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► **To cite this version:**

Christian Weidig, Nicole Menck, Pascal Winkes, Jan Aurich. Virtual Learning Factory on VR-Supported Factory Planning. Luis M. Camarinha-Matos; Hamideh Afsarmanesh. 15th Working Conference on Virtual Enterprises (PROVE), Oct 2014, Amsterdam, Netherlands. Springer, IFIP Advances in Information and Communication Technology, AICT-434, pp.455-462, 2014, Collaborative Systems for Smart Networked Environments. <10.1007/978-3-662-44745-1\_45>. <hal-01392151>

**HAL Id: hal-01392151**

**<https://hal.inria.fr/hal-01392151>**

Submitted on 4 Nov 2016

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# Virtual Learning Factory on VR-Supported Factory Planning

Christian Weidig<sup>1</sup>, Nicole Menck<sup>1</sup>, Pascal A. Winkes<sup>1</sup> and Jan C. Aurich<sup>1</sup>

<sup>1</sup> Institute for Manufacturing Technology and Production Systems, University of Kaiserslautern, Gottlieb-Daimler-Straße 47, 67663 Kaiserslautern, Germany  
{weidig, menck, winkes, aurich}@cpk.uni-kl.de

**Abstract.** Learning Factories are becoming popular as tangible measures to teach engineering methods while making use of them in an industrial-like environment. Their core component is usually a factory demonstrator, users are physically working with. For factory planning such approaches can hardly be adapted, due to long lasting realization phases.

To overcome this obstacle a virtual learning factory has been developed whose core component is not a real factory but a digital factory model. Based on an exemplary product and production model participants learn how to use factory planning methods for a clearly defined use-case. They apply software tools coming from the digital factory and learn how to use VR-systems for validation purposes. The comprehensive digital planning facilitates the collaboration between multiple planning participants. Further extension of the approach towards distance collaboration and use-cases covering the whole product engineering process are proposed.

**Keywords:** Learning Factory, Factory Planning, Digital Factory, Virtual Reality

## 1 Introduction

Learning factories became a relevant measure for companies and research institutions. Several advantages for the industry and also for the research institutions can be united in learning factories.

Every company has to face different challenges on a daily basis. These challenges can result from external factors like governmental requirements or technological innovations but also from internal factors like qualification of employees [1]. For instance, increasingly shorter product life cycles and shorter innovation times for technologies require a more changeable production and a wider knowledge base of employees [2]. Especially establishing, applying and communicating of consolidated knowledge of employees in regard to changing production conditions is a challenging task for companies. Another challenge is the collaboration between employees. Empirical studies on the extent and relevance of communication in projects revealed, that the majority of project managers stated that communication is the key factor for

the success of a project [3]. The success of a project depends significantly on the collaboration between the participated employees. Several projects will take place where participants are located in the same team or location. But, production networks and spatially dislocated teams complicate the information exchange.

On the other side, also research institutions have to face new challenges. It is expected and required for example by national growth strategies and European programs, that research institutions provide a higher number of graduates with an excellent knowledge based on sophisticated methods and tools [4]. This is challenging due to demographical changes and shorter study periods. In order to meet those expectations and objectives while maintaining the excellence and quality of teaching, new didactical methods with innovative structures need to be applied and communicated.

Learning factories can bridge those challenges from both sides and unite several advantages. They close the gap between real challenges provided by industry and sophisticated methods and tools offered by research institutions. In general, learning factories can be defined as teaching and learning environments in which participants are given the option to consolidate theoretical taught knowledge under real conditions in a supervised environment [5]. Beside the teaching and learning environment a didactical concept is provided. This didactical concept is needed to reassure the success of the learning process. This broad definition of a learning factory is not finalized and leaves the option by which terms the definition will be specified. For example, in the general definition participants can be specified by using the term undergraduate students as well as advanced students or even industrial representatives. Different morphologies are providing helpful lists of attributes to describe and define learning factories [6].

The biggest advantage can be stated in the fact that learning factories consolidate and assure theoretical knowledge by directly applying learned methods and tools to real use cases and conditions. The required theoretical knowledge is communicated by traditional teaching means for example through face to face classes or comparable teaching methods like e-learning. With this theoretical background participants enter the teaching and learning environment. These environments can be part of real systems and processes but usually they are just authentic models that represent real systems and processes. Within these environments, participants can apply their theoretical knowledge and get their hands-on experience by physically interact with the components of a learning factory. Since effects and interrelations of actions can be observed, learning effects can be provided faster and the knowledge is consolidated.

