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Approach for predicting production scenarios focused on cross impact analysis

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Abstract

One of the most consistent challenges in business is anticipating what the future holds and what impact it may have on current production systems. The scenario technique is a well-established method for developing and forecasting multiple future development paths for companies. However, this method is mostly employed to develop and to support strategic long-term decisions. The core idea of the approach introduced in this paper is to convey the future impact of today's decisions on production systems to employees involved in production planning processes. With the help of immersive visualization, performed in virtual reality (VR) systems, planning participants can perceive how the factory must adapt to fit future demands.

In this paper, the focus is on the fourth phase of the scenario technique – so called scenario development – and, in particular, the cross impact analysis. With this methodology, the interrelations, or cross impacts of the different basic elements are determined. The cross impact analysis results serve as a basis for the development of a standardized tool that can be used to create probable production scenarios out of given production systems. This standardized tool will facilitate the usage of the scenario technique for factory planning projects, as it focuses the immense diversity of future uncertainties companies are faced with on the factory level.

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Keywords: Production planning; Decision making; Scenario technique

1. Introduction

Companies set their long term strategy based on their business' vision and the company's size. The strategy determines the future business orientation of the company and all long-term business objectives as well as defining concrete measures to ensure the company is moving in the right direction. The decision about these objectives is set at the strategic management level from the leadership. Conventionally, the strategy of small and medium-sized enterprises is for a period of anywhere between three to five years. For larger enterprises, a long-term strategy can extend out as many as eight or ten years [1]. The necessary tools and methods for making and supporting future predictions are developed in the field of future sciences. However, due to increasingly shorter product life cycles and shorter innovation times for technologies, as well as constantly changing customer requirements for products, companies are forced to revise their strategies in shorter time intervals [2]. In order to use methods from the area of future sciences within a reduced amount of time and without losing any accuracy in the outcome, employees working at the operational level, such as machine operators, assembly line workers, shop floor supervisors, and other employees directly involved with manufacturing must be part of the decision making process. This cooperative decision making process can be difficult due to the inequality of information held between employees in senior leadership positions and employees at the operational level. Senior leaders must ensure that high-level strategic information is provided in basic, general terms that is fully understood and comprehended by everyone involved. At the same time, participants from the operational level must ensure that the information provided is not too detailed such that it may detract from the general purpose of building a strategic plan [3]. Most importantly the

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information must remain focused on the production system and not on information that does not have a direct impact on the production system. This forms the basis for the integration of all relevant persons from various fields and disciplines in a company that are needed for the establishment and communication about future prospects.

This paper highlights the reasons why the scenario technique is relevant for our subsequent approach. An abstracted taxonomy compares different forecasting methods based on characteristics that describe the information source and handling of information. These characteristics are necessary for the approach for shortening the acquisition of information and for facilitating communication between the involved participants. Based on the chosen characteristics, the scenario technique can be seen as a connecting link between the different forecasting methods and integrates them into one. The approach presented in this paper is developed so that the scenario technique can be applied on the operational level through a generalization of information and individual process steps such as the cross impact analysis. Generic results are therefore achieved and will serve as input for the prediction of future scenarios for specific factory planning projects. The way to develop these specific scenarios is sketched and introduced at theoretic level.

2. Forecasting methods to predict the future of a company

The core idea of the approach introduced in this paper is to convey the future impact of today's decisions on production systems to employees involved in production planning processes. With the help of immersive visualization, performed in virtual reality (VR) systems, planning participants can perceive how the factory must adapt to fit future demands. Analysis of proposed planning solutions should be performed in order to assess the factories ability to master estimated future predictions at shop floor level. Therefore a lean, visualizable, and fast forecasting method must be selected to design multiple visions of future shop floor layouts (following called Production Scenarios) according to different future perspectives.

2.1. Forecasting methods of future studies for developing future perspectives

The key to unlocking a company's full potential is contingent on management's ability to accurately predict the future and implement strategy which takes full advantage of the firm's resources. Therefore, one of the most consistent challenges in business management and organization is how the future develops and what impact this has on current factories and production systems. Different forecasting methods of future studies can be used to predict how the future may evolve, derive strategies, and provide recommendations for actions. Following, some of the characteristic forecasting methods are presented briefly.

