CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2020

1st Conference on Production Systems and Logistics

Methodology And Use Of Variant Fields In Factory Planning

Matthias Dannapfel[1], Sebastian Patrick Vierschilling[1], Florian Becker[1]

[1]*WZL of RWTH Aachen Univercity, Aachen Germany*

Abstract

Anticipation capability, responsiveness as well as the ability to deal with changes have become key factors of manufacturing companies. These developments directly affect factory planning. Factories need to provide a constant and responsive adaptability. This paper contributes to the adaption of the planning process with regard to the key factors. Modularization of the production system is one aspect of addressing the described challenges, the planning process itself has to be adapted to modular factory structures.

The question to answer is which variation of production system modules is most appropriate in specific conditions. Today's planners lack a tool that enables them to make the right decision about the configuration of the factory. This paper proposes a configuration logic for the modularized production system. The logic intends to generate an optimally configured production system. Furthermore the developed Variant Fields offer the possibility to apply the configuration logic within the planning process in practice.

In a Variant Field features of a module of the production system (e.g. room utilisation factor) are related with one another, which span a two-dimensional field. Each axis is divided by different characteristic values of variants of a module. According to the characteristic values along the axles different areas within the Variant Field are determined. These areas are thus linked to the variants of a module. For the configuration of the production system, its requirements in the two features of the Variant Field then are marked in it. The variant is selected according to the area in which the marking falls. In the paper the methodology and the use of Variant Fields will be explained. In order to do so, the configuration of logistic systems is used as an example for illustration.

Keywords

Modular factory; factory configurator; requirement-orientated design; productions systems; logistics systems, logistics planning

1. Introduction

Planning processes are characterized by a high number of challenges and requirements. Efficient and productive processes are a precondition for successful planning. This paper proposes a method to better fulfil this precondition for a specific planning domain through the use of the modular factory concept in planning. This domain is factory planning that is facing the challenges mentioned before. However, the proposed method is designed in a way that it can be applied to various planning activities.

Factory planning is strongly influenced by an increasing dynamic and complex environment. Today, manufacturing companies are confronted with challenges like shorter product lifecycles, higher variance, innovation pressure and dynamic change processes [1], [2]. Thus, anticipation capabilities, responsiveness as well as the ability to deal with unexpected changes have become key factors for success [3]. Factories need to provide a constant and responsive adaptability [4]. Therefore, the time needed to plan the factory is a strategic success factor for manufacturing companies [6]. The time needed to plan the factory is influenced by the complexity of the planning project. In order to reduce the complexity and create mutable structures within the factory a modular factory structure is already developed by researchers [7], [3]. This leads to a significant reduction in complexity, which in turn reduces the planning and implementation costs of planning projects, shortens planning and implementation cycles and improves the general adaptability of the factory. The benefits of such a modularisation of the factory design can, however, be substantially increased. Today, the planning process itself does not comply with the challenges and requirements factory planning is facing. Thus, time goals cannot be achieved. [8] Therefore, the planning process itself needs to be adapted in order to keep up with the standardization and modularization of the factory. This paper contributes to the necessary adaption of the planning process.

Currently, there is a lack of methodology in order to decide how to configure a modular factory. The question to answer here is which variant of production system modules is most appropriate in specific conditions. This paper proposes a configuration logic as a part of a modularized planning process. As an exemplification the configuration of logistic systems is used as an example. The developed methodology for the planning process enables optimal results by the existence of defined decision guidelines. The configuration logic intends to produce an optimally configured system or subsystem for an individual application based on given input information. The developed application of the methodology is called Variant Field, which is a two dimensional graph, and represents its final result. They will be described in Chapter 2.2.

The Variant Fields and the corresponding methodology propose a solution to the above described challenges. By usage of Variant Fields, the planning efficiency and the planning effectiveness should be increased. While a specific area of factory planning is chosen for exemplification, the above described challenges are valid for all kinds of industries where planning processes take place. Variant Fields can be used whenever there is the need to choose between different variants based on different factors. Thus, the proposed method not only contributes to the efficiency and effectiveness of the factory planning process but also to efficiency and effectiveness of planning processes in general.

2. Methodology and use of Variant Fields

In order to introduce the methodology and use of Variant Fields, an overview of the configuration logic is given first, with logistic systems as an example. The Variant Field and its structure is introduced afterwards. The second part of the chapter deals with the development and application of the Variant Field.

