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Procedia CIRP 88 (2020) 133–138

www.elsevier.com/locate/procedia

13th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '19

Holistic integration of a VR solution into the planning process of scalable production systems

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Abstract

Due to the emission scandals and politics the automotive industry is forced to focus more on electromobility. Along with electromobility comes the risk of a volatile consumer market, which the motor industry tries to minimize by implementing scalable production systems.
This paper aims to provide a solution to support the planning of scalable production systems by using the virtual method virtual reality (VR). To achieve this goal, a model for the holistic integration of VR into the production planning process of scalable production systems is developed and different possibilities of implementation are compared and evaluated.

Peer review under the responsibility of the scientific committee of the 13th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 17-19 July 2019, Gulf of Naples, Italy.

Keywords: Virtual reality; scalable production system; production planning; automotive; electric engine; electromobility; industry 4.0; digital factory

1. Introduction

The automotive industry experiences a severe transformation. In 2009 the European parliament passed a regulation which directs automotive companies to reduce the average CO_2-emissions of their vehicle fleets [1]. Adding to that, the recent diesel scandal and the diesel driving ban in some European cities [2] show that there is a need for change in the automotive industry.
In Germany politics and industry see electromobility as the direction this transition should take. While the automotive industry increases their production of hybrids and fully electrical vehicles [3], politics enlists support for investing in electrical mobility by subsidizing electrical vehicles and hybrids [4].
The challenge the automotive industry faces during this change is the fluctuating demand for electrical vehicles in the consumer's market. Due to constantly changing public sponsorships, many different points of view in media coverage and comparably high prices for electrical vehicles, a very volatile market emerged. This volatility becomes visible by comparing different forecasts of future development of this market. Looking at various studies covering this topic, the range of the forecasted numbers of electrical vehicles in the future differs significantly from study to study [5]–[9]. Those uncertainties within the forecasts lead to a fast moving production planning of electrical vehicles.
To reduce the risk of hyperproduction, a transformable production like introduced by Nyhuis et al. [10] with the focus on scalability can be used. Such a scalable production system as examined in this article is built in different steps (Figure 1). Especially the stages of expansion lead to a higher risks in production losses during the integration of new machines and therefore offer a high potential in enhancement of productivity [11].
Using such a scalable production system, the investments made regard a shorter period of time and hold a smaller risk then a big one-time investment. As a result, the size of the next production step can be adjusted to the most recent forecasts and therefore be as precise as possible.

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10.1016/j.procir.2020.05.024

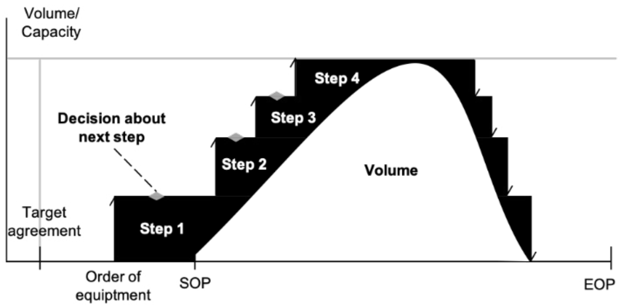


Fig.1. Scalable production system

Besides the advantages of the scalable production system, there are some challenges that surface especially during the expansion phases between the steps. After evaluating an expert study in the industry (53 participants), the most significant inefficiencies occur due to untrained workers and during as well as after the integration of new machines into the existing production line.
The study was carried out through the chair of Production Engineering of E-Mobility Components (PEM) of the Rheinisch-Westfälische Technische Hochschule Aachen (RWTH). It demonstrated, that more than 90% of the questioned industry experts see virtual methods as a solution to face the challenges they are confronted with when implementing a scalable production system. Therefore, this work aims to find a way to reduce the inefficiencies that accompany the integration of a scalable production system by holistically integrating virtual methods into the planning process. This work focuses on virtual reality (VR).

2. Comparable Works

Comparable works and relevant literature were identified and analysed. Thielemann elaborated that the integration of VR into production planning leads to an improved overall system if implemented correctly [12]. Though there are different approaches on how to support production planning with VR solutions. Most of those solutions focus on one particular part of the planning process and not on the process holistically. Most of those solutions deal with the optimization of a work station's layout [13]–[16]. This suggests, that the biggest potential lays in that particular area.

Other approaches imply that the potential of VR does not stop there. Different steps within the planning process for example virtual trainings on VR simulations are examined by Buzjak & Kunica [17] and Kunz et al. [18]. Therefore, the assumption that a holistic integration of VR into the planning process would make sense can be made. McLean [19] and Wiendahl et al. [20] already came to that conclusion in the early 2000s and Kunz et al. [18] and Menck et al. [21] came up with some approaches on how to do so.

