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Virtual Reality as a Collaboration Tool for Factory Planning based on Scenario Technique

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Abstract

Over the last couple of years several factors have changed the behavior of companies to interact and collaborate. This can be attributed mainly to a turbulent environment. In addition, the use of Virtual Reality (VR) as a tool for collaboration to exchange information and data has increased significantly over time in production-related areas. The purpose of this paper is to identify the recent state of application areas and stages for the expedient use of VR as a collaboration tool for factory planning. Therefore, a literature review is given on how to handle factors that influence companies in general, but also regarding the factory planning processes. Based on this, the scenario technique in the area of factory planning is presented. These scenarios can be used as a basis for long-term planning of strategic actions. This technique can be especially helpful in an unpredictable future to support long-term decisions. Furthermore, an overview is provided in regard to the phases of factory planning that are supported by VR applications. In contrast, phases are highlighted where a VR support is needed. The basis for a concept is given that strives towards a continuous VR supported factory planning process.

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Keywords: Virtual Reality; Factory Planning; Collaboration

1. Introduction

Big corporations as well as small and medium-sized companies are facing the same challenges. The environments these companies operate in are constantly confronted with a network of different factors and drivers (e.g. govern regulations, customer demands, technology evolution, involvement of multiple stakeholders etc.). Since businesses are not passive parts in today's market system, these factors are actively involved in a company. Without exception, they are having a lasting effect on business behavior. Also, factors are rapidly changing over time. This makes the companies´ environments more dynamic and complex than the decades before [1-2]. This situation is affecting every company. Due to limited resources and existing circumstances, German companies are experiencing an increased level of competition in the area of production and are affecting their global standing [1].

These factors and drivers are affecting the realm of factory planning. More specifically, within the factory planning process decisions are made that have a long-term impact on the business structures. In addition, these decisions have to be made in early phases of the process on uncertain data basis. The integration of multiple participants with dedicated sub-objectives even increases complexity and the need for a joint future estimation.

Due to the amount of factors involved, it is difficult to respond to these changes accordingly. The sooner a company recognizes the need for adaptations on factory level and implements an appropriate response, the more competitive they become. This appropriate response can be placed under the term of changeability of factories. However, the recognition for change is more substantial. Although strategic planning methods exist and planning processes are technological supported, it is difficult to make predictions about the future [2]. The scenario technique is an appropriate method to quarrel this complexity. This technique is a strategic planning method and it is used in many different application areas. The method allows the user to create multiple future development paths [3]. Using the scenario technique, companies are given an option to predict

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drivers of change and convert challenges into enablers of change.

This paper focuses on the theoretical background of the use of the scenario technique within the factory planning process. First, a literature review is presented for identifying different drivers and factors of change. Then, a general introduction of scenario technique is given. This will be followed by an investigation of how the factory planning process is supported by the use of Virtual Reality (VR) as a collaboration tool. Furthermore, the proceeding of further research will be introduced. This work is used as input for a concept where the continuous use of Virtual Reality as a Collaboration Tool for Factory Planning will be introduced.

2. Factory Planning in a turbulent environment

Today, the environment in which companies operate is complex, dynamic, and unpredictable [4]. These characteristics cannot be considered independently. They influence each other and impact one another. Also, the factory planning process itself is influenced by these circumstances. Therefore, a literature review is given on different factors that influence a company followed by a review of factory planning processes.

2.1. Turbulent environment due to influential factors

The companies' environment can be described as turbulent. Companies no longer operate independently and are part of a value network that consists of companies focused on value, their suppliers, and their customers [1-5]. This fact is not further examined in this work. Secondly, the environment in which companies operate is complex and dynamic. The complexity results from the number of different factors that affect a company's environment, the diversity of these factors, and the interdependency of these factors. This dynamic relationship can be stated in terms of factors changing characteristics and the interaction of these elements over time [6].