2.1 Configuration logic

The Variant Field is a part and the result of the followed explained configuration logic. The configuration logic enables the configuration of factory elements in terms of their variants with regard to the requirements and operating conditions of the factory. To develop the configuration logic, all features of a factory element are identified and evaluated, in order to find out which features have to be changed by configuration to meet the requirements. The variants of a factory element are then identified. Since a variant of a factory element may not be compatible with or require combination with a particular variant of another factory element, the creation of combination rules is required. These show mandatory and optional relationships that must be taken into account during the configuration.

A factory element is a subsystem of a factory itself. A factory element is characterized by different features. Additionally, a factory element can be realized through different variants and extension modules. The term variant is used for each design or alternative solution of a factory element, which differs in at least one qualitative or quantitative parameter. An extension module is a self-contained unit that provides the factory element with additional or better features or functions. It can also influence the combinability of a factory element with other elements (see Figure 1).

The main difference between an extension module and a variant is that variants have to replace each other, whereas also several extension modules can be used in parallel. Moreover, two types of extension modules exist. General extension modules, on the one hand, are independent of the variant and can therefore generally be used for a factory element. These modules are regarded as cross-variant. Variant-specific extension modules, on the other hand, can only be used for one or more specific variants. Figure 1 shows a schematic variant structure of a factory element. Variants and extension modules are characterized by specific characteristic values of the features of factory elements.

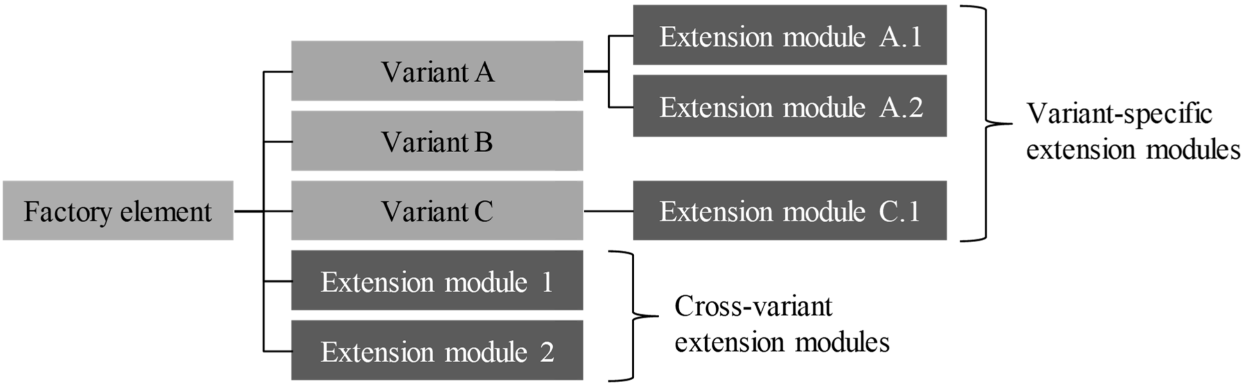

Figure 1: Schematic structure of a factory element

The above described terms are illustrated in the following example. Typical features that characterize a storage equipment are, among others, their height, their room utilisation factor und their assortment size. The values for the room utilisation factor, for example, are reaching from low to high. Possible variants of storage equipment are a floor storage, a pallet rack and a high level rack. Examples for extension modules are an automated booking system for entry and exit of products or an anti-theft protection for very valuable parts. It is also possible to quantify the characteristics. To keep the example in this paper simple, qualitative values are used to explain the methodology. So a floor storage has a low room utilisation factor, it can be characterised as middle for a pallet rack and as high for a high level rack.

The basis of the configuration logic are different factory elements. Important factory elements can be identified using a literature analysis. The identified elements are then clustered into subsystems in order to increase the transparency. As an example, Figure 2 shows an overview as part of the results for logistic systems.

