Concept of Semi-Autonomous Production Planning and Decision Support Based on Virtual Technology

C. Prinz[2], D. Jentsch[1], N. Kreggenfeld[2], F. Morlock[2*], A. Merkel[1], E. Müller[1], and D. Kreimeier[2]

[1]Department of Factory Planning and Factory Management
Technische Universität Chemnitz
Chemnitz, 09107, Germany

[2]Chair of Production Systems
Ruhr-Universität Bochum
Bochum, 44801, Germany

ABSTRACT

The following conceptual contribution is based on the two scientific fields Digital Factory (DF) as well as end-user electronics. The two fields which describe the starting points for the conceptional contribution offer promising potential for the future production and planning process. At first it can be stated that the DF is an established umbrella in industry. However, many enterprises are not capable to reap the full potential of the DF. Major obstacles are the efforts for creating digital models, updating models due to adjustments of real-world systems and employing digital models for operational planning like production planning and control. Hence, there is a clear gap between real-world production systems and their digital counterparts, which should be filled by synchronizing both worlds in reasonable – or even real – time. A further observation provides the second starting point: Latest end-user electronics made for everyday life provide powerful computing and visualization power as well as intuitive design at reasonable cost. Hence, virtual technologies (i.e. Augmented- and Virtual Reality) are not restricted to a small group of specialists anymore. The consequent question is how such rapid developments fit or can be fitted into the harsh industrial context. We propose that shop floor employees use virtual technologies to interact between synchronized worlds and software agents offer aggregated information to users. Utilizing software agents leads ultimately to semi-automatic planning processes where agents run simulations autonomously and propose planning scenarios.

1. INTRODUCTION

Nowadays companies of the producing sector face an increasingly complex market situation. Especially companies from Asia and South America rush forward on the global market, becoming vast competitors for German companies and thus challenge Germany's position on the global market [1]. In addition companies are similarly affected by challenges, such as increasing product customization, gradually increasing flexibility requirements and cost pressure as well as a constantly declining predictability of the industrial and economic environment. As a consequence, traditional supply chains often do not lead to success and the number of short cycle adjustments in production planning and control increases, whereas the process complexity increases. Reasons for the ongoing transformation can be found in the historical growth of the IT landscape as well as the alliance with external business partners within the supply chain [1, 2]. Consequently, employees' tasks are strongly influenced by such turbulences. Shorter reaction times, a steadily growing system complexity and an increased heterogeneous information overload confront employees with complex challenges. As a result, the working environment and tasks of employees will change [3].

On the other hand there is the rapid progress in the field of automation, networking, and visualization. Developments in the field of embedded systems and virtual techniques (e.g. virtual- and augmented reality) offer enormous potential to counteract the outlined challenges adequately in the future. German Federal Government outlined a future-oriented project, called "Industry 4.0", which is supposed to initiate the fourth industrial revolution. Its vision is a consistent combination of the physical and digital world, in which facilities machines and workpieces continuously exchange information via the "Internet of Things". Links will be established across process levels of companies as well as within value-added networks [3]. As a result, the flexibility of companies, the workload of production plants, and the efficiency should be increased and error rates within the production should be reduced.

[*] Corresponding author: Tel.: +49-234-29890; Fax: +49-234-09890; E-mail: morlock@lps.rub.de

The given article will examine the issue of synchronous production and outline the challenges associated with the future vision of "Industry 4.0". In this context, the term “synchronous production” differs from the classical definition as a system status, in which required products will be available at the required point in time and in the appropriate quantity, while the amount of employees and machines being in use, as well as the throughput time, are at a low level [3]. In the given article the term “synchronous production” refers to the validity and permanent alignment of real world production systems with their digital counterparts, ideally in real time. Based on this, basic approaches for solutions and ideas with particular focus on production planning will be presented.

2. Basics on Synchronous Production

In order to elaborate the challenges for a synchronous production in section 3, a brief overview of the basics principles of production planning (2.1) and virtual techniques (2.2) is given in this section.