Several organizations, research institutions as well as industrial organizations, recognized this potential and established learning factories at their facilities. However, many learning factories regarding manufacturing systems are dealing with changeability, energy efficiency and lean management methods [7, 8, 9].

Especially within these subjects, real environments or authentic parts of systems can be implemented easily. But, for factory planning such physical learning environments cannot be implemented. The factory planning process is very complex. It consists of several sequent planning phases [10]. Results of the different planning phases cannot be implemented and evaluated directly. The establishment of a comprehensive real model that covers all elements of a factory planning process within a learning factory is not realized, yet. Not only because of the extent of such

projects, but also because of the temporal aspects. Traditionally, preparation and conduction of different work packages of each individual planning phase cover a long period of time. A workshop within a learning factory should not exceed ten workshop sessions [6]. In addition, several people from different domains are involved in such a project. A large amount of data and information is generated. Every participant needs a different set of information depending on their personal objective and task. An authentic learning factory of the comprehensive factory planning process could not handle the amount of information.

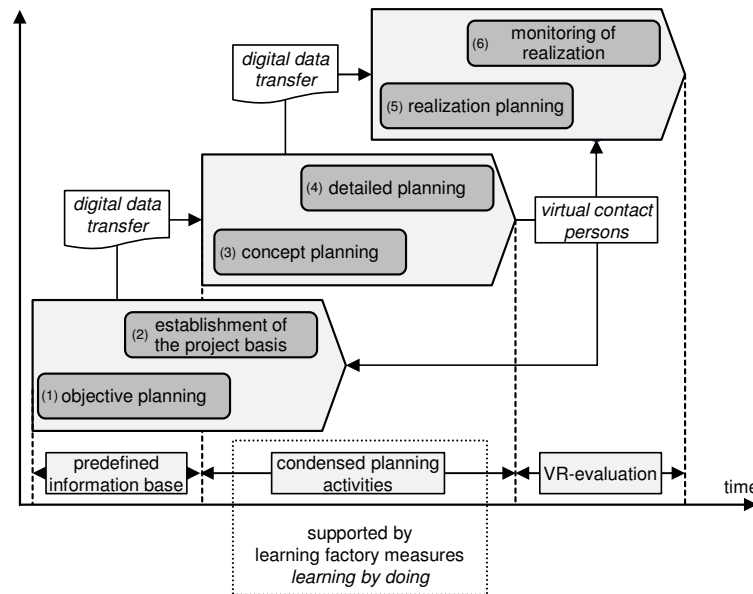
## 2 Virtual Learning Factory Approach

To overcome the duration and realization dilemma within learning factories facing on factory planning, the sole virtual execution of a learning factory has been developed at the Institute of Manufacturing Technology and Production Systems (FBK). Its core component is not a real factory but a digital factory model. Here is one main difference to other established digital learning factories, which also use digital tools, but validate the planned factory with physical models. An example is the learning factory advanced Industrial Engineering (aIE) at the IFF at the University of Stuttgart [9]. The focus of this virtual learning factory is a virtual supported factory planning process. The participants will pass different milestones during such factory planning projects. For example, they apply software tools coming from the digital factory and learn how to use Virtual Reality (VR) systems for validation purposes. The participants will experience to interact and how to prepare information in order to collaborate in interdisciplinary teams.

The main objectives of this virtual learning factory are placed in the shortened time period to understand complex interrelations and processes in the field of factory planning, to analyze and to identify weaknesses, and to develop appropriate solutions. Thereby time consuming early and late stages of the factory planning process are substituted by beneficial alternative actions (Fig. 1). The collaboration between the different planning participants is concentrated on the central planning stages. This will focus the attention on the key planning and communication tasks during factory planning.

The early stages (1) objective planning and (2) establishment of the project basis are captured by specially prepared basic conditions. In contrary to most real industrial projects the overall objectives are predefined and the initial situation is summarized in a structured and clear way. This ensures that all required information is available for fast and easy access, inconsistent information from multiple sources will be prevented. The late stages (5) realization planning and (6) monitoring of realization will be captured by an immersive VR-evaluation of the planning results. Therefore the participants will directly create a digital layout model during the learning factory execution which will be the basis for a VR-model. This VR-model will be evaluated by all planning participants against the initial objectives at the FBK CAVE (Cave Automatic Virtual Environment). By providing these two substitutive actions, the

implementation of the condensed planning activities within a real industrial project is simulated with limited complexity, while reducing time consuming activities.



