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# Variety-driven design to reduce complexity costs of a tire curing press family

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**Abstract**

As a result of the prevailing megatrends, many companies are diversifying their product program further and further. Additional product variants are being developed in order to implement the increasing variety of offers. However, these variants increase the complexity within the company. The development of variety-oriented product structures is one way to counteract this increasing complexity. In this contribution, we will show how variety-oriented product structures can be developed with the help of the *Design for Variety Method* (DfV), using the example of a tire curing press. Furthermore, a new visualization of variety is introduced and it is shown how DfV and complexity cost analysis can be used to evaluate variety-oriented product concepts. Finally, an outlook on further possible research topics is given.



*Keywords:* Design for Variety; Complexity; Case Study; Variety

## 1. Introduction

Rising cost pressure and an increasing diversification of customers require companies to increase their offerings [1]. However, by offering new product variants, not only the external variety of products offered increases, but also the internal product and process variety [2,3,4]. In the mid-term, this leads to an increasing variety-induced complexity within the company, resulting in increasing costs in all departments of the company [1,3,5]. To counteract the rising costs, variety-oriented product structures can be developed [1,6,7].

The objective of methods for variety-oriented product design is to provide the required variety of offerings with the minimum number of intra-company components [1,7,8,9]. One example of such a method is the *Design for Variety Method* (DfV) according to *Kipp* [1,7]. In this method, components are structurally adapted across product variants and the variety is only permitted for those components that directly contribute to fulfilling customer-relevant product properties [1,7,10].

By decreasing the variety, positive effects within the company, such as lower error rates and costs, can be enabled [3,8]. However, many of these effects occur with a time delay [11], or have an effect on complexity costs that are difficult to assess [3,12].

For the assessment of complexity costs the method according to *Ripperda et al.* [3] can be applied. It allows an evaluation of alternative product structure concepts with regard to their effects on complexity costs. The analysis of process times provides the necessary data for this evaluation [3,12].

Therefore, the objective of this contribution is to show how *DfV* can be linked with a complexity cost analysis for the evaluation of concepts based on process times in different departments of a company.

In section 2 the fundamentals of the topics *variety-oriented product design* and *variety-induced complexity* are described briefly. Following this, section 3 presents the modified approach for DfV, while section 4 shows the application using the example of a product family of tire curing presses with a subsequent concept evaluation based on process times. The results will then be discussed in section 5. Finally, an outlook on further work is given in section 6.


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## 2. Research background

A high degree of component variety causes various effects along the product life cycle [13,14]. For example, an increase in variety leads in the life phase *development* to additional part numbers [15], additional component and product tests [3] and the effort required for documentation increases [3]. In *procurement*, the number of suppliers is increasing [2] and warehousing is becoming more complex [16]. In *production*, the variety of components is accompanied by an increase in the variance of production processes [8,17]. These effects result in a widespread increase of complexity within the company. The share of complexity that can be traced back to the high variety is summarized under the term variety-induced complexity [2,3,18]. Which effects will occur in specific companies varies with the respective boundary conditions.

Several methods for variety-oriented product design exist in the literature [1,9]. To reduce the variety of components, [7] have defined four ideals that characterize a variety-oriented product structure. These include the *differentiation between variant and standard components*, *reduction of components to the carrier of a variant property*, *1-to-1 mapping of customer-relevant properties and variant components* and the *decoupling of variant components*.

To achieve the above-mentioned ideals of a variety-oriented product structure, [7] have developed the method of variety-oriented product design. The DfV according to *Kipp* is a method unit of the *Integrated PKT-Approach for the Development of Modular Product Families* and has been applied to various products and continuously improved since it was introduced [1,6,7,10,19,20].

To support the evaluation of several developed concepts, [3] developed a procedure that enables a relational comparison of variety-induced complexity costs between different concept alternatives. For this purpose, the changes of the process costs resulting from the concepts are analyzed [12]. Since a comprehensive determination of the complexity costs is not cost-effective, only the especially cost-driving processes are examined and the corresponding process times are recorded. To gather this information, the existing process times are evaluated and interviews with employees from different departments are conducted. This allows a semi-quantitative estimation of the saving potential of the variety-oriented product structures at the end of the procedure. The calculated process times can then be charged with the hourly rates of the respective employees to determine the complexity costs [3].