2.1. Basics on Production Planning and Control

A major task of manufacturing companies is the value creation process, in which input factors, that are acquired in the procurement market, are transformed into value-added output factors, that are demanded by the market [4]. Especially the processing of orders is of particular interest for the value creation process [5]. The production planning and control (PPC) plays an important role, being responsible for the planning and organization [6]. Order processing includes the tasks of the quotation processing right up to the distribution of finished products. On the one hand the challenge rests in the coordination of resources as well as processes within the factory and on the other hand it rests in the generation of value, for which the customer is willing to pay. However the main object is always to optimize the entire production system [6].

Thereby the production planning and control is almost completely supported by IT systems [7]. Since companies use variable IT systems within production, they also face the challenge of connectivity between the different systems. The integration of IT systems in production is shown in the automation pyramid. The levels of the automation pyramid depend on the time horizon and the level of detail. The Enterprise Resource Planning (ERP) system is located at the top level, which include modules of production planning and -control. These systems have a longtime horizon and a small level of detail. In the mid-level, Manufacturing Execution Systems (MES) are located which execute the production management. The process level is the lowest level of the automation pyramid and covers sensors and actuators [8].

In order to construct value creation processes efficiently, production systems must be optimized in terms of costs, time and quality (target systems of the production). In this context, the Digital Factory (DF) offers a variety of concepts and tools. Simulation techniques are a key instrument within the factory planning process and are used for analysis, design, functional testing and optimization of factory-, production-, and material-flow systems [9]. The term simulation is understood as a process, in which an existing or non-existing real system is represented in a model that reflects the reality with defined deviations and in which the system behavior can be examined. Finally, conclusions can be drawn from these examinations for the real system [10]. Simulation studies are carried out in a complex and long sequence (see VDI 3633) and therefore often have the character of a project. Thereby a model is created from the real system by abstraction and modeling, which is approximated in several iterative loops by parameter variation until it reflects the reality with sufficient precision. Conclusions obtained from the simulation can finally be transferred into the real (production-)system in order to modify the corresponding sequences [10].

The essential advantage of simulation lies in the possibility of testing the effects of system modifications quickly while those modifications do not affect real systems and associated processes, because of the complete decoupling of the system [10]. Thus, possible problems can be corrected early, planning reliability can be increased and investment decisions can be estimated more precisely [9].

Nonetheless, there are approaches with a direct connection between the digital model and the real factory, for example via the established standard interface OPC. Those models, which are used for example in the context of virtual commissioning, contain both virtual and real components (VDI 4499, sheet 2). Especially latest developments in computing power challenge the classical automation pyramid proposing a Diabolo structure linking the shop floor by means of an information model with Apps form the DF [11].

2.2. Basics on Virtual Technology

The previous section on PPC highlighted the importance of IT-systems like ERP and MES for transaction-oriented planning and control. Simulation systems (e. g. discrete even simulation) were introduced furthermore due to their capabilities to explore system behavior without harming or having the physical system. All mentioned systems provide graphical und numerical user interfaces (visualization) and user interaction by means of established technologies and practices like monitor, key board and mouse. In order to challenge the current practices we focus this section of the paper on the basic principles and technological advancements for visualization and interaction summarized as virtual technologies. The basic tasks users seek in visualization can be conceptualized as follows [12]:

- Achieve an *overview* for all available information and objects
- Allow users to scrutinize information or objects with a *zoom*
- Help users to focus on particular information or objects and *filter* the unnecessary
- Reverse to filtering is the provision of *details on demand*
- Connections or *relations* between objects should be accessible
- Support user retention by keeping a *history* of tasks
- Enable the *extraction* of information and objects

Schenk et al. [13] emphasized the use of augmented reality (AR) as one particular instance of virtual technologies to improve planning and operation of real factories. As stated in Azuma's influential work, "AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world." [14]. The following table summarizes the most important conceptual aspects of AR. The overall structure (i.e. the main AR-topics) of the table is derived from [15].