A literature review shows that different kinds of factors and different categorization of factors can be distinguished. The following examples show these different levels of categorization. A list of examples for specific factors is given in Table1. Wiendahl et al. [7] differentiate factors regarding their internal and external origin. External factors are derived from three different subclasses: technology, market, and environment. Internal factors are separated in subclasses of proactive origin and reactive origin. Lanza et al. [4] categorize factors based on Wiendahl. However, factors are classified in terms of their observation period and the companies´ location motive in addition to the internal and external origin. Hernández [8] differentiates factors by guidable and respectively non-guidable factors. Guidable factors come from the factory environment whereas non-guidable factors come from global environment and business environment. Haag et al. [5] assigns factors to specific areas of influence and impact levels. Areas of influence are companies, network, branch, and environment. Impact levels are economical, technological, demographic, socio-cultural, ecological, and political-legal. Apparently, all sources are referring to more or less the same factors. Also, the majority define factors as drivers of change if the regarding factor may trigger a change in the company.

Table 1. Example List of influential factors

capacity utilization	environmental regulations	manufacturing technologies
collective agreements	exchange rates	market behavior
company targets	fluctuating material availability	market dynamics
competition	health and safety legislation	market share
degree of specialization	Individualization of customer requirements	product quality
demand	IT technologies	product variants
demographic changes	labor costs	production process
employees	labor supply	taxes

2.2. Steady Factory Planning Process in turbulent times

Although the environment became more complex and dynamic, some processes still have a common base. The production-related systematics of factory planning processes has not changed in its fundamentals. In general, five different planning phases can be distinguished: preparation, structure planning, detail planning, implementation planning, and execution [9]. Within the literature, several different approaches can be found that have been developed within the general planning phases. All approaches start with objective setting before they diverge. The specific order of events and tasks performed in those planning phases can be found in Figure 1.

The production-related systematics with its five phases supports a progressive approach in the problem solving process. It can be used as a regulation framework to guide the project [10]. It is helpful to have this steady base, especially during turbulent conditions.

In addition to the production-related systematics for factory planning, general concepts have been developed to counter challenges at a given time.

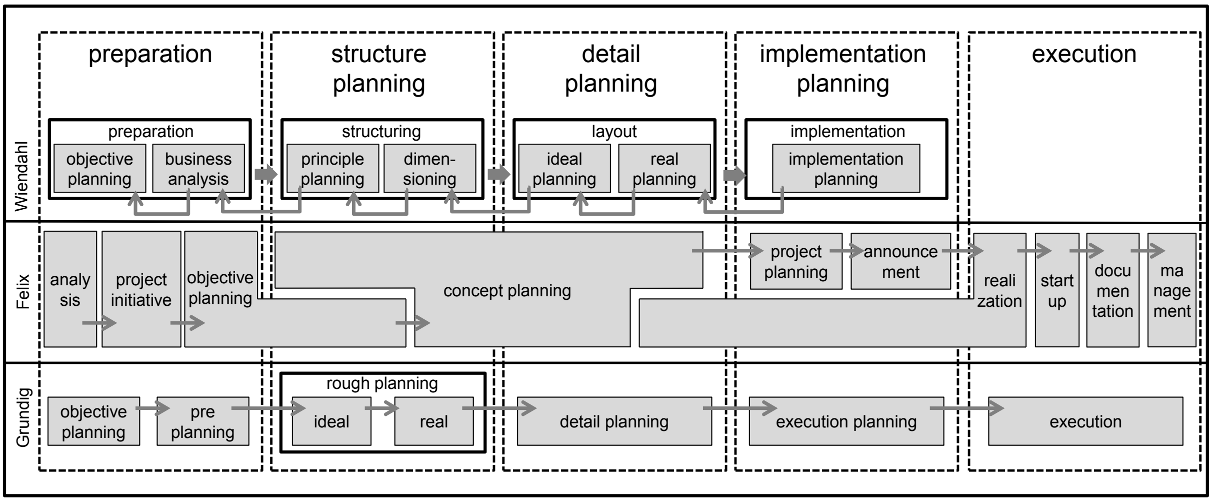

Fig. 1. Comparison of classic factory planning processes based on [9]

Because of their relevance for this work, Changeable Factory, Digital Factory, and Cooperative Factory must be mentioned here briefly. They reflect general trends (e.g. globalization, innovations in technology etc.) which will have a lasting effect on areas of factory planning [10]. The Cooperative Factory tries to meet the time constraints by processing the respective planning phases synchronously and cooperatively with help of specific planning tools. The focus is to bring all participants who are necessary for the success of the project together and give them a baseline on which to cooperate [2-10]. The Digital Factory is defined as a "generic term for a comprehensive network of digital models and methods" [11] with the aim of creating a digital image of the real factory. The Changeable Factory has the ability to detect changes in the factory's environment in an early stage based on monitoring drivers of change and to adjust accordingly.