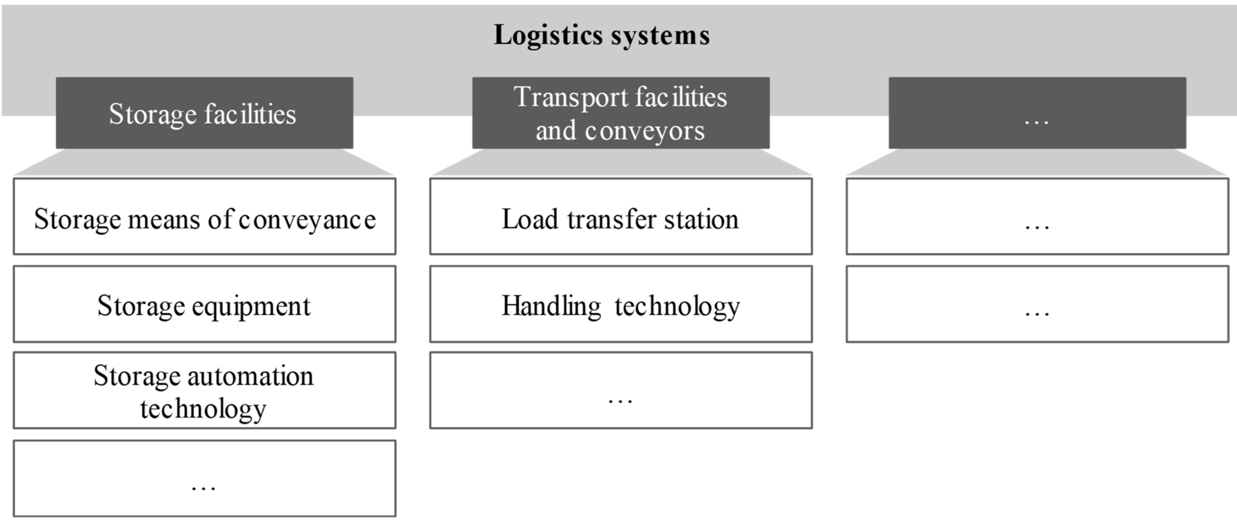

Figure 2: Overview of factory elements of logistic systems [4], [10], [11], [12], [13]

The elements can then be categorised in order to specify how the particular element is treated within the configuration logic. The factory elements are assigned to one out of three classes. These classes are individualization, modularization or standardization. A factory element in the class individualization is planned and designed individually. It is therefore not suitable for a modular system or a configurator and will not be considered further. Factory elements in the class modularization or standardization are relevant for the configuration logic. Factory elements in the class modularization can be partially standardized. Due to different demands on the factory element, different variants of the element should be used in the factory. So they are configured according to specific requirements for each individual area of the factory in which the element is to be used.
Factory elements which are categorized as standardization can be fully standardized across the entire factory. This elements exist in the entire factory in only one variant. They are rigidly dimensioned for the maximum design requirement with a view to its long-term development.

In order to assign the factory elements to one of the classes, the factory elements are generally assessed in terms of the interactions with the product, the influence on the Return on Planning (ROP) [9] and the module suitability. The assessments are then transferred to a portfolio from which the classification can be derived. To evaluate the interactions with the product and the influence on the ROP different key figures are calculated. A standardized factory element should have a high influence on the ROP with the least possible interaction with the product. The suitability examines whether a factory element is principally suitable for standardization. This is done by using module drivers for the evaluation.

The underlying assumption when using the configuration logic is that there is an optimal configuration for each factory element for a certain operating point in the factory. This optimal configuration will be identified by using the configuration logic and the Variant Field. In terms of the above described example, the configuration logic and the Variant Field will answer the question which storage equipment shall be used in the factory.

The configuration logic is generated by using a four-step approach. First, relevant features of the factory element are identified. However, the most important aspect is to filter the most relevant features from the total set of identified features. Afterwards, these features are collected in a feature record for each factory element. The selected features should express the performance of the factory element, meaning that the requirements to the factory element can be expressed directly by its features. Features that only indirectly describe performance are not included in the feature record. This also includes features from which other features can be derived. In addition, the selected features must be communal so they can be applied to all variants and extension modules of the respective factory element. For example, the feature room utilisation factor is relevant for all of the above described variants (floor storage, pallet rack and high rack).

In a second step, the variants and extension modules of that element are defined. At first, all identifiable Variants are generated by analysing the state of the art. Those variants that are suitable for use in the existing factory are selected from the variant pool, based on the specifications of the products manufactured in the factory and the structural conditions of the factory.