Main AR-topic	**Components**	**Explanation/Example**
Sensing / tracking [16]	Sensor-based	Utilization of sensors (e.g. ultra sonic) or sensor networks to determine the user location
	Vision-based	Feature-based: recognition of images (e.g. markers) or natural features like points, lines or textures
		Model-based: Utilization of e.g. CAD models to link features with the model
	Hybrid	Combination of sensors (e.g. inertia) with vision-based tracking
User interaction [16], [17]	Interactivity	Passive: Users can only see the predefined information or object
		Interactive, non-editable: Despite some opportunities for interaction like zoom and filtering, no content of an object or information can be changed
		Interactive, editable: Content of objects or information can be modified
		Interactive, contextual editable: User can manipulate e.g. the spatial context of an object or information
	Tangibility	Gesture: Manipulation of real objects is tracked or specific gestures are utilized
		Voice: Verbal commands are used for interaction
	Collaboration	Single user AR
		Multi user AR
Information Representation [15]	Temporality	Continuous: Virtual objects or information are shown all the time
		Discrete: Particular events (e.g. a specific user location) triggers the appearance of a virtual object or information
	Dimensionality	2D information or objects like text
		3D objects, e.g. arrows or virtual machine models
	Viewpoint	Egocentric: The display takes the user's perspective

	reference (handheld or head-mounted)	Egomotion: The display takes the user direction without the full perspective (e.g. a user directed map instead of a north-directed map in car navigation)
		Exocentric: the display shows a different and independent perspective
	Mounting and registration	Mounting refers to where the information or object is attached to (human, environment, global coordinate system, multiply mountings). Registration is the particular spot for mounting in the real world and links to tracking accuracy.
	Type of reference	Direct overlays and references: Physical and virtual object or information are coherently in the field of view
		Indirect overlays and references: Virtual object or information is shown despite the invisibility of a concealed physical object (e.g. virtual x-rays to see through walls)
		Pure references: Virtual object directs to a location that is not in the field of view (e.g. virtual arrows on the road for car navigation)

Applications of AR in industry [18] have been reported for product development, robot control and assembly (e.g. [19]) as well as facility layout planning [20] and maintenance (e.g. [21]). However, there is no application of AR in PPC reported yet.

One of the most important drivers for future AR applications could lie furthermore in latest developments of consumer electronics. We all witnessed the massive diffusion of smart phones, tablets or wearable computing (e.g. glasses and watches) augmenting our everyday reality outside the factory already. These consumer electronics offer interesting and rapidly increasing functionality at very reasonable cost (cf. [22]) and fit moreover to the current trend of bringing own devices (BYOD) to work [23]. Hence, there could be potential employing consumer electronics in the industrial context while paying attention to the contextual requirements.

3. Challenges for the Synchronous Production

Challenges of synchronous production appear manifold and should not be understood as solely technical concern. Recent publications (e.g. [24]) highlight the applicability of the socio-technical system view in the 21st century. Building upon Strohm & Ulich [25] and their socio-technical approach, we clustered the challenges of synchronous production around the major system elements work task, people, technology and organization. We will discuss selected challenges derived from the socio-technical view in turn. Due to the conceptual nature of the paper, we will limit ourself to rather generic challenges and postpone details to later contributions.

The overall goal of synchronized production is the support of people who are responsible for production planning and control. Hence, their work tasks are the driver of technology development. Previous discussions highlighted already that PPC-tasks are increasingly turbulent due to flexibility demands imposed on production. One major challenge is therefore the need to adjust plans quickly while ensuring plan feasibility and the fulfilment of the key performance indicators (e.g. delivery time). It is consequently necessary to ensure the accuracy of production plans and implement a reasoning, which is strictly related to the real conditions on the shop floor. Hence, a typical gap between virtual models or data supposed to represent the real production system and the actual conditions on the shop floor must be closed ideally with real-time accuracy. This might induce even organizational implications questioning the current processes of industrial enterprises, where planning assumptions and real conditions mismatch.