## 3. Modified Design for Variety according to Kipp

The method is divided into five steps, which are performed one after the other. In the first step, the goals are defined, for example the reduction of variety, especially in development. This is followed by analyzing the external variety in the second step. This describes the variety from the customer's perspective and is defined by customer-relevant characteristics and their characteristics. The external variety can be displayed in the *Tree of external Variety* (TeV) (see Fig. 1).

The internal variety is analyzed in the third step of the method. In this step the product functions and components are examined. In both cases it is important to analyze not only individual product variants, but rather an entire product family. Only by doing so the variety and its effects can be captured and analyzed completely. For the representation of the variety, specially developed visualization tools are available [21]: The functions can be displayed in the *Product Family Function Structure* (PFS) and the components in the *Module Interface Graph* (MIG) (see Fig. 1). The MIG allows to capture the essential information about the product family by a simplified representation of the components, the flows between components and a color-coding scheme for the variety.

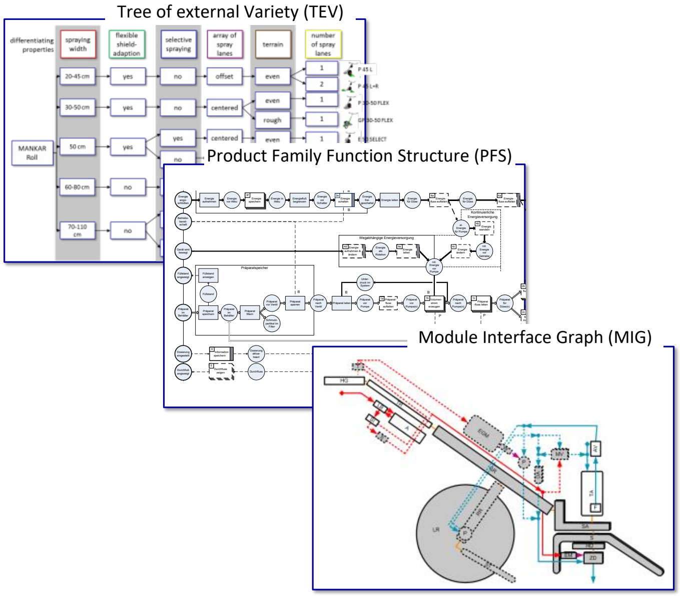


Fig. 1. Tools for the analysis of product variety - schematic illustration [1]

The variety-oriented product design itself is performed in the fourth step of the method. For this, the information from the analysis of external and internal variety is linked together in the *Variety Allocation Model* (VAM). As shown in Fig. 2, the VAM is made up of four levels: *differentiating properties* as first level, *variant functions* and *variant working principles* as second and third level and *variant components* as fourth level. The special feature of the VAM is that only the variant components are shown, as these increase the variety. Standard components are not included, because they do not cause any variety. The VAM shows which customer-relevant property is realized by which components and where the need for action exists. Critically are components, which are variant, but do not have a connection to customer-relevant characteristics, or are affected by several customer-relevant properties. For the improvement of the variety-orientation and development of concepts different design principles are suggested in the literature [1,19]. These support the designer in developing solutions at the different levels of the VAM.

So far, the degree of variety of the components in the VAM is not sufficiently represented. The color *gray* indicates that the components are variant, but it is no indication of the amount of variety. According to [7] the degree of variety can be indicated by an additional label in the form of *low*, *medium* or *high*. However, this is less intuitive. In the following, a visualization is proposed in Fig. 3, which allows the degree of variety to be easily displayed, understood and quantified.

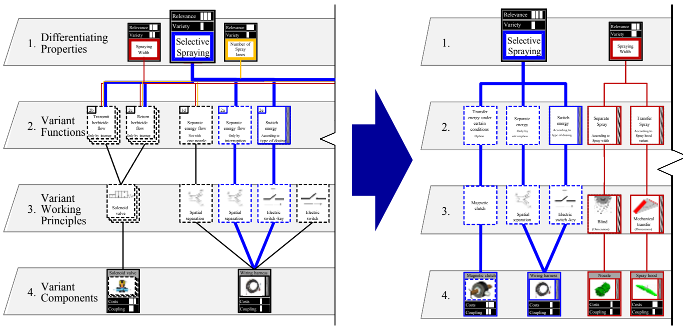


Fig. 2. VAM before (left) and after (right) the derivation of variety-optimized concepts - schematic illustration [1]

The given example shows that the variety of component C is much larger than the variety of component A. In addition, this type of visualization allows more detailed comparisons between individual components, since the variety is no longer described in three discrete categories, but as a continuous value.