The third step deals with combination rules of variants and extension modules. As a variant of a factory element may not be compatible with or require combination with a particular variant of another factory element, the creation of combination rules of variants and extension modules are required. Combination rules define mandatory and non-relationships or bids and prohibitions when combining certain variants and extension modules of different factory elements. For example, only a narrow aisle high-bay warehouse can be served with a suitable forklift, which does not fit to any other rack variant. Once these steps have been terminated, the Variant Field can be set up as the fourth step of the methodology, which is described in more detail below.

2.2 The Variant Field

The Variant Field is the key element of the configuration logic that, once set up, enables the fast and optimal planning of a factory element, self-sufficient of location and requirements. It visualizes the configuration logic and ensures its applicability. The goal of the Variant Field is to decide which variant of an element shall be chosen based on specific boundary conditions. Before describing how the Variant Field is developed its structure will be introduced first.

In the Variant Field two features are related with one another in a two-dimensional field. Each axis represents one feature and is divided by different characteristic values of the feature, defined by the variants of the factory element. These characteristic values can either be qualitative or quantitative (which will be further detailed in chapter 2.3). Moreover, the relevant extension modules with the areas along the range in which they shall be used are also marked along the axes. Depending on whether it is a cross-variant or a variant-specific extension module the nomenclature is different (see Figure 1). While a cross-variant extension module is called EM 1, a variant-specific extension module contains the variant in its name, for example EM A.1, for an extension module used for variant A (see Figure 3).

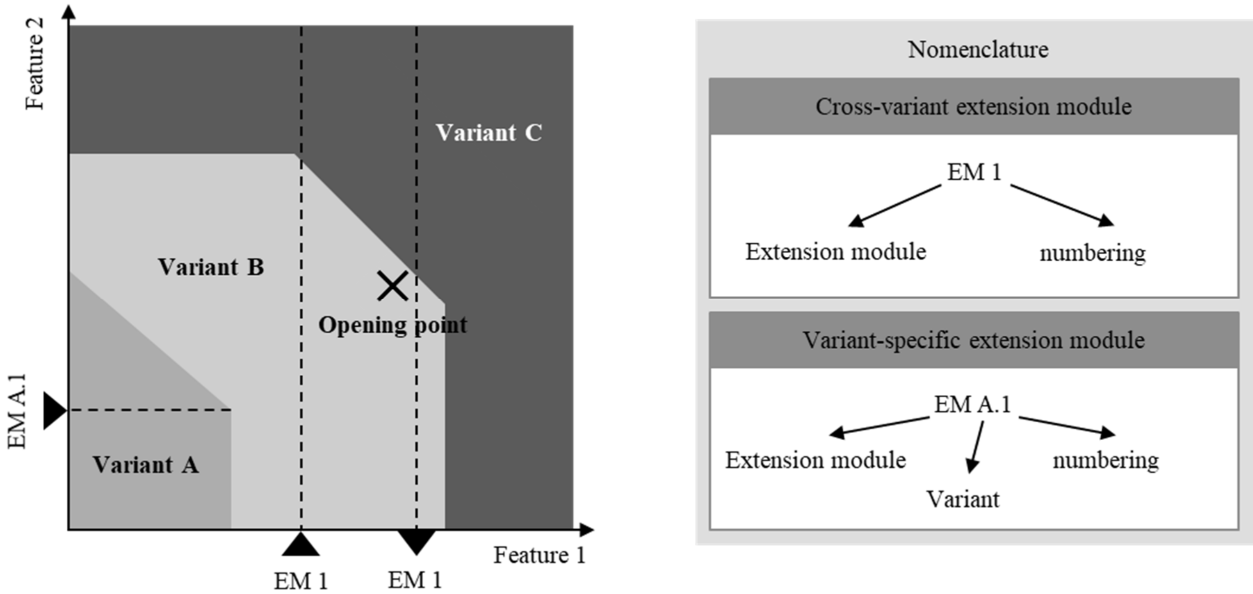

Figure 3: Structure of the Variant Field

The area in which an extension module is to be used is marked by two arrows. The arrow pointing to the inside of the field indicates the point from which the module is used, the arrow pointing out of the field indicates the point to which the module is used. Whereas there does not have to be an arrow pointing out. According to the characteristic values along the axis different areas within the Variant Field are determined. These areas are linked to different variants of an element. In order to determine which variant should be chosen, the requirements for the element needs to be defined related to the features. Once this is done, the defined requirements for both features are marked along the axis. The point of intersection marks the operating point. The operating point is located in the area of a certain variant and is used to identify the best variant and the necessary extension modules for the given requirements.