However, the biggest challenge when trying to holistically integrate VR into the planning process is caused by the lack of efficient interfaces between existing production data and possible VR solutions. Also, a consistent database for the different process steps is not established yet [17], [19]–[21].

All the approaches mentioned above focused on planning processes for conventional production systems. Scalable production systems were not examined. Besides a higher complexity in scalable systems, every ramp-up for a new stage of expansion provides a potential in efficiency savings. This is why this work focuses on the holistic integration of the virtual method VR into the production planning process of scalable production systems.

3. VR within the Planning Process

To develop a model to holistically integrate VR into the planning process of scalable production systems, first possible areas for VR applications and the resulting potential were identified. Following the identification of the potential, a timeline for the integration of the identified VR applications was established.

3.1 VR-potential within the planning process

To identify areas in which VR applications could be used to support the planning process of scalable production systems different workshops were held. In those workshops one workstation of an already planned production line which was implemented in VR was shown to the stakeholders involved in the planning process. To setup a tethered PC virtual reality system, a computer with a high performance mainboard and graphics card was installed alongside the Head Mounted Display (HMD) provided by HTC with the latest model the Vive Pro.
In Table 1 below an overview of where the different stakeholders see potential when implementing VR applications and which kind of potential they predict is presented after summarizing expert interviews at a German OEM.

Table 1: VR potential within the planning process

Stakeholder	VR Application	VR Potential
Common consensus	Discussion and analysis of facilities in VR	Overall quality improvement of the planning process
Assembly planning	Examination of ergonomics, walking path analyses	Earlier Safeguarding, easier documentation
Maintenance and logistics planning	Examination of maintenance possibilities, supply of materials, accessibility & travel path	Easier quality assurance
Operator	VR-trainings for workers	Risk-free trainings, trainings in earlier stages in the process
Management	VR as a project monitoring / process planning tool	Higher employee satisfaction through gamification

Compared to state-of-the-art 3D visualization programs that are used to visualize working stations in earlier planning stages, the questioned stakeholders all agree that the implementation of VR applications will improve the overall quality of the planning process.
In addition, the assembly planning experts see earlier safeguarding of the working stations and easier documentation

of feedback when implementing ergonomics examination and walking path analysis in VR.
Maintenance and logistics planning predict earlier quality assurance when examining maintenance possibilities, supply of material, accessibility and travel paths in VR.
Operators of the production line see the biggest potential in the implementation of VR-trainings for workers. Those will lead to risk-free trainings in an earlier stage of the planning process.
Finally, the management predicts a higher employee satisfaction when implementing VR as a planning tool due to gamification of the planning process.

3.2 VR-Implementation into the planning process

To ensure an efficient implementation of VR applications into the planning process of scalable production systems, the goal was not to introduce more process steps, but to replace existing planning steps with more efficient VR-based solutions.
Within the workshops mentioned in 3.1, together with the planning experts four process steps of the planning process were identified as the main use cases for implementation of VR (approval percentage of replaceability by VR in brackets):

- *Virtual cardboard simulation (72%):* Replaces the physical cardboard simulation with a first and more detailed simulation of a manual working station in VR.

- *Virtual planning optimization (89%):* Starting with the first 3D-Computer-Aided Design (CAD)-files provided by the supplier of the working station that is to be planned, the different stakeholders will visualize and analyse the working station in VR. This conveys a very concrete impression of the working station at a very early stage within the planning process to the planners. As a result, the communication between supplier and planner improves drastically as does the overall quality of the planning process.

- *Virtual design approval workshop (91%):* Takes place as a final milestone of the virtual planning optimization. All relevant stakeholders take part to analyse and discuss the final design of a given working station. The realization in VR provides an optimized basis for discussions to communicate more efficiently and find possible planning mistakes. This step also improves the overall quality of the planning process.

- *Virtual trainings (59%):* Once the final designs for the working station are approved, production sequences can be integrated into the final VR applications resulting from the design approval workshop. Following this integration, the VR-training of the workers can be started. When implemented, the VR-trainings lead to better prepared and efficient workers at the start of production (SOP) which leads to a higher overall productivity of the production line at SOP. New workers that start working at an already running production line can also use the existing VR trainings to get to know their tasks.

Figure 2 provides the timeline of the production planning process where the four process steps that include VR applications will be implemented:

3.3 VR-impact in scalable production systems

The VR applications mentioned in the chapters before can be applied in conventional production systems. There they result in the optimizations mentioned in 2.1. For scalable production systems these optimizations achieve an even higher gain in productivity, one reason being the multiple planning phases (one for each step) for each production system. Another significant reason is the lack of testing in the already running production process.
In scalable production systems, besides the raise in quality of the planning process, VR applications also lead to a higher productivity in the critical transformation phase between the different steps of the production roll-out.
In conventional production systems a first setup of the production line can be put in an empty production hall and then be optimized. There is also a phase in which a pilot series is produced in order to let the workers get used to their workstations and to optimize productivity. However, after step one in scalable production systems there already is a running production line in which new workstations need to be integrated. Figure 3 demonstrates that during the integration phase, production has to be stopped, and line productivity falls to zero, which equals an Overall Equipment Effectiveness (OEE) of 0 %. Therefore, the time in which the production line is on hold needs to be minimized.