The cross impact analysis enables a holistic view of possible future developments. Possible dependencies, interactions, and relations can be considered within this forecasting method [4]. The implicit and explicit knowledge of experts forms the basis of expert interviews. The survey may not follow a certain structure. The Delphi method, similar to expert interviews, gathers different expert judgments by using anonymous structured group interviews. Any future projection is independent and possible interactions are not considered [5]. Extrapolating the trend line is a statistical method. Thereby already existing data of a time series is mathematically extrapolated into the future. Mind mapping is a creative and participatory process that allows to create future projections by pursuing a logical chain of events.

The scenario technique is a well-established method for developing and forecasting multiple future development paths for companies on a strategic management level. It generates different future projections by systematically considering different influential factors and disturbance events. The result is an amount of equally valid possible future developments that are consistent in their explanatory power.

2.2. Classification of forecasting methods based on information source and information handling

There are different taxonomies to classify the introduced forecasting methods based on basic characteristics [[6], [7]]. Fig. 1 shows a short taxonomy abstract for common future forecasting methods based on such characteristics. The most relevant characteristics for the approach in this paper are the clear allocation of information types (to speed up and facilitate information gathering) and the ability to communicate information among multiple planning participants (to achieve cooperative assessment).

First, methods can be structured by characteristics such as quantitative information (based on data), or qualitative (based on expert information) [6]. This is important for the formation of the initial situation from which the development of different future perspectives can begin. Because the time required to develop potential future perspectives needs to be reduced (e.g. due to shortened product life cycles), the time needed to provide and retrieve information can be directly linked to the information source. The origin of information retrieval, data-based or expert-based, provides conclusions about the duration of information provision.

Secondly, the characteristic in regard to the handling of information can be broken down into a process consisting of four steps: identifying the information, providing the information, assessing the information, and communicating the information. The identification of information deals with recognizing, processing, and setting information needs. Providing information handles the search of the relevant information's origin. This includes, for example, the distribution of responsibilities to gather information, structure the information, and cluster the information based on its origin. The assessment of information evaluates the situation and environment in which the information was collected. In addition, the information is reduced to a manageable size and processed according to the general objective. Last, the communication of information deals with the distribution of information through different communication channels [7]. These information activities are important for our approach. In particular the last phase (communicating the information) is of significant importance due to the fact that this phase plays a key role and represents an indispensable prerequisite.

As shown in Fig.1, none of the common methods and tools cover all the characteristics or activities besides the scenario technique. Based on the chosen characteristics, the scenario technique can be seen as the connecting link between the different forecasting methods and integrates them into one. The integration of the cross impact analysis and the option of simulating the results (communicate via VR means) will be discussed further during the course of this paper.

	information type		information activities			
	quantitative (data-based)	qualitative (expert-based)	identification of information	providing the information	assessment of information	communicating the information
cross impact analysis	X	X			X	
Delphi method		X	X	X	X	
environment analysis		X	X	X		
expert interview		X	X	X	X	
extrapolating the trend line	X		X		X	X
mind mapping		X	X	X		
scenario technique	X	X	X	X	X	X
simulation	X		X	X	X	X

Fig. 1. Classification of forecasting methods based on [2][4]

2.3. Cross impact analysis is as part of the scenario technique

The integration of cross impact analysis and simulation provides good strategic starting points to achieve a generalization of the scenario technique. Although different forecasting methods are connected into one, they need to be investigated separately and not as part of the scenario technique. The focus within this paper is the cross impact analysis to provide a standardized, consistent set of future scenario projections. A brief outline of the different phases of the scenario technique can be seen in Fig. 2 based on Gausemeier et al. [8].