3. Factory Planning based on Scenario Technique

Due to the turbulent environment the future is more and more unpredictable. Especially for long-term decisions like factory planning, it is necessary to forecast future developments. One way to counter this difficulty is to use the scenario technique [3]. The scenario technique can be placed in the area of strategic corporate planning. Similar to other planning objects, scenario technique is divided into several phases. Gausemeier et al. [12] defines a scenario management process, which consist of five phases: scenario preparation, scenario field analysis, scenario prognostic, scenario development, and scenario transfer. The following explains the phases based on Gausemeier et al. [12] and examples regarding factory planning are given [7].

The core idea is to sketch out how today's decisions will influence tomorrow's factory. Therefore, key factors which influence the production process and the production environment are analyzed and their future development will be predicted. By forecasting not only one optimal future development path, but also multiple potential developments, a whole corridor of potential future visions will be created. Based on these potential developments, estimations will be made, how the key factor development impacts on the factory and its planning. In the end, this future prediction serves as decision aid for factory planning purposes.

During Phase 1 (scenario preparation), the general project objective is set. This includes the description of the project as well as identifying a specific decision field and scenario field. The decision field describes the objective which should be supported in the decision making process. The decision field in factory planning is "factory" as the general objective. Additionally, the current state of the decision field is reported in this phase. The scenario field covers a specific observation area of the decision field. It can be identical with the decision field, but more likely the environment and adjacent areas are analyzed. To describe the scenario technique phases, "technology development" serves as an example of a scenario field.

In Phase 2 (scenario field analysis), the decision field is divided into subsystems. Referring to factory planning, these subsystems are the different production levels (e.g. shown in Figure 2) which represent different levels of detail and special focus areas. Then, different factors are identified regarding the subsystems. Afterwards relevant factors are developed which are then declared as key factors. Those key factors are gathered in a list. For the factory planning, factors, which are already mentioned in Chapter 2.1, are referred to as examples. From this list, specific key factors are detected which are specifically relevant. In the example scenario, “technology development” would focus on the Production cell level and specify the upcoming development of new manufacturing technologies. Therefore, the list of factors would include different upcoming bonding technologies, for instance laser welding and adhesive connecting. To limit the complexity of the example, laser welding is identified as a single relevant key factor.

In Phase 3 (scenario prognostic), the current state of key factors is reported and future projections of the key factors are formulated. Several future projections per factor are valid. By sketching different future trends, a solution corridor will be put up that represents the certain development of key factors. A very strict forecast cannot be done, but estimations will be made and serve as a planning aid. In the example, the development of the laser welding technology will be predicted. Within the best prognosis, laser welding can replace all conventional welding workstations with better quality and decreased process time. A medium prognosis will predict a mixture of conventional and laser welding, where complex and highly stressed parts will be welded by laser. A pessimistic prognosis will predict, that laser welding cannot be universally deployed at the factory and only very few parts will be welded by laser.

Phase 4 (scenario development) proofs the future projections on their consistency. Therefore, a set of future projections is examined in terms of their consistency. Afterwards, characteristic values are assigned to projections and scenarios are developed with the help of graphical representations. The scenarios are built upon the estimated development of the key factors. But in addition, also the impacts of the key factor development to the decision field are considered. As a result of this phase, scenarios are nowadays described in full text. One objective of the approach introduced in this paper is to extend such textual description by VR-based visualizations. In the example for each of the laser welding estimations, factory layouts are designed according to the technology development. While the different estimations correspond directly to bordering factory areas and functions (e.g. number of needed conventional welding workstations), the impacts on the layout can be visualized in a clear way.