**Fig. 1.** Placement of the virtual learning factory activities regarding the factory planning process (based on [10])

Hence the major part of the learning factory activities are the (3) concept planning and the (4) detailed planning stages. They form the condensed planning activities in which the creative, collaborative planning activities are methodically supported. The planning participant will develop a factory design to capture the given objectives and to suit the prepared basic conditions. Thereby the objectives and basic conditions are covering the whole set of typically limitations at industrial level. This includes constraints from multiple domains such as product design, production planning, material flow, logistics, ergonomic and security, financial, and architectural. The given objectives from various domains affect each other which makes the development of an ultimate solution a complex challenge that cannot be solved from one single planning participant alone. To address this area of conflict the planning participants need to analyze and divide the overall problem into smaller parts by their own and develop part solutions. The part solutions will be assembled afterwards. This workflow requests a high level of commitment, effective communication, and ability to analyze problems from different points of view from all planning participants. These soft skills are a central ability that is taught by the learning factory.

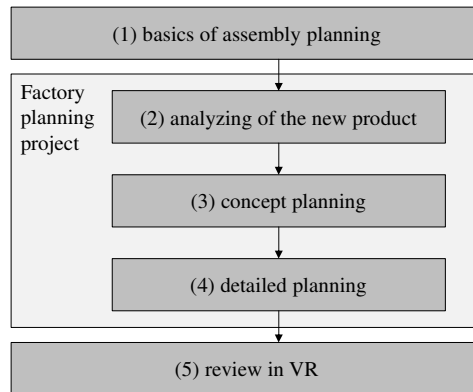
To allow the sole virtual execution of the learning factory a continuous transition of digital information and planning data is established through the factory planning process. This includes the digital data transfer between the predefined information base and the condensed planning activities (e.g. digital product models) as well as the

digital data transfer between the condensed planning activities and the VR-evaluation (e.g. digital layout plan) (Fig. 1). The data transfer is realized by a central server which represents a joint companywide storage systems for factory planning related information.

To allow collaboration not only between the planning participants, but even within the simulated company, virtual contact persons are established. They are described by an organization chart containing responsible persons for multiple domains. In case of discussion demand, planning participants can contact them via e-mail and request information or clarification for certain points. For instance logistic planners can be contacted to get information among used type and number of forklifts. Thereby the organization chart reflects the different source domains of objectives and their interrelationships as well as dependencies.

### 3 Virtual Learning Factory Design

The following section describes the course outline of the virtual learning factory. The workshop is organized in five phases as shown in figure 2. In those phases, the participants learn the basics of factory planning and apply the methods to a given factory planning project. At the end, the planning results are evaluated in the virtual environment.



**Fig. 2.** Phases of the virtual learning factory

A line assembly for truck axles is defined as subject of the virtual learning factory and serves as the application scenario within the workshop. In the scenario, a new axle type will be introduced with complex sub-assemblies determining a wide range of variants. The amount of parts handled within this specific assembly line will increase. The current assembly line will not be capable anymore to carry out the required assembly operations and the reorganization of the current assembly line will be initiated. The major objective in this application scenario is to restructure the assembly line due to these changes in the production program.

The workshop is held and supervised by the Institute for Manufacturing Technology and Production Systems in Kaiserslautern, Germany. In addition to the physical supervision, a virtual contact person will be introduced in the first phase of the workshop which can be contacted for further information to the context of the scenario as well as providing specific data during the execution of the scenario.

(1) In the first phase participants receive the knowledge and tools which are needed to deal with the challenges of the virtual learning factory application scenario. These are the fundamental principles of factory planning. These principles include for example methods for analyzing and optimization of layout plans, material flow, storage concepts, scheduling, and budget planning. In addition to the theoretical foundations taught by the workshop supervisor, the participants are introduced to the application scenario with its initial situation, needs of adaption, and strategic vision. They obtain information among the initial situation and all necessary information in form of digital plans and data in order to start the restructuring task.

(2) In the second phase, the analysis of the product, in this case the new variation of the axles, and the production program are in focus. Different methods are used to generate for example the bill of material, required equipment, or capacity. At this point it is important that the participants learn how to deal with the provided information, how to extract required data out of a given data set and to work independently on a task but also in a team towards a given strategy.