2.3 Development of the Variant Field

The central challenge in developing the Variant Field is the consistent integration of elements, their variants and characteristics. Therefore, two mutual complementary or competing features have to be examined. Two features can be indifferent, complementary or competing. Indifferent features do not influence each other. For complementary features, the increase of one feature leads to the increase of the other feature, while for competing features it is the other way around; the increase of one feature leads to the decrease of the other feature. In case of a complementary relationship, the relation can be either symmetrically complementary or asymmetrically complementary. Two features are symmetrically complementary if the increase of feature A leads to an increase of feature B and the increase of feature B leads to an increase of feature A as well. Symmetrical complementary features can be eliminated, when this relationship is valid over the entire value range, thereby reducing the number of features.

Once this is done, characteristic values of a feature are determined which is a decisive step for the configuration logic. To configure the factory elements, the characteristic values for each variant and extension module must be known in order to be able to adapt the factory element to the given requirements. In this step, variants and extension modules are assigned to a characteristic value of each feature. In this way, the different characteristic values indicate the limits to which or up to which a variant or extension module can be scaled.

As already mentioned above, the range of the characteristic values can either be quantitative or qualitative.
A qualitative range can be developed by using eligibility criteria or expert interviews. As an example, a qualitative range can contain the values low, middle and high, as used in the example before. Moreover, a qualitative range can be used when indicating the presence or absence of a certain characteristic. The range then contains the values yes and no. In general, qualitative scales are used as guidelines for the configuration. A quantitative range allow an objective configuration of the factory element. Therefore, quantitative scales are preferred. The scale can be linear as well as logarithmical. An example for a quantitative range is the storage volume per storage area, which is measured in cubic meters per square meter.
Figure 4 shows examples for both, a qualitative and quantitative range of characteristic values.
Moreover, extension modules are marked with regards to their range for each feature. This is realised by arrows. For cross-variant extension modules (see EM 1 in Figure 4) both, the starting and ending point of the area in which this module is to be used, needs to be determined. Starting points are marked with an arrow pointing upwards, while ending points are marked with an arrow pointing downwards. Whereas for variant specific extension modules (see EM B.1 in Figure 4) their range never extends beyond the range of the corresponding variant and therefore, only the specification from which the module is to be used must be determined. Finally, these results are visualized, i.e. the Variant Field is generated.