Phase 5 (scenario transfer) concludes with how the scenarios interfere with the decision field. As a result, strategies for the company are derived based on the scenarios and their impact on the company. This impact is evaluated in a collaborative session, where several planning participations and strategy developers assess the scenarios together. This leads to a comprehensive solution. E.g. based on the projection of the key factor “laser welding” in the scenario field “technology development”, forecasts for logistical requirements can be derived and future strategies for production planning are stated. Beside the impact on the Factory Layout, the implementation of new technologies is influencing the product design as well.

4. Virtual Reality Support

Following the Digital Factory approach, several IT tools have been developed to optimize manufacturing systems during the planning stage. They should be used jointly to allow a common view on business functions and functional departments within an enterprise [14-15]. Within this context VR has become one major concept to support factory planners by visualization means [16]. With today’s complex manufacturing networks, a comprehensive investigation of the whole production system is crucial. Therefore, VR can be beneficial if used as communication platform to foster the cooperation of different planning specialists. To consider each perspective, a production system can be subdivided into six hierarchical production levels. The production levels are each focusing on special areas and challenges within a factory. From the very detailed view on process parameters up to the interrelations within a supply-chain network, multiple levels of detail must be considered when planning a factory. The connections between production levels even increase dependencies and should be considered as well. Against this backdrop, VR has the ability to visualize domain specific content based on common models of a factory and therefore ease communication among different points of view and different production levels [13-17]. Complementing these different production levels, the factory planning process must be analyzed for its chronological sequence. Referring to Grundig [10] several classification schemes were developed throughout the scientific community. Even though there are some slight differences, a common basic classification is accepted.

Combining the two concepts of ‘production levels’ and ‘factory planning phases’ (Figure 2) a multidimensional area of tension is created, which has to be considered in all dimensions when planning a factory. For each planning phase, demands and constraints on every production level need to be considered. Adaptations on one production level may generate impacts on related production levels. Impacts do not always become visible during the same planning phase, which makes iterations necessary. Besides that, a joint factory model covering each production level for all planning phases does not exist in most cases. An integrated planning process is proposed to establish a continuous usage of equal constraints and reuse of planning results.

In the scientific field of VR-supported factory planning, some promising projects have been initiated to tackle the seeming less integration of IT tools into the factory planning. The Virtual Factory Framework (VFF) project is aiming at an integrative platform to support the design and management of factories. Therefore, several design and planning tools are connected to a core application (the Virtual Factory Manager) that provides data-exchange and communication between the design tools [18]. The DiFac project focuses on the collaboration of Product Designers, Factory Planners, and the training of Workers in an integrated process, highlighting the human factor during industrial production [19]. Also, commercial tools are available which claim to provide an all-comprehensive solution (e.g. Siemens PLM, PTC and Dassault Systems). By comparing the offered functionalities and capabilities of the VR-tools, their potential to support multiple production levels is assessed. They enable design and management of factories in a partially scalable way. However, when looking at the factory-lifecycle continuous support, VR-tools are not able to support the whole planning process. They fail in supporting the early phases and are more or less only suitable for detailed planning of factories.

In conclusion, several approaches could be identified that support a complementary VR usage over the different production levels. In contrast, a continuous VR support among all different planning phases is not provided. The approach described in this paper is a tentative attempt at integrating VR support due to the lack of support in the early phases of the planning process.

