Towards the Smart Factory: Process Optimization in Virtual Commissioning

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Abstract. Since the early 1990s, virtual models have been used in production planning to digitally support production lines before beginning physical construction. These digital models, commonly referred to as "digital twins", are currently primarily used for virtual commissioning. Despite being first used decades ago, digital twins are still not established in production planning on a global scale. The benefits of developing and testing a planned system in a virtual model are often not fully capitalized. While this can be partially explained by the technological challenges of designing accurate virtual models, we argue that the current processes for production planning are another important factor that hinder the widespread use of digital twins. In this paper, we summarize and analyze each step and the involved participants in a typical production planning workflow. Based on this analysis, we discuss how current practices conflict with the goal of incorporating virtual models into the established work environment. Then, we derive concrete recommendations of how a production process can be adjusted to allow easier digital twinning, showing how comparatively few changes could make virtual models significantly easier to apply.

Keywords: Digital Twin · Virtual Commissioning · Information Management · Dynamic Production · Automotive Production

1 Introduction

Ever changing political requirements and social trends accelerate the ongoing transformation process in the automotive industry [1]. EU climate goals, the COVID-19 pandemic, and the ongoing chip shortage keep adding pressure to the companies. A growing product variety over the last years further increased process complexity [2]. One potential approach for handling this complexity is the concept of digitalization. Virtual commissioning (VC), in particular, allows for a reliable virtual validation of production systems without the physical machine having to be built. Despite this idea being almost 30 years old, a widespread establishment of this technology still remains to be seen. Even recent papers

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such as [3] from 2021 still investigate how to use and integrate virtual commissioning, demonstrating the lack of practical experience in this field. Considering the significant potential benefits of digitalization for production systems, the question arises why tools such as virtual commissioning are not yet ubiquitous in the industry. While digitalization is not a new topic, there is still a lack of comprehensive work to investigate why digitalization sometimes fails to be established in the first place. This paper addresses this pressing issue and proposes a practical workflow for resolving these challenges. We investigate what the reasons for the hesitant adaptation of digitalization might be. We focus on the general process workflow in production planning and analyze it with regards to its potential for digitalization. We make the following main contributions:

1. Identifying the obstacles for digital technologies such as virtual commissioning in the processes typical to the industry
2. Conceptualizing mitigating measures that allow for removing these obstacles
3. Showing how these solutions can be applied in practice

The rest of this paper is structured as follows. In Sect. 2, we summarize the state of the art. In Sect. 3, we analyze a typical production process. In Sect. 4, we discuss how to optimize such a process. Section 5 concludes this work and gives an outlook on the next steps.

2 State of the Art

To understand the obstacles that prevent wide-spread use of digitalization in the industry, the current state of production plant planning is summarized first.

2.1 Conventional Planning

Traditionally, the planning process of production systems can be categorized into four distinct phases, as described by Weber [4] in 1992: draft, development&planning, construction, commissioning, and production.

After commissioning, the machine changes owners, along with all its responsibilities. While the subsequent production phase also faces challenges, this work focuses on the earlier stages, where digital tools are already being applied and a mitigation of errors can be observed [5]. Modern, automated production lines are highly complex mechatronic systems. Achieving an interdisciplinary and parallel collaboration of the disciplines of mechanics, electronics, and information technology requires novel approaches. To ensure smooth operation, data consistency appears to be a fundamental requirement to allow for the necessary exchange between the fields. In general, the development is attributed the most significant role, since its results will determine the future productivity and efficiency of the machine. An example of a modern way of development collaboration is presented in VDI 2206 [6].

Starting with the mechanical design, the electronics can only be specified once the 3D concepts are available and signed off on by the client. The electronic planning needs to be completed to allow for the software development to begin. Works such as [7] emphasize that software plays a major part in modern plants.

2.2 Digital Factory and Twin

Terms such as digital factory and digital twin have been around for a long time. In theory, they should enable production lines to be planned more efficiently and in a more flexible way. The core principle is to use tools such as simulation to evaluate concepts without the risk of costly changes late in the project or even hardware damages on the construction site [8].