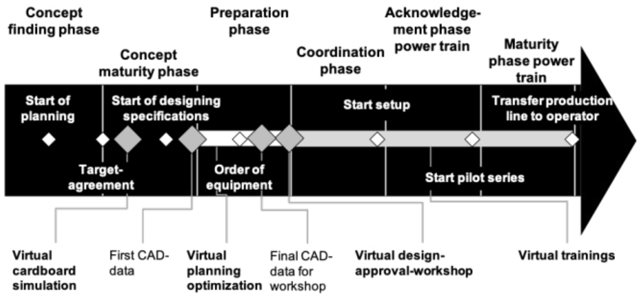


Fig.2. Timeline VR in production planning

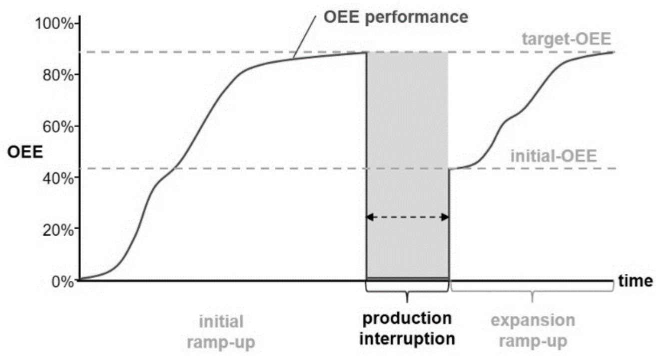


Fig.3. OEE performance during expansion of the production system

Integrating new machines of a next stage of expansion into a VR setup of an existing production line is one step to achieve this goal. When successfully integrated in an accurate VR simulation of the existing production line, most of the geometrical problems (e.g. machine to machine, machine to structure, evacuation or logistics routes) with the new machines can be avoided entirely. Therefore, an integration of new working stations in VR simulations of the existing production line helps to optimize the integration process and minimize the downtime of the production line.
To restart production at a comparable level of productivity after the production was stopped and to integrate new working stations, training workers with the help of VR simulations is a suitable approach. As soon as the downtime of the production line ends, workers need to be as productive as possible, because there is no pilot series to slowly approach the productivity needed. Consequently, a VR training before the restart of the production line is inevitable.

4. Implementation Possibilities

In this work three possibilities of implementing VR applications into the planning process of scalable production systems were analysed and evaluated:

- *Implementation through a service provider:* An external service provider implements every working station of a production line in VR.
- *Implementation by programming in game engine:* The VR applications are programmed by an employee of the producing company using game engines.
- *Implementation through use of VR-frameworks:* VR applications are created by using VR-frameworks. The frameworks (software) are used by the planners planning the production line.

In order to find the right solution for an implementation into the regular planning process, the three different options were evaluated.

4.1 Evaluation Criteria

To evaluate the three possible options regarding their implementability into the planning process, four criteria were defined. The first and the second criterion are related to cost efficiency [23]. The third and the fourth criterion are determined by empirical usability evaluation [24] through expert interviews at a German OEM:

- *Cost of integration:* The first step is to look at additional costs resulting from the integration of the possible way of implementation. The criterion mainly focuses on cost for extra personnel that is needed to implement a given way of realization.
- *Cost for licenses:* The costs for the licensing of the different software solutions are compared.
- *Documentation:* The documentation of the VR sessions held during the planning process are of great importance. Only with a simple, detailed and efficient documentation the results can be used for the planning process
- *Time needed:* Finally, the time that is needed to transform the given CAD-data into a VR-simulation is considered. The critical path for this criterion is in the design approval workshop. Here the CAD-data is only provided a short period of time before the workshop. Therefore, it is inevitable that a VR simulation can be created during that short period of time.

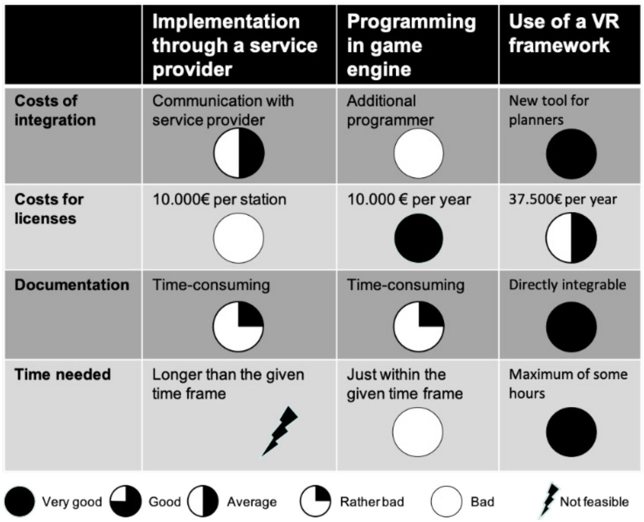
These criteria were evaluated either very good, good, average, rather bad or bad.