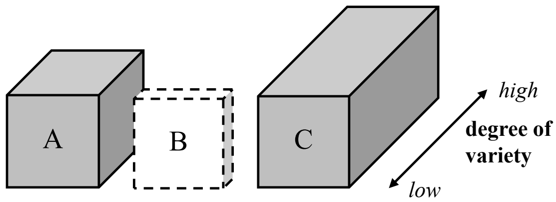


Fig. 3. New visualization of variety degree in the Variety Allocation Model (VAM)

In the fifth step of the method, the developed variety-oriented concepts are being compared with each other in order to select a concept for implementation. To support the concept selection, this contribution proposes a complexity cost analysis.

## 4. Variety-driven design of a tire curing press family

The modified DfV was applied by using the example of a product family of tire curing presses. The tire curing press shown in Fig. 4 is used to vulcanize tires.

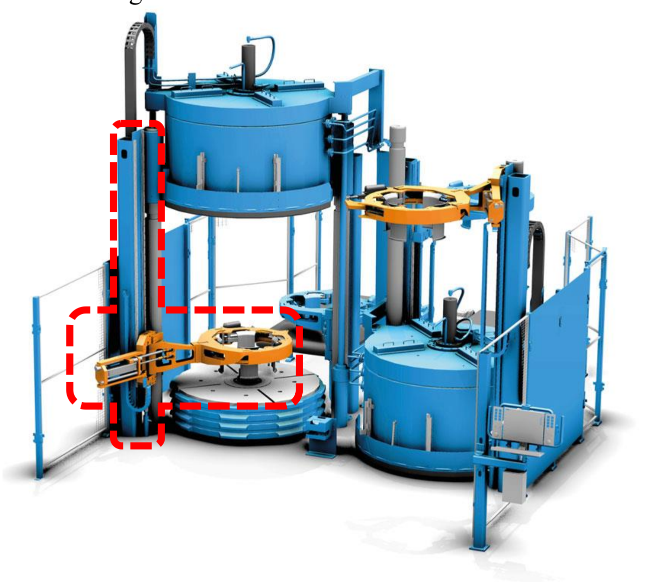

Fig. 4. Tire curing press [22] with highlighted loader

The green tire is transported into the machine by the loader (marked red in Fig. 4) and placed in the mold. Then the drum is lowered and the tire is heated under pressure for several minutes to vulcanize it. The pressure forces the tire into the mold, which results in its profile. The machine then opens again and the vulcanized tire is moved out of the machine by the unloader and transported away. The structure in Fig. 4 shows that two tires can be vulcanized simultaneously in one machine.

In this case study, the main assembly of the loader is examined as an example (marked red in Fig. 4). This is subject to a high degree of variety, since it represents the interface between the supply of the green tires by the factory infrastructure of the tire manufacturer and the machine itself. For instance, the loader must be adapted in height and swivel angle to the respective geometric boundary conditions of the existing factory buildings.

### *4.1. Modified Design for Variety*

Due to limited space, not all steps of the method can be displayed in detail. Instead, the main results are presented.

The goal of DfV in this case study is to tailor the product structure in such a way that the company is able to transform from an engineer-to-order to a configure-to-order strategy.

The main assembly of the loader consists of 43 components in total, 38 of them are variant and 3 are standard components. The analysis of different product variants of the main assembly from the tire curing press product family has shown that especially the *adjustment mechanism for the paddles* and the *loader pillar* vary. In order to visualize the variety, the Module Interface Graphs of the components have been generated (see Fig. 5).