The idea of a digital factory encompasses a digitalization of an entire factory. In this work, we restrict our focus on the concept of a digital twin. While there are different definitions, this paper will use this common understanding: A digital twin describes a digital, i.e., simulated, entity running in parallel to the real machine [9]. Only recently, more research has been dedicated to the question of how to methodically introduce digital technologies to existing structures [2]. This can be seen as yet another indication that, despite their potential, digital twins are not yet established everywhere, and careful decision making is required to turn the use cases into beneficial business cases. To support such decision making, the processes used in the industry need to be properly assessed and potentially changed to facilitate the introduction of digitalization. Barbieri et al. propose a high-level approach on how to get to a digital twin from virtual commissioning, but do not go into detail on how to properly introduce the foundation for digitalization [10]. Similarly, Leng et al. focus on digital twins and on how to use them for smart manufacturing systems [11]. The work in [12] provides a general overview of virtual commissioning with its benefits and pitfalls. So, while some work has been done on virtual commissioning and its practical implications such as the guideline in [12], work directly derived from production systems is still lacking. To address this, our paper focuses on the practical applicability of virtual commissioning. We derived all concepts proposed in this work and all results obtained from our analysis directly from the automotive production sector. The work by Liebrecht goes into more detail than the VDMA guideline in [2]. Similarly, we build on the VDMA guideline to investigate the claims from [12] hands-on in the automotive industry. We therefore perform an in-depth analysis to serve as a starting point for optimizing the processes used in this field.

3 Process Analysis

In this chapter, we analyze a typical process in production planning as a first step towards assessing why digitalization is not more commonly used. While addressing and improving technical aspects of the implementation is one factor, we focus on how the underlying processes can be changed instead. Problems such as computing performance, hardware cost, or data consistency are present in most technological fields, but are much harder to change than the processes established in production planning. Changes to these processes can be as straightforward as changing existing specification sheets. Next, we first discuss the main obstacles faced in a planning process. Then, we derive potential solutions that are straightforward to implement. This problem analysis along with its considerations all stem from automotive production planning. We gathered insights by interviewing experts in the field of planning and virtual commissioning.

3.1 Metrics

Before analyzing the processes to identify possible problems, it is crucial to establish metrics by which to measure these problems by. They are derived from expert interviews and hands-on experience by the authors. We summarize the proposed metrics in Table 1.

While cost efficiency might be the most important goal in any company, we argue the most important metric is time. It can be dangerous to try and optimize for money, if it diminishes the output quality. In that case late improvements are required, which are significantly more expensive than investing a comparatively small amount during the early stage of a project. So, rather than trying to save money, we argue that the most important aspect should be to try and be as efficient as possible. If done correctly, this will automatically reduce costs, while simultaneously improving the acceptance.

Table 1. Metrics for process analysis and solution identification

Metric	Description	Prio.
Time efficiency	processes, automation, standardization	1
Employee acceptance	specifications, trainings, workshops	2
Information flow	automation tools, exchange formats	3

This leads to the second important metric, the acceptance amongst employees. Without it, no technology can last. The human factor plays a significant role and must not be neglected, because ultimately any technology ends up being used by human employees and support tools have to be focused on them.

Finally, this paper proposes to consider the information flow along the processes. By putting emphasis on its quality, problems such as lacking synchronization and having to do work multiple times by not realizing available synergies can be identified and avoided.

3.2 Problem Analysis

In this section, we identify four key problems that current production processes face regarding the implementation of digital twins and virtual commissioning. The first problem is a lack of synchronization across the planning pipeline. A typical planning process can be divided into several main phases: 3D construction, electrical planning, software programming, and the actual physical construction site. These phases are typically not sufficiently synchronized or connected. Following a sequential pattern, information can get lost and usually only flows in one direction: forward. Changes in a later phase are thus often not properly fed back to the initial phases. With such a restricted flow of information, digital twins are inherently restricted as well, which in turn prevents them from becoming established in the industry.