The view on the human aspect of the system yields on the one hand well-known challenges of IT acceptance (see [26]) and the usage of decision support systems [27] like performance expectancy (e.g. improved productivity due to system usage) or facilitating conditions (e.g. knowledge to use the new system). On the other hand, there is a new challenge or opportunity when people employ at least partly the same technology they use at home. This potential must be counter-balanced with an estimation of where and how consumer electronics can support PPC depending e.g. on:

- Physical conditions of the work environment (noise, etc.)
- Necessary links to information systems and their requirements

- Data safety and security

A major technical challenge is the integration of necessary information systems (ERP and MES), planning systems (simulation) and devices without “hard wiring” every component individually rather than following e.g. a service oriented architecture, which allows also future components to be integrated with low efforts.

4. CONCEPT FOR THE SYNCHRONOUS PRODUCTION

Today the complexity in production has increased enormously, so that it is hardly possible to realize a synchronous production on the physical level (machines, sensors, employees, etc.). For this reason there is a need for support by assistance systems, which operate on the cyber level, exploiting the potential of this level. These so-called cyber-physical systems (CPS), which are characterized by an interconnection between real and virtual objects and processes through information networks [28], will be a key element of the future-oriented project “Industry 4.0” of the German Federal Government [29]. The continuous transparency in real time will play an essential role for improved decision making [30].

Fig. 1 shows an approach for a synchronous production with CPS. Given the defined challenges, the implementation of innovative hardware components, as part of an assistance system, in the physical level, which can completely exploit the advantages of the digital world, is the logical implication. These include AR technologies of the consumer sector, such as Google Glasses, Galaxy Gear, Kinect, tablets etc. These End devices must be classified by morphology and typology to cluster them according to their adaptability for individual visualization and manipulation tasks.