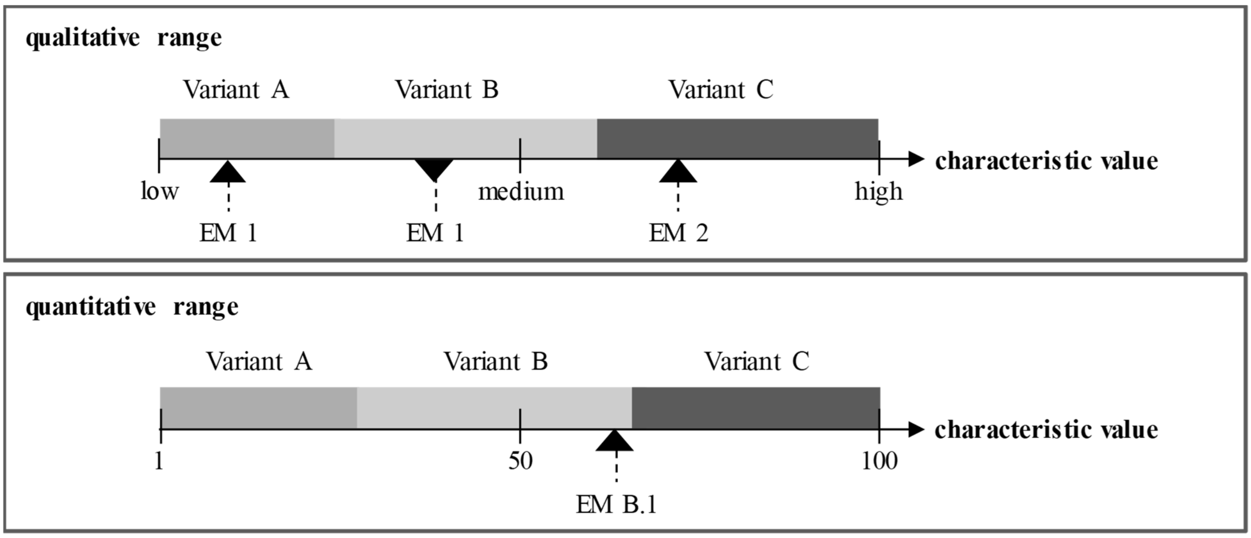

Figure 4: Qualitative and quantitative range

For complementary features, the values along the axes have to be arranged in an increasing way from the intersection of both axis. For competing features, one axis needs to be increasing while the other needs to be decreasing. For indifferent features, there is no general rule nor guarantee, that an arrangement of axis can be found to generate a consistent Variant Field why indifferent features should be avoided.

3. Application and benefits

A fictional example for a specific Variant Field can be seen in Figure 5. It was developed in order to configure the storage equipment mentioned above. The identified relevant features are the assortment size and the room utilisation factor [4], [10], [11]. Both are described with qualitative ranges. The relevant variants are floor storage, a pallet rack and a high level rack. As seen in the Variant Field a high assortment size and a high room utilisation factor are realized through a high level rack storage, whereas a low assortment size and a low room utilisation factor are realized through a floor storage.

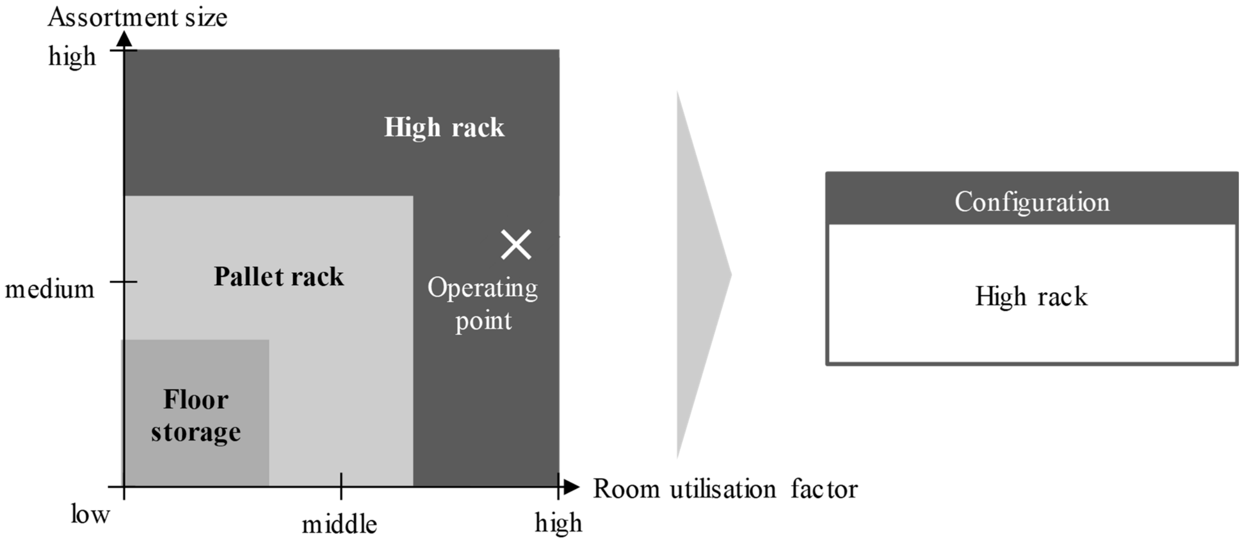

Figure 5: Variant Field example

In this example the company for which this Variant Field has been generated, has grown over decades and has no capacity reserves in terms of area and space. Due to the lack of space, the requirements to the space utilization level of the warehouse are very high. However, the requirements for the product range that can be stored are medium to high. The optimum configuration of the storage is derived from the Variant Field based on the described requirements. The operating point is located in the area of the variant high level rack storage. For the company it is therefore recommended to use this variant.

The underlying goal of the configuration logic and the Variant Field, as described above, is to increase the efficiency and effectiveness of the planning process in order to increase flexibility and responsiveness. The variant field is particularly suitable for rapidly changing boundary conditions for the selection of variants in the factory, whereby the possible variants remain largely the same. Thus, the new requirements to the features only have to be transferred to the variant field and a new variant has to be read, instead of having to carry out a new technology and variant search with the new requirements.