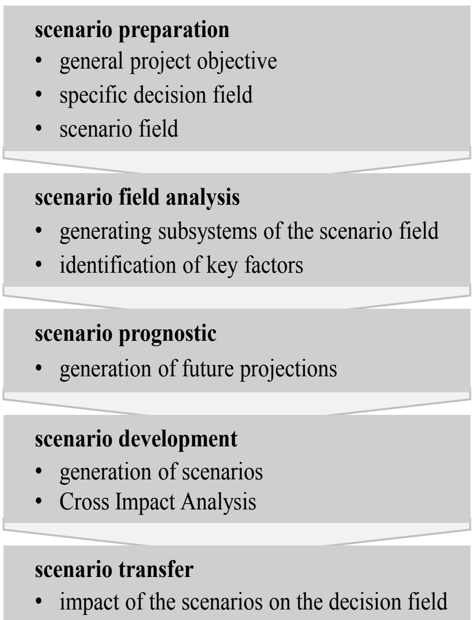

Fig.2 Brief outline of different scenario phases based on [8]

As shown in Fig. 2, the cross impact analysis is already part of the scenario development phase. It is used to investigate interdependencies between different attributes and derive implications based on the results. After defining a set of factors that are relevant for the development of the future (similar to defining factors on the scenario technique), specific attributes are defined for each factor. Furthermore, these attributes may have multiple characteristics which represent possible future developments for each attribute. To clarify this concept, a specific example follows in the next section. Once these characteristics are defined, the probability of future occurrence for each is defined. The attributes and characteristics are subsequently transferred into a matrix and their interdependencies are assessed. An ordinal scale can be used for the assessment. The interactions are evaluated by working through the matrix line-by-line and evaluating the mutual influences [9]. The biggest strength of this forecasting method can be seen in the combination of every individual characteristic and thus any change of an attribute is taken into account [10]. Other advantages are the transparency and traceability, which is based on the high degree of formalization. But, the formalization is an advantage as well as a disadvantage. Especially for non-experts, it can be challenging to assess interrelations [11]. Also, even a small set of characteristics can lead to a very high level of complexity. After describing the process steps of a cross impact analysis in general, it will be applied to the specific field of production systems.

2.4. Representation of production scenarios in the cross impact analysis

As mentioned in the beginning, companies are constantly facing challenges like shorter product life cycles, shorter innovation times for technologies, as well as constantly changing customer requirements for products. However, other internal and external factors can be identified that force companies to act and react as well [2] [13]. The different influential factors are not an explicit part of this research, nor are the reaction of companies towards them [11]. The center of attention is on the impact that these factors have on the production system and how this can be described in a universal way.

The impact will always affect the same group of production elements in a company in a similar way; these elements are categorized as the basic elements of a production system. Five different basic elements can be distinguished: Product (what is produced?), Process (how is it produced?), Employees (who builds it?), Manufacturing equipment (what is it built with?), and Production program (how much is built?). Based on these basic elements Production Scenarios will be build. Thereby a Production Scenario can be understood as a model of a factory that has been adapted according to match the requirements of a future estimation. If multiple potential future estimations are possible, multiple Production Scenarios will be created to fulfill the differing requirements of each future perspective. The convergence between the different Production Scenarios and the ability to adapt flexible on changing environmental conditions can be assessed through VR review processes and are measures of the planning quality.

The direct effect that influential factors have on the basic elements is called Primary Effect. A Secondary Effect is defined as the effect one characteristic has on a second characteristic as the result of the initial primary impact [12]. In order to generalize the scenario technique for all basic elements, different standardized attributes are defined and different characteristics are set in regard to each attribute. This universal set of basic elements and their characteristics will help to mitigate the problem of rising complexity in regard to the cross impact analysis.

The first step in the cross impact analysis is the identification of different characteristics of the attributes. To perform a robust interaction analysis, the various attributes and characteristics of the basic elements will be explained. It can be anticipate that this is a basic set of matching attributes and characteristics, but it is important to limit them to some universal characteristics. Therefore, the possible future developments will also be similar for most of the basic elements e.g. increases, decreases, and stay constant.