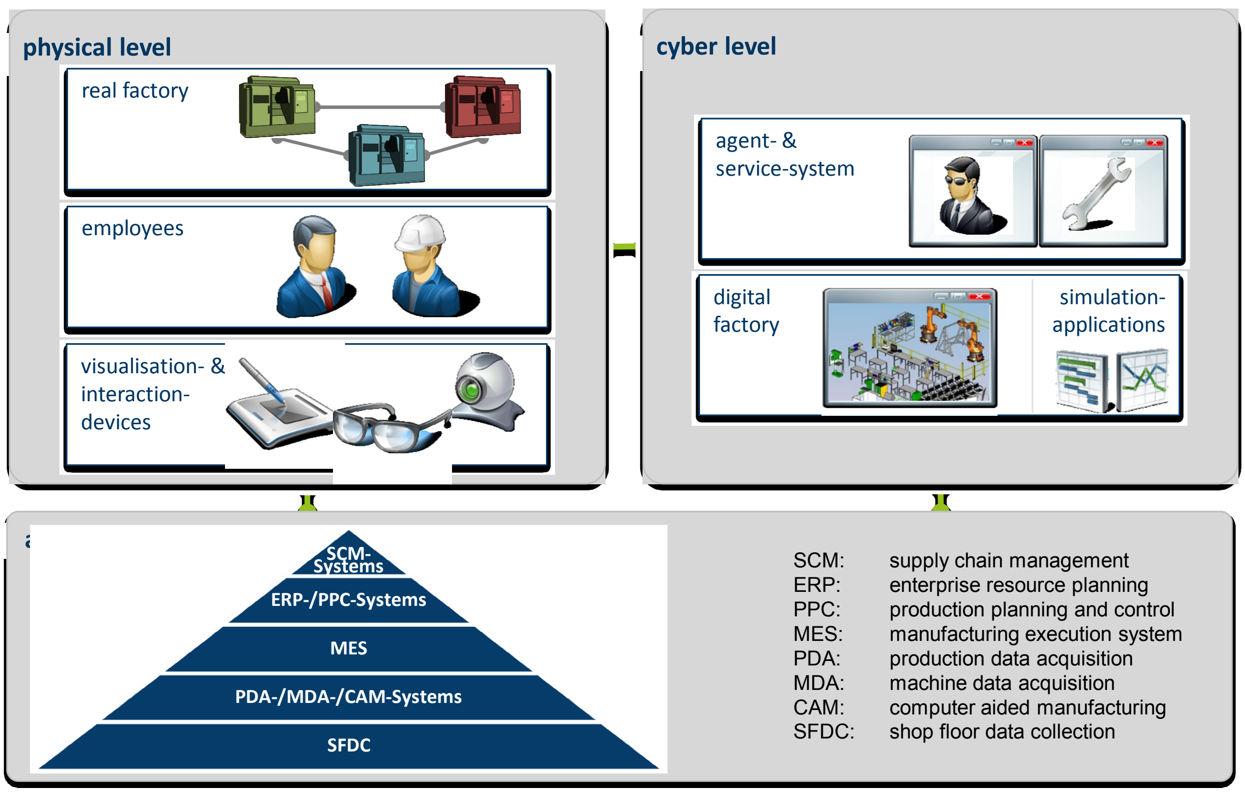

Fig. 1. approach of a synchronous production with CPS.

In order to define respective usability requirements, it is necessary to identify and analyze industrial reference processes with the subsequent development of role- and context specific use-cases. This procedure has to comprehend the areas of the socio-technical approach, assuring a holistic treatment. The findings will present the industrial suitability, usability and thus a method for the evaluation and integration of virtual technologies (EIT method) for factory planning and operation.

Also a simultaneous expansion of the cyber level with autonomous assistance systems is necessary in order to exploit the advantages of the DF in the best possible way. For example, faster production start-ups using an optimized production planning can lead to accelerated market introduction of new products [31]. Similarly, the activity distribution of a production planners, for example in the automotive production, which consists at 60 % of gathering and adjusting information, at 20 % of presentation and documentation and only at 20 % of planning, can be influenced positively by reducing the percentage of information gathering [32].

To face these outlined challenges, agent- and service-systems are promising systems, providing the opportunity to make the static systems of the automation technology more flexible by using decentralized networks with autonomously cooperating elements [33]. Due to the disintegration of the hierarchical automation pyramide as described in [28] a pure interconcection of isolated applications is not sufficient. A holistic approach is required for a cps-based automation, in order to assure an optimal human-machine-interaction. To support employees of the production planning and control, assistance systems must be able to access simulation programs and other services of the DF autonomously. Current data (live-data) must be implemented in the digital models representing real systems. By this, a simultaneous coexistent DF can be created. With support of simulation programs, such as Siemens Tecnomatix Plant Simulation, agents can access this DF and create optimization studies based on current data. Besides the development and programming of the function of those agent- and service-systems, the integration into existing system architectures plays an important role as well. In this case, the challenge consists of designing an open system which is able to integrate itself and to which new systems can be connected easily. The aim is a cross-functional data transfer to the automation level. In this case, OPC UA represents a promising solution to transfer machine data (process data, measured data, parameters, etc.) and to make it semantically readable [34]. Optimization suggestions are made available for the employees, demand-oriented and in suitable granularity, by corresponding services and new devices, thus enabling employees to make decisions for the production and substantiate these by using the CPS generated data.

5. Conclusion

The given article reveals a large amount of different approaches affecting the technical realization of a “Semi-Autonomous Production Planning and Decision Support Based on Virtual Technology”. Those however represent largely independent development paths. On the one hand there are classical systems and approaches like ERP or MES as well as the DF with its numerous methods and tools. On the other hand innovative virtual technologies offer enormous potentials to integrate digital elements directly and effectively into the real world and real factory operation. Therefore an integrative procedure is necessary in order to unify these parallel paths to generate new and efficient semi-automatic planning processes.

In summary the article has identified the following fields to be investigated in detail:

- Implementation of digital factories with real-time capability
- Necessity of an IT-integration for a collaborative crosslinking of existing isolated IT-systems in the field of production planning and control
- Utilization of an agent-based software solution for planning support in production planning and control
- Experimental investigation of mobile and simulation-based performance support systems
- Usage of existing mobile AR-devices in the industrial environment, taking into account consumer technologies

For that reason, future activities in the field of “Industry 4.0” have to aim at a consequent integration of the described fields of activities. By this, powerful concepts can be generated which unify the virtual and the real world in order to do a decisive step towards the realization of a synchronous production.

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