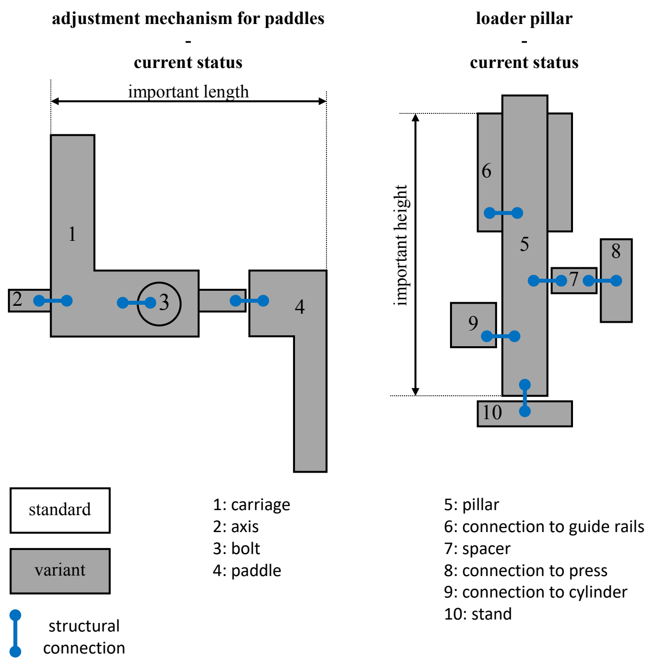


Fig. 5. Module Interface Graphs of the components – current status

The adjustment mechanism consists of four separate parts and allows the loader to be adapted to different bead diameters. There are several possible solutions to adjust the distance shown in Figure 3, each varying in different parts.

The pillar must equalize the differences in height between the infrastructure in the plant and the tire curing press. This variation in height results in different variants, which are each connected differently to the rest of the tire curing press. The individual parts vary, for example, in their hole pattern or the distances to the rest of the machine.

Fig. 6 shows the extract of the VAM for the adjustment mechanism. On the left side the current status is displayed. It can be seen that the three customer relevant properties are linked to different components. Among the four components of the assembly, especially the carriage and the paddle are highly variant. On the right side in Fig. 6 the respective developed variety-oriented concept is shown. It was developed by designers based on the information in the initial VAM, MIG and the other tools introduced above. Several ideas were developed and eventually the concept that corresponds most to the four ideals of a variety-oriented product structure was chosen. On the component level, two components have been standardized (2 and 3), which are therefore no longer shown in the VAM. Furthermore, the amount of variety of the two remaining components could be reduced. Altogether, the ideal of a 1-to-1 mapping could be achieved. The customer-relevant property *fine adjustment of paddles* is only implemented via the carriage. Furthermore, the paddle is only affected by the customer-relevant property *bead diameter*. Through a partial standardization of the paddles, it was possible to avoid that the number of paddles has an effect on the geometry of the paddles.

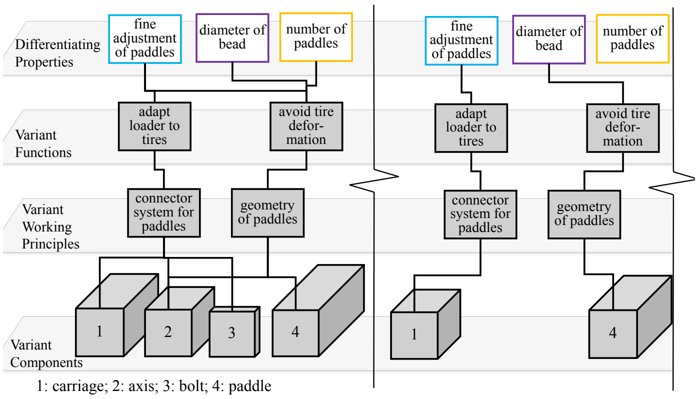


Fig. 6. Extract of the Variety Allocation Model (VAM) for the adjustment of paddles; current status (left) and concept (right)

The VAM extract for the loader pillar is presented in Fig. 7. As in the previous figure, the current status is described on the left side. There is only one customer-relevant product property for the pillar, affecting two of the six components. The other components are not linked to a customer relevant property, but still differ in their geometry. This variety is unnecessary and should be eliminated in the new concept. The resulting variety-oriented concept for these components is shown on the right side in Fig. 7. Again, a 1-to-1 mapping was achieved so that the customer-relevant property only affects one component and has no junctions. The remaining components could be standardized by clearly defining the interfaces to the rest of the tire curing press. Thus, the assembly still varies with the height of the pillar, but all other components are kept the same.

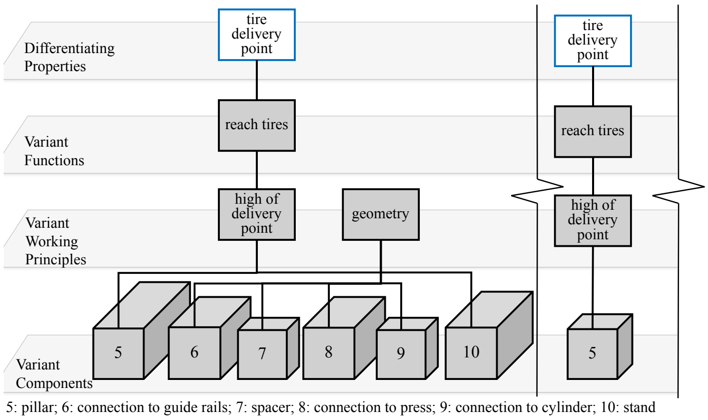


Fig.7. Extract of the Variety Allocation Model (VAM) for the pillar; current status (left) and concept (right)

