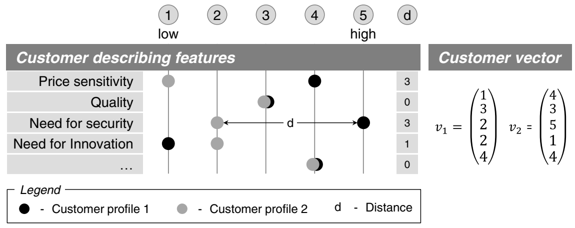


Fig. 3. Description of a customer by features.

On the customer requirement level products can be described by features and specifications addressing more detailed product features. This level is usually used in internet-based product configurators. Typical examples from the automotive industry for features on this level of detail are horse power, color, number of doors or the installation of a navigation system. Specifications for the feature color would be blue, red or yellow, for example. Every order can be described by an m-dimensional vector, where m is the number of all feature specifications that exactly define the product on a customer requirements level. The similarity between orders is calculated based on the comparison between the customer requirements vectors (1 indicates an equal feature specification between two orders, 0 indicates non-equal feature specifications respectively).

On the product level the main modules and components are used to describe a product. For the description of one product the part numbers of all components necessary to build this product variant are utilized to exactly define the product variant. Therefore, every order can be described on this level by an o-dimensional vector, where o is the number of components of the product. The similarity between products is calculated based on the comparison between the product vectors (1 indicates an equal component between two orders, 0 indicates non-equal components respectively).

4.3. Identification and visualization of similarities

This methodology is based on the gradual identification of similarities between orders on all three levels. For this purpose the distance between all pairs of orders is calculated using the Euclidian distance metric (see Figure 4, step I). In order to represent the different importance of the used features, a specific weight for every feature is used. The calculated distances between the feature pairs are displayed in a distance matrix on each level. A high distance between two orders represents a huge dissimilarity, while a small distance represents two similar orders (see Figure 4, step II).

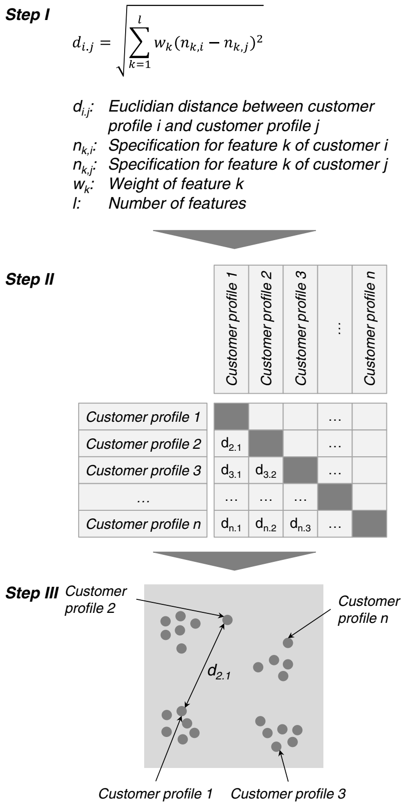


Fig. 4. Calculation of distances between customer profiles.

By using multidimensional scaling every distance matrix can be converted into a two-dimensional diagram that represents the similarities between products. Products that are allocated next to each other are very similar (see Figure 4, step III). In the following all three levels are explained in detail, using two generic orders, A and B (see Figure 5).

In Figure 5a all existing orders are shown in a diagram based on multidimensional scaling of the describing features of the customers. The importances of different features, defined by expert interviews in the company, are used as weights for the different features. According to the visualization, there are three different market segments. Customer A belongs to the market segment 1, customer B to the market segment 2.

In Figure 5b the customer requirement level is displayed. Based on the equally weighted customer requirements all orders are classified with multidimensional scaling. In this example there are apparently four groups of similar customer requirement vectors with each group consisting of several orders. Product configuration A, belonging to customer A, is in segment 1. Product configuration B, belonging to customer B, is located in segment 3. It is obvious that different customer segments do have different customer requirements.