4.2 Evaluation of the implementation possibilities

In order to identify the best way possible to implement VR into the planning process, the different possibilities were evaluated and compared regarding the criteria determined in 4.1.

Looking at the cost of integration, implementation through a service provider is evaluated average due to extra time that is needed during the planning process for communication between the planners and the service provider.
Costs of integration for implementation by programming in game engines is rated bad. The rating is caused by the need of an additional programmer who is inevitable to realize this way of implementation.
Using a VR-framework leads to no costs of integration since the framework can be used by the planners as a replacement for their existing tools. Therefore, this option is rated very good.

Cost for licenses are rated bad for the implementation through a service provider. In a pilot project conducted during this work, the implementation of one workstation costs 10.000€. Considering five production lines with combined more than 100 workstations, costs would add up to more than 1 Mio. €.
Programming in game engines would only require licenses for the chosen game engine and a converter program to convert the given CAD-data into VR data. Those licenses would add up to a maximum of 10.000 € a year regardless how many stations are implemented. Therefore, a rating as very good was evaluated here.
Licenses for the examined VR framework would lead to costs of about 37.500€ a year which lead to a rating as average.
Since the service provider that was examined during this project also was programming in game engines, the way of documentation for the service provider and the in-house programming in game engines is the same. It is rated as rather bad because feedback and proposed changes of a VR working station which are discovered during a VR session need to be implemented in the raw CAD-data before it can be viewed in VR. They cannot be changed within the VR session. This takes time and many feedback loops.
The VR-framework enables the user to change anything within the whole VR simulation in real time during the VR session. The changes can be saved and kept as documentation. Therefore, this option is rated very good.



	Implementation through a service provider	Programming in game engine	Use of a VR framework
Costs of integration	Communication with service provider	Additional programmer	New tool for planners
Costs for licenses	10.000€ per station	10.000 € per year	37.500€ per year
Documentation	Time-consuming	Time-consuming	Directly integrable
Time needed	Longer than the given time frame	Just within the given time frame	Maximum of some hours

Fig. 4. Evaluation of possible implementation strategies

As mentioned in 4.1 the needed time to transform CAD-data has a critical path between the delivery of the CAD-data through the supplier of the working station until the design approval workshop. The implementation through an external service provider cannot be done within this time frame which is therefore rated as not feasible.
With programming in game engines, it would be possible to stay within the given time frame. However, it would take up almost all the given time and therefore leave no time for remakes or mistakes. It is therefore rated bad.
Using the examined VR framework, it is possible to transform CAD-data into a VR simulation within minutes. This leads to an evaluation as very good.
The evaluation of the three possibilities of implementation regarding the considered criteria which is visible in Figure 4, leads to the assumption that the use of a VR framework would be the best option when holistically integrating VR into the planning process of scalable production systems.

5. Conclusion

The growing relevance of electric vehicles which is induced through politics, technical development and market awareness, leads to challenges for the automotive industry. The volatility of demand for electric vehicles is confronted with scalable production systems. Those scalable production systems can react quickly to new demand forecasts. This is realized through different steps in the roll-out of a production line.
However, during those roll-out-steps inefficiencies can surface. These inefficiencies occur during and after the stop of production which is needed before the realization of a new step. The reason for that are workers who cannot be trained in the conventional way within the scalable production system. New working stations can also not be planned, using all the conventional planning methods.
This work proposes a model to support the realization of scalable production systems with the virtual method virtual reality. The model defines when and to which extend VR needs to be established within the planning process of scalable production systems.
This work also evaluated different possibilities of implementation and identified the use of a VR framework as the most suitable one for the integration into the examined planning process.

6. Discussion

The model only identifies potential in different areas of the planning process in a qualitative way. Further research should quantify this potential. The scope of such research could be case studies in which for example a design-approval workshop could first be performed conventionally and then virtually using VR simulations.
The given model also only looks at the virtual method VR. To examine other virtual methods and integrate those into the planning process of scalable production systems will lead to using the full potential discovered in the study regarding scalable production systems mentioned in chapter 1.
An interesting approach exists in Dahl et al. [22]. This work focuses on the combination of virtual commissioning and VR. But this approach only focuses on one process step within the planning process. A next step should be to combine Dahl's approach with the holistic integration of VR into the planning process this work provides.

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