Fig. 8 shows the respective MIGs for the developed variety-oriented concepts. The standard components, which are eliminated in the VAMs, are shown in color *white* in the MIGs. For the adjustment mechanism, two of the four components could be standardized. The carriage (1) and the paddle (4) are connected via a standardized axis (2). The variety can be limited by defined interfaces and specifications as to which dimensions may be varied by the designers. For the pillar, a concept was developed in which all connecting parts are standardized and only the pillar itself is variable in length. The connection points of the pillar (5) to the other components (6-10) are clearly defined and specified relative to the lower end of the pillar. This reduces the number of geometric dependencies and is beneficial in production.

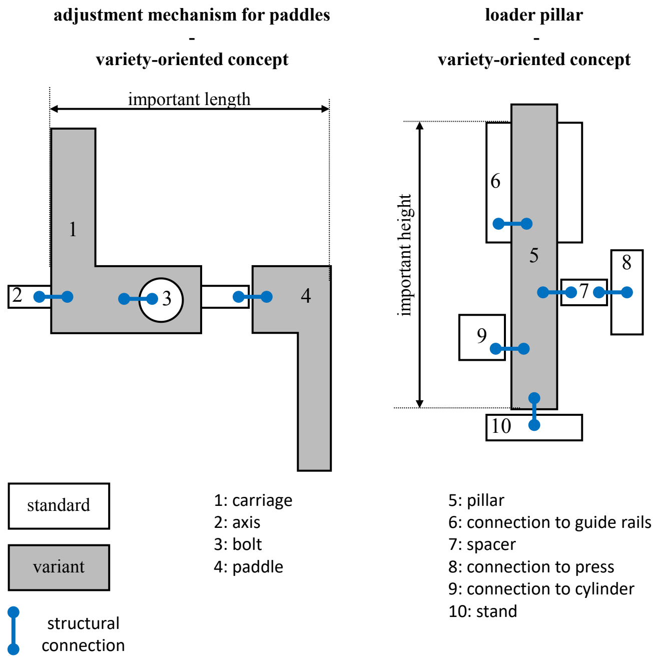


Fig. 8. Module Interface Graphs of the variety-oriented concepts

### 4.2. Evaluation of process times in different departments

The potential reductions in process times made possible by the variety-oriented concepts will be analyzed in the following.

Therefore, the individual processes, which are needed for the development of a new product variant, were surveyed by interviews. Firstly, the main processes in the respective departments were recorded and then detailed further. The interviewees were asked to describe the steps they would be required to go through in order to develop and design a new product variant. This was based on a fictitious customer order. Since the hourly rates are confidential, the following analysis is based on the recorded process times instead of process costs.

Fig. 9 and Fig. 10 visualize the distribution of the analyzed process times for each of the two considered assemblies as the current status and for the variety-oriented concepts.