The product level is shown in Figure 5c. On this level the adjustment costs of the components (costs that arise if a component is changed from one order to another) are used as weights for the components. This means that components with high adjustment cost do have a heavier weight compared to components that can be changed easily. The products A and B are located within the same of the two product segments of similar products.

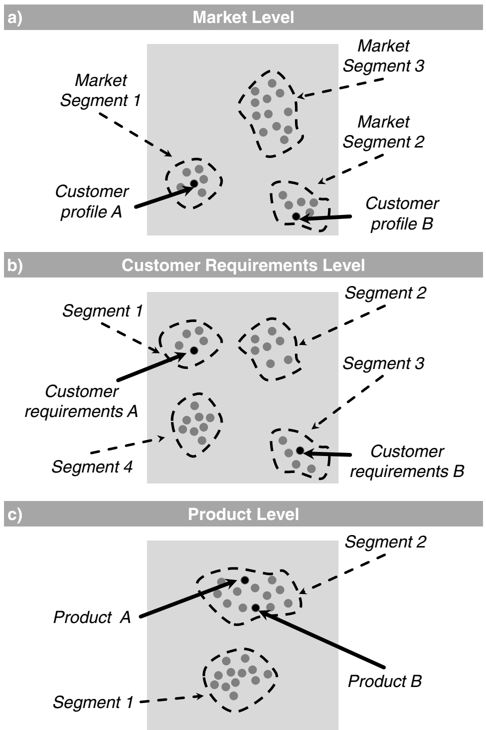


Fig. 5. Multidimensional scaling diagram for the three levels of customer and product description.

4.4. Similarity-based configuration process

The visualizations on all three levels as presented in section 4.3 build the base for the similarity-based configuration process. The aim of the process is to identify the “optimal configuration” of a new product variant in the trade-off between cost and benefit of a product variant. The process consists of three major steps: classification of the customer, derivation of the most probable customer requirements and assessment of the adjustment costs.

At first the customer is classified according to the features defined before. After having build up the customer vector v_n the distances to all former customers are calculated and the customer is embedded in the multidimensional scaling of the customers. In Figure 6 the new customer is indicated with N. It can be seen that the customer belongs to the market segment 3.

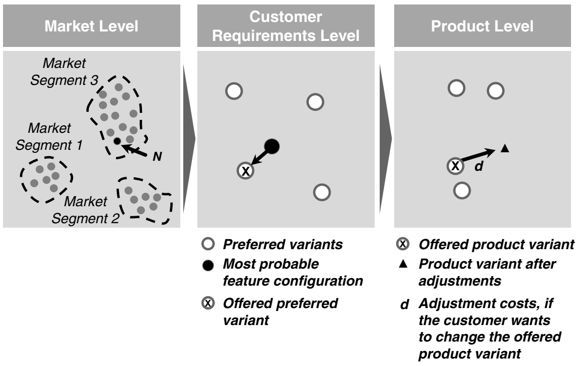
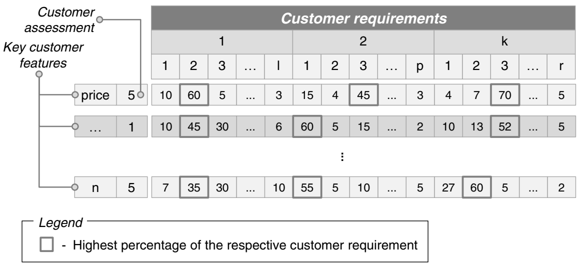


Fig. 6. Similarity-based configuration process.

Based upon this knowledge the most probable feature configuration of this customer needs to be derived on the customer requirements level. At first, key customer features are identified as features with a very high or very low importance for the new customer (indicated by 5 or 1 respectively). Afterwards, for every key customer feature the probability distribution of the customer requirements of former orders is calculated. If the new customer rates the importance of the key customer feature "price" as very high, the probability distribution from all orders with a very high importance for "price" is shown for all customer requirements (see Figure 7).