(3) After they had a closer look at the product in the second phase, the participants deal with function structures of the production in the third phase of the application scenario. The concept planning of the assembly area is performed. Based on the product data, the best assembly order of the different parts and subassembly groups needs to be determined. Accordingly, the resources are specified, which are needed for the assembly task. Therefore the cycle time for the assembly process has to be taken into account as well as several different alternatives of tools and machines, for example electric or pneumatic screw drivers with different specifications. Those include for example differences in machining time, costs, required energy supply, noise level, size, safety, and operation complexity. The different specifications have to be weighed with regard to the constraints and restrictions at industrial level. The chosen resources have to be compared with the existing ones. For some assembly tasks, new machines and tools are needed due to the larger size and higher requirements of the new axle. In this phase the participants are learning how to extract and use information from the product data for the assembly program and resources. The third phase closes with a rough layout planning of the production hall.

(4) In the fourth phase the detailed design of the factory layout concludes the application scenarios. Within this phase, the concept planning gets detailed out. The exact arrangement of all the resources is defined. Also details regarding the subassembly groups are discussed as well as questions regarding the layout of the different working stations. First, the participants have to examine which assembly types are useful for the assembly of the new axle variation. Further they investigate what assembly type arrangements are possible and reasonable. For example, if there are any significant advantages of a specific assembly type or if there is no need to change the common line. After details regarding the assembly line, the detailing of workstations is discussed in the next step. Here, the number of workstations and the allocation of assembly tasks to workstations is determined. At this point, it is

important to meet the requirements of the program planning by designing the resources accordingly and adjust their capacities. Regarding the layout of different workstations, the participants apply the basics of layout planning. Boundary conditions of the given production hall must be considered. This includes the positions and orientations of the work places, tools, and machines. Also considerations concerning the dimensions of the axle, workstations' exposure to light, legally noise limitations, and occupational safety must be discussed. Storages and buffers have to be planned accordingly. Different methods and tools regarding the planning and visualization of assembly lines in 2D and 3D are focused and internalized. Altered arrangements of assembly stations can be visualized to see the effects and impacts of different formations. For instance, a net plan can be an effective tool to visualize the logical order and connections of the workstations and the subassembly and the assembly line. In this phase, the participants learn to plan workstations for the main assembly and the subassembly groups. This includes methods of capacity planning, schedule planning, and layout planning tools. The outcome of the detailed planning phase is the final layout and process plan of the new assembly area for the new truck axle with its subassembly groups and variants.

(5) In the fifth phase the final layout is evaluated which concludes the application scenario. The data is converted in a VRML-file, which can be read by the VR-System at the FBK. The 3D VR-System at the FBK consists of a 4-sided CAVE with Tracking Cameras. Here the participants of the virtual learning factory have the opportunity to analyze and evaluate their planning results together with the supervisors in a realistic way. They are given the option to walk through the new assembly scenario and identify critical sections. During that review, some obvious inaccuracies in the planning are determined, like tight walkways or neglected safety areas. The trainers will indicate more subtle problems in the layout and suggest solutions.

## 4 Outlook

Learning factories close the gap between theoretical taught knowledge and industrial hands-on experience. They unite the advantage of bringing together sophisticated methods and tools offered by research institutions and real challenges and problems stated by industrial organizations. This paper introduced a virtual learning factory that focuses on the condensed planning activities of a virtual reality supported factory planning process. It discussed why in cases of factory planning a virtual solution is needed. A special focus is set on the collaboration between the participants and how to handle and prepare a large amount of information.

In the future analysis are planned to compare the learning effectiveness of such hands-on experiences with established learning methods (e.g. through books, within real factories). Further the virtual learning didactic model will be improved, by purposeful usage and application of specified factory planning methods according to the participants' background.



The growing number of established learning factories mirrors the importance of the subject matter. In order to meet demand from industrial side and the offer on research side, learning factories must differentiate and complement each other. Therefore, a further extension of the approach towards distance collaboration and use-cases covering the whole product engineering process are aspired as well as the collaboration with other establishments in order to create a network of learning factories.

#### **Acknowledgments.**

The research leading to these results has been conducted in cooperation to WGP activities of the FBK. This work was funded by the German Science Foundation (DFG) within the International Research Training Group (IRTG) 1131 “Visualization of Large and Unstructured Data Sets Applications in Geospatial Planning, Modeling, and Engineering”. Further funding from the European Community’s 7th Framework Programme under grant agreement VISIONAIR n°262044 was provided. The VISIONAIR project ([www.infra-visionair.eu](http://www.infra-visionair.eu)) creates a European Infrastructure for Visualization and Interaction based Research.

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