Basic element Product: For the basic element Product two attributes are defined. The first attribute is the product variants. Product variants are products with similar features. The characteristic of this attribute describes how many different product variants of a product can occur [12]. The number of different variants can increase, decrease, or stay constant. The second attribute describes the complexity of the product. The complexity may also increase, decrease, or stay constant.

Basic element Production program: A production program is defined as setting the number of different products and the production quantity for each of the products. For the basic element Production program two attributes can be defined. The first attribute is the number of different products. The second attribute describes the total number of produced pieces. For both attributes the characteristics are increasing, decreasing or staying constant.

Basic element Manufacturing equipment: Manufacturing equipment is defined as every piece of equipment or facility that is used in order to perform an output [13]. By selecting the equipment, the technological, organizational, structural, and strategic adaptability of a production system can be determined [12]. The basic element Manufacturing equipment consists of only one element that quantifies the number of different manufacturing equipment The characteristics are increasing, decreasing or staying constant.

Basic element Process: A process includes every operation or sequence of operations that is needed to produce a product [14]. For the Basic element Process two different attributes can be identified. The first attribute addresses the number of operations in a process chain. The characteristics are that the process chain can be extended with new process steps, the process chain can be reduced through elimination of steps, the process chain can be rearranged, or the process chain can stay the same. The second attribute covers the manufacturing technology. There can be a substitution of manufacturing technology, an implementation of a new additional manufacturing technology, or keeping the current technology.

Basic element Employee: Basic element Employee: There are two attributes identified for the basic element Employee. The first attribute is the number of employees, which can increase, decrease, or stay constant. The second attribute considers the qualification of the employee which can be increased or remain at current state.

After defining the attributes and characteristics of the basic elements, it is then possible to transfer them into the cross impact matrix and rate their interrelations. Following the cross impact analysis method the strength of the direct correlation between two characteristics is rated on a scale from -3 to +3. In this case, -3 represent a strong negative correlation (inhibitory), while +3 states a strong positive correlation (boosting). The values for each correlation will be defined on the basis of expert interviews, industrial workshops and best practices out of literature reviews. Thereby it is assumed that the direct correlations between the universally defined basic elements can be gathered as universally valid relationships.

3. Production scenario development

3.1. Overview of the development process

The results of the cross impact analysis on basic elements of a production system which has been elaborated in this paper serves as one key feature for the development of production scenarios. The whole approach for the development of production scenarios is composed of several elements, which are described hereafter (see Fig. 3).

The process is subdivided into two main processes. (1) First a universal analysis of change mechanisms and impact mechanisms of factories in general is explained. This leads to the introduction of universal Production Scenarios. (2) The second main process deals with the development of specific Production Scenarios which are valid only for a dedicated factory. This process applies the generic results coming from the universal analysis.