Key customer features	Customer assessment	Customer requirements 1					2					k				
		1	2	3	...	l	1	2	3	...	p	1	2	3	...	r
price	5	10	60	5	...	3	15	4	45	...	3	4	7	70	...	5
...	1	10	45	30	...	6	60	5	15	...	2	10	13	52	...	5
⋮																
n	5	7	35	30	...	10	55	5	10	...	5	27	60	5	...	2

Legend
☐ - Highest percentage of the respective customer requirement

Fig. 7. Probability distribution for a key customer feature.

This results in the most probable feature configuration on the customer requirements level (see Figure 6). Since this profile might not be an existing or possible combination of features, one needs to derive the most similar preferred variant, defined by product management. In order to identify this configuration the most probable configuration is embedded in the diagram by multidimensional scaling. Having embedded the new combination, the nearest preferred variant can be easily recognized (see Figure 6).

This preferred variant is offered to the customer. If the customer is not satisfied with the offered product variant adjustments need to be done. By adjusting the customer requirements, the product configuration "moves away" from the preferred variant that corresponds with one specific combination of modules and component on the product level. Concerning the exact dependencies between customer requirements and chosen components it is referred to the common literature [3, 8]. Depending on the grade of adjustment the adjustment costs can be derived from the visualization on the product level and can be presented to the customer (see Figure 6).

4.5. Case study

The methodology has been applied to a manufacturer of roller coasters with more than 300 orders in the last five years. On the market level the customers have been described by four features (price sensitivity, customer base, safety, and size). On the customer requirements level twenty features could be identified (e.g. number of seats, seat material, upholstery color, seat heater, safety bar). The product itself mainly consists of eight components (e.g. guide rail, bench seat, seat back). As a result of the similarity analysis, different segments on all three levels could be identified (see Figure 8). Based on this data set, new order processes could be carried out using the steps described before.

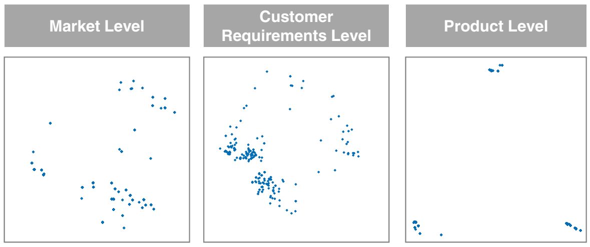


Fig. 8. Case study: Multidimensional scaling of different orders.

This practical example reveals several advantages of this methodology. First, the variance of different customers, customer requirements and product variants is combined in one method which can be used by the three divisions sales, product management and development. Second, this method leads to an increase of transparency concerning the costs of product variants at an early stage of the order fulfillment process. Third, the early classification of a customer and the offer of a preferred variant works as an anchor for the following configuration process. This leads to a reduction of internal complexity, since many customers remain with the recommended option due to the lower adjustment costs.

5. Conclusion

Due to increasing customer orientation, companies are forced to meet customer requirements regardless of a higher variance within the order and production processes. However, due to a lack of cross-sectoral coordination transparency concerning benefits and costs of new product variants is missing. In the early phase of quotations there is currently no systematic approach that would result in a product variant that is similar to both, the internal standard variants and the customer requirements.

In this paper, a methodology has been presented that allows companies to determine the optimal configuration of a product based on similarities between product variants. Similarities are identified with the help of features and specifications covering all three major levels: the market level, the customer requirements level and the product level. Similarities between product variants are shown on each level by multidimensional scaling, that allows a simple visual evaluation. This methodology provides a practical guide to increase transparency in order processing of new variants across departments and is, therefore, a new approach for the control of the quotation process.

The results presented are aimed both at researchers and practitioners in the industry. With respect to the research community this submission is an important driver for the analytical identification of similar products during the configuration process. Future work will focus on the managing of the order process of products with many variants and on the consideration of direct costs related to product variants. Moreover, the benefit of different customer requirements still needs to be analyzed quantitatively. With respect to the practitioners, the main implications can be seen within mechanical engineering companies with many product variants. The concept will be validated in further companies in order to support the applicability in different initial situations.

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