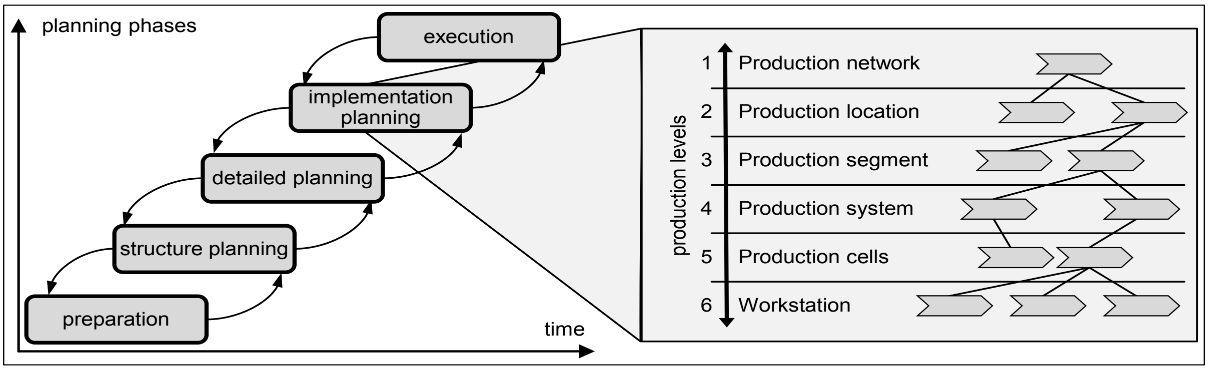

Fig. 2. Factory planning phases and their correlation to production levels in a production system, based on [10] and [13]

5. Concept

Even if the need for a continuous factory planning is identified throughout the research and industrial community, the methods and tools used are more or less still focusing on specific phases of the planning process. This fact is due to the specific characteristics of the methods, and also historically grown based on their initiating scope. To overcome this challenge, VR tools will be used for collaborative and communicative means to couple the central factory planning tools with the scenario technique method (Figure 3). The usages of VR-enhanced collaboration tools will be extended towards the early phases of the factory planning process and thereby facilitate visualization during the scenario technique method. Visualization will be realized by using immersive VR Systems like a CAVE (Cave Virtual Automatic Environment). Global Factory Layouts will be visualized, including the impacts of decisions made by expert planners to the Factory Layout. Thereby Visualization is the key function to mediate scenarios to the users. Multiple users are allowed to analyze and investigate the whole planning status regarding their perception. This extends the Visualization capabilities of the VR System as it is the basis for further discussions and communication within the planning members. The extension of VR-enhanced collaboration methods towards the posterior phases will round up the continuous factory planning, but will not be the main subject of this discussion.

At the 'establishment of the project basis'-phase, scenario technique is an increasingly used method to define objective corridors for planning. To improve the validity of these planning constraints, several experts are involved in the scenario analysis. This means that any competing different points of view among the factory planning task have to be merged. Unfortunately experts coming from different domains are often 'talking in different languages'. Here, VR will be used as communicative means, to illustrate complex relationships through visual means. This allows the assessment of a scenario that considers several parallel objectives at one glance.

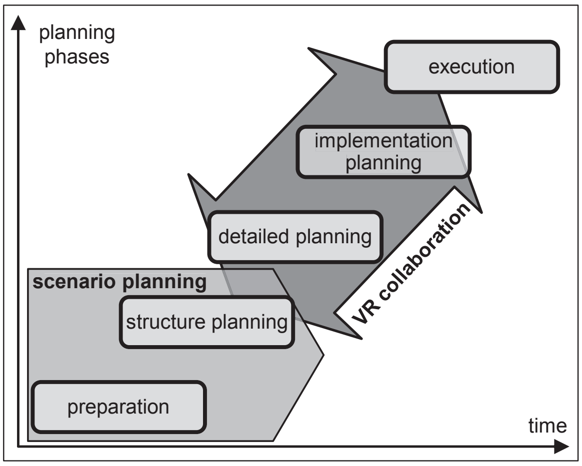

Fig.3. Extension of the VR-support towards early and matured phases of the factory planning process

Regarding the extension of VR-enhanced collaborative tools towards the scenario technique, both methods must be adapted to match joint constraints. The VR collaboration tools must be enabled to visualize several scenarios. This will not make sense for all kinds of factory planning projects and influencing factors. For VR visualization of scenarios, digital content must be provided that could be perceived clearly by all users. Such clear representations are not always available for all potential factors or their corresponding effects. The geometric layout analysis in the VR system can be easily established. However, other effects provided by specific factors may only be described textually or numerically.

6. Outlook

A major current focus in VR support of factory planning is on the central planning phases of the factory planning process. Future work has to focus on a framework which recommends a continuous use of VR in every phase. Within this framework, VR should not only be used for visualization means, but also for collaborative and communicative means.

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