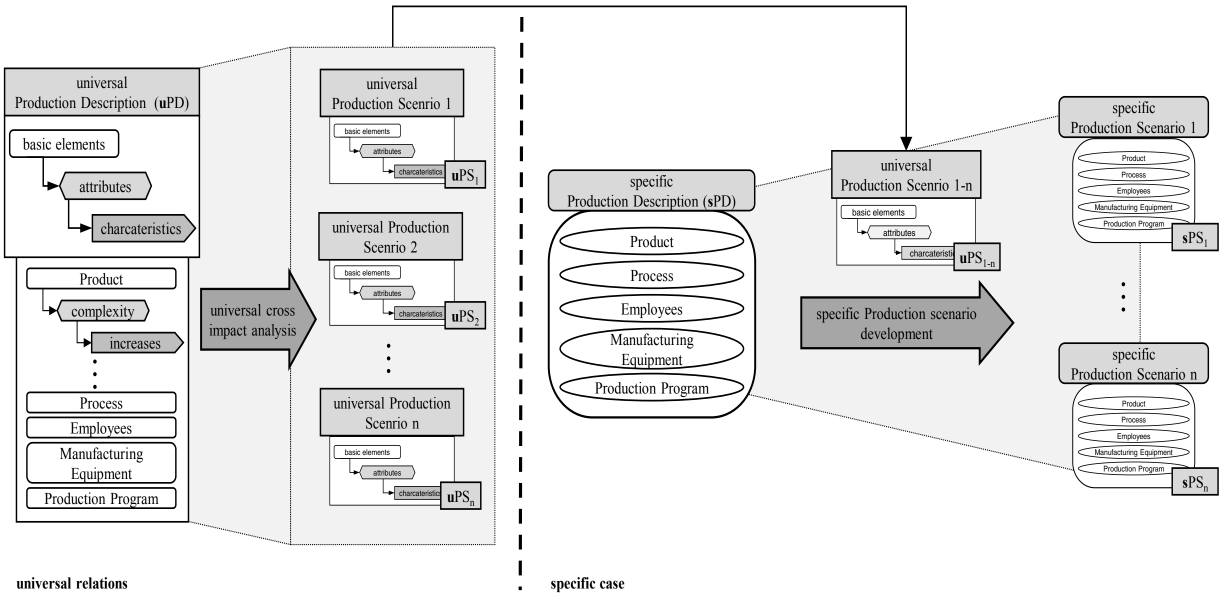

Fig.3 Development of Production Scenarios

3.2. Universal analysis

The cross impact analysis is based on a universal Production Description (uPD) that is able to represent all production systems in a very general sense. Thus the correlations which have been identified are universally valid as well. Out of the uPD multiple future scenarios can be derived which are called universal Production Scenarios (uPS). They contain information on the major impact mechanisms between the primary and secondary effect of influential factors affecting industrial companies. To develop a set of uPS, one single basic element is threaded and identified as the most important for the future (e.g. a new product will be introduced into the production process). The initial change of this basic element is projected and the most probable future scenarios that correspond to this change are derived using the cross impact analysis. The way basic elements, attributes, and their characteristics react on such initial change can be predicted via general and reproducible interdependencies. This leads to uPS which represent most probable future scenario and the corresponding impacts of the initial change which effect basic elements, attributes, and characteristics of a production system in general.

This set of uPS will be used as a type of generic tool to develop concrete production scenarios for a specific production system. Based on the uPS the mechanisms how basic elements, attributes, and their characteristics influence each other will be transferred to a specific production system.

3.3. Adaptation to a specific factory

First a specific Production Description (sPD), containing detailed information about a specific production system will be developed. This sPD represents a specific factory at the current state and detailed representations are given for the basic elements to describe how the factory is composed. The way to describe the sPD is based on the description of the uPD, so that the universal impact mechanisms between influences can be mapped to this specific description later on. The most probable uPS for a specific future prediction are then applied to the sPD in the second step. Due to the fact that uPS contain the way basic elements, attributes, and characteristics may change when future scenarios occur, the impact mechanisms can be transferred from generic analysis to this specific case. For each selected uPS a specific Production Scenario (sPS) will be created. Thereby the sPS describes how the specific factory may have to change in the future, based on the results and interrelations which have been acquired when creating uPS. In the end each sPS represents a probable projection of how the factory may look like (and may have to adapt) in the future.

Due to this approach major advantages for the efficient development of production scenarios can be achieved. The generic definition of uPS allows reuse and standardizes the impact mechanisms and reasoning clauses between basic elements, attributes, and their characteristics. Thus the impact mechanisms don't have to be analyzed for each specific factory again. The sPD can be described and modeled in a more complex and detailed way, because the interrelations between the basic elements don't need to be investigated for each specific case in detail. This leads to fast scenario development cycles and allows for very specific production scenarios.

4. Outlook

The cross impact analysis revealing universal relations between basic elements of a production system which has been presented in this paper is a key feature on the way to develop future predictions in the range of factory planning. The generic results will serve as a main input to develop a tool that is able to support the creation of specific Production Scenarios (sPS).

The next logical step will be to define a very concrete way of representing a factory at the current state. This description model will be reused for deriving multiple sPS. The final step will be to integrate these sPS into an immersive virtual reality system. This leads to a tangible method for communication of future predictions to planning teams at all levels of the factory.

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