The rise in efficiency or in effectiveness result in a greater ROP value. Moreover the Variant Field offers the possibility to practically apply the generated configuration within the planning process. The visualization of different options and their coherence increases the understanding of complex decision aspects. The presentation is clear and easy to understand. The Variant Field is universally applicable. It can be used in various industries and planning scenarios, since the displayed variants as well as the characteristics of a feature can be adjusted. Moreover, the Variant Field can be used both in initial planning processes as well as adjustment processes.

4. Discussion

Variant Fields allow planners to derive the optimal variant of a factory element directly from the requirements to the element, described by its variable features. The Variant Field as a key result of the

application-oriented configuration logic enables the simple and qualitative or quantitative configuration of factory elements. It thus speeds up the planning process and increases the ROP through reduction of the planning costs. Moreover, it increases the planning reliability. The Variant Field supports the change from a one-time, project related planning to a continuous planning throughout the factory lifecycle. By using the Variant Field, elements can be planned with less effort and easily be adapted to changing boundary conditions. In addition, the Variant Field contributes to the modularization of the planning process by identifying elements suitable for modularization and standardization. The knowledge gained and the generated Variant Fields can be used across projects to further reduce the planning effort.
Moreover, the intended decision support for the planner is fully realized through the Variant Field. Finding the optimal configuration with the Variant Field requires no knowledge about the background of the configurator or the factory element. Thus, short training is needed for employees before using the Variant Field. This makes the tool interesting for a variety of applications.

Despite these benefits there are also some limitations when using Variant Fields.

An underlying assumption when using the Variant Field is that an optimum configuration exists for each element for a specific operating point. By using the Variant Field only the characteristics of the elements but not their required number are determined. Practical application has shown that it is difficult to make a clear distinction between features of a factory element and to define influences on an element and its boundary conditions. In addition, the development of a Variant Field requires a great amount of information that is not necessarily available immediately. The evaluation of the features remains a subjective process and is thus subject to uncertainties. The selection of variants and their assignment to a characteristic value can lead to ambiguities or contradictions in complex application examples, which contain, for example, more versatile requirements in the factory or overlapping characteristics of variants. In addition, the exact determination of the characteristic values, on both quantitative and qualitative scales, requires high effort. Furthermore, combination rules can only be utilized if all variants and extension modules of all factory elements, used in the configurator, are known. This circumstance causes high efforts for the complete development of a factory configurator.

5. Outlook

Despite the various benefits, further research needs to be done in the future. The design of the configuration logic is to be expanded by defining the rules to select the variants used in the configurator from the state of the art. Furthermore, the different areas of the Variant Field, which are linked to the variants and extension modules, are separated by non-linear boundaries in the case of complex interactions of the features. Their definition must be examined. The dependency of features also lead to non-linear functions describing the areas of the Variant Field. The relationships between the axes need to be analysed in more detail in order to be able to set up the Variant Field. Moreover, a clear distinction from and up to which point a variant shall be used should be worked out. Nevertheless, the Variant Field is a strong tool that fulfils the needs of today's planning processes. Once their development has been described in more detail, nothing stands in the way of their widespread application.

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Biography

Florian Becker (*1992) studied mechanical engineering and production technology at RWTH Aachen and received an award for his master's degree and is member of the Dean´s list. In 2017 he started his doctorate at the WZL Aachen. Currently, he works as a member of the research group 'Digital Factory Planning' researching and developing integrated factory modelling processes as well as automatized planning procedures. His main areas of research are automation of planning with the help of AI, regarding the matching between planning tasks and automation algorithms.

Dr. Matthias Dannapfel (*1986) is Chief Engineer of the Department of Factory Planning at the Chair of Production Engineering within the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University. During his research he focuses on the topics Factory of the Future as well as automated and integrated factory planning processes. Furthermore, he is CEO of the ONEFACTORY GmbH.

Sebastian Patrick Vierschilling (*1990) is research associate at the Department of Factory Planning at the Chair of Production Engineering within the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University. Currently, he works as group leader of the research group 'Digital Factory Planning' researching and developing integrated factory modelling processes as well as automatized planning procedures. Beforehand, he finished a Double Master Degree Program within RWTH Aachen University and Tsinghua University, China.