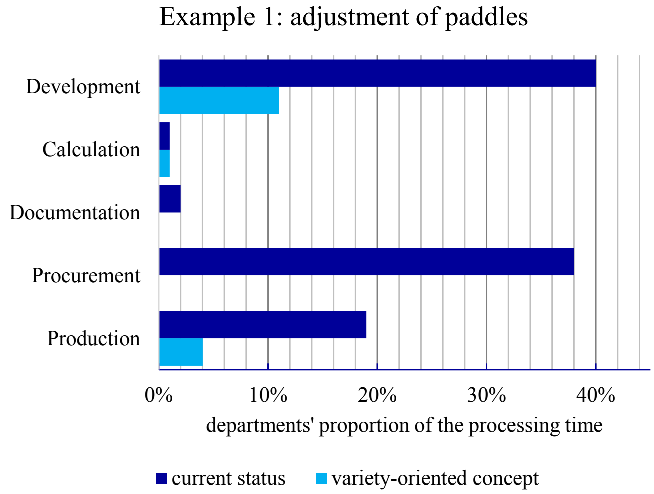


Fig. 9. Distribution of the process times for the adjustment of paddles

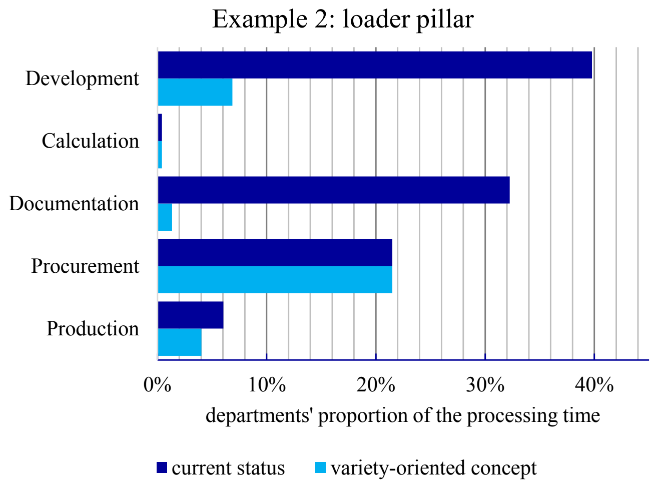


Fig. 10. Distribution of the process times for the loader pillar

In both cases, only 40% of the required working hours for the current state occur in development. The tasks in development include researching existing designs, clarifying specifications, the design itself and the final control and documentation in the ERP system. The other 60% of the processing time is spent in downstream processes. The distribution of the 60% varies between the examined components. While many hours are spent on the purchase of semi-finished products and production planning in the first assembly group (see Fig. 9), the second assembly group is primarily associated with high efforts in documentation and procurement (see Fig. 10). This can be explained by the fact that the pillar is a component that is visible to customers. If it is changed, different images of the machine in the CAD model have to be adapted for the technical documentation, which leads to a great deal of effort here. The adjustment mechanism, on the other hand, is not visible from the outside and therefore has no effect on the technical documentation and the required views.

The production times in the two cases refer to the production planning, the production hours were not considered, since no significant differences are to be expected according to the interviews and the focus of the analysis was on the pre-production processes.

Through the variety-oriented concepts, significant savings in process times can be achieved for both assemblies. In both cases, development times can be reduced by 75% (Fig. 9) and 85% (Fig. 10) respectively. Due to the variety-oriented components, the search for already existing components, the construction itself, the control as well as the documentation in the ERP system are omitted or significantly reduced. However, the clarification of the specifications remains unchanged.

In the example in Fig. 9, there is no additional effort in purchasing, since the variety-oriented concept enables all component variants to be manufactured from the same semi-finished product. In production, work preparation and the creation of machining programs can be significantly reduced.

In the second example in Fig. 10, the times in procurement remain constant. However, the variety-oriented design eliminates the effort for technical documentation, since it is not necessary to create a separate visualization for each product variant. As with the first assembly, the time required in production can be reduced, but not as much as in the first example.

## 5. Discussion

By using the adapted DfV, variety-oriented concepts for the tire curing press were developed. The newly introduced visualization of the variety makes it possible to identify critical points in the VAM faster and be quantified. In addition, the level of variety before and after the redesign can be better compared and is also comprehensible for external decision makers who are not experts in the applied method.

The benefits of the reduced variety, which are made possible by the variety-oriented product design, could be quantified with the approach for complexity cost evaluation. Although the identified savings are subject to uncertainties in the interviews, a significant trend to reduced process times and thus reduced complexity costs can be identified. This shows that by the variety-oriented product design significant savings in the process times for the tire curing press family can be expected.

In summary, the application of the DfV and complexity cost evaluation using the example of the tire curing press family has shown how the analysis of the process times in different departments can be used by designers for concept evaluation after variety-oriented product design.

## 6. Conclusion and outlook

In this contribution, section 2 briefly describes the background to the topics of effect of product variety and variety-oriented product design. Based on this, section 3 introduced the modified *Design for Variety Method* (DfV) and presented a new visualization of the variety. The presented method was then applied in a case study using the example of a tire curing press, which is presented in section 4. By an additional analysis of the process times, it could be determined in the specific case of the application example that the process times can be reduced by 66% or 85% for the examined assemblies. The results regarding variety-oriented product design, savings in process times and the application of the method itself were then discussed in section 5. The application of the method demonstrated how it supports designers in developing variety-oriented product structures and illustrates the benefits of variety-oriented product structures through the analysis of process times.

Since a high variety is not only a challenge for products, but also for service providers and product-service systems [18,23], further research should investigate whether the presented method and findings can be applied to product-service systems as well.

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