A second issue is the fact that the processes used in the industry have been established over decades. Changing such a fixed process is inherently challenging since these processes were not designed to be flexible or dynamic. By using digital twins and virtual commissioning, the CAD data is required much earlier. This requirement disrupts the conventional workflow. The programming of the software required for a process has to start significantly earlier.

Thirdly, the human factor is an important issue. Digital tools can only fulfill their potential if the people involved in the production have sufficient knowledge in the field. Considering the current lack of digitalization in a typical production planning, the expertise in corresponding tools subsequently is low.

The last problem, which is easily overlooked when focusing only on the technical side of digitalization, is the increased demands on the management of production plants. The managerial support that is required for any change to take lasting effect is significant.

3.3 Problem Solutions

For remedying the problems outlined in the previous section, a range of solutions can be considered. Building upon the work of [13], we categorize potential solutions into three main categories: process-related (PR), human-related (HR), and technical-related (HR), as described in Table 2. The right column illustrates the priority, i.e., the urgency, with which a solution should be implemented. To illustrate the problems described in the previous section and the identified solution categories, we take a look at a conventional planning process in Figure 1. It is shown, what exemplary problems can hinder the effective use of digital tools such as virtual commissioning. We depicted the identified problems along with applicable solution categories in the same figure.

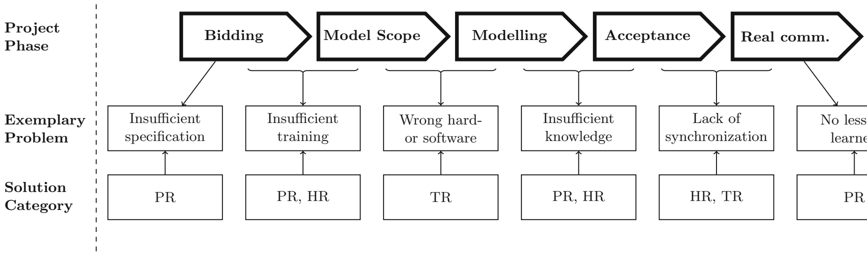

Fig. 1. VC process with identified problems and possible solutions from Table 2

Table 2. Solution categories, prioritized by urgency for efficient digitalization.

Category	Solution	Prio.
Process-related [PR]	Identification of starting points for digitalization	1
	Specification documents adapted to the growing processes	1
	Expert project managers for flexibility beyond these specs	2
	Training processes to ensure being ready for VC	2
	Lessons learned to adapt quickly and sustainably	3
Human-related [HR]	Communicating changes to allow them to be embraced	1
	Systematic training of required experts with specific roles	1
	Regular trainings and workshops to keep up to date	2
	Transparency of processes and responsibilities throughout	3
	Human in center of tailored digitized processes	3
Technical-related [TR]	Well-suited hardware and software	1
	Lab environment for uninterrupted testing	1
	Data consistency throughout for efficiency and automation	2
	Automation of generation and testing	2
	Tangible visualization to make digital tools approachable	3

While not an exhaustive list, these three categories cover the most important fields to incorporate digital technologies. More importantly, the given priority shows a clear roadmap to highlight where the focus should be put at what stage of the digitalization process. We argue that optimizing only one category will not yield sustainable solutions in the long run. Instead, a coordinated procedure that considers solutions prioritized in the right order from all three categories is needed.

4 Process Optimization

In this section, we present how such a coordinated procedure could look like in a concrete project scenario. We propose that the typical process can be optimized in the following ways.

4.1 Process Integration

First, digitalization is more than just a tool or a plug-and-play solution. It is a process that needs to be integrated thoroughly into existing structures. In order to accomplish this, qualified team leaders have to supervise this digital transformation. Managerial support has to be ensured to allow for a smooth transition. Following the priorities from Table 2, it is crucial to approach this step by step. While all-encompassing solutions might appear tempting, they rarely work. Incremental improvements, on the other hand, can take effect immediately and serve as building blocks for the next phases.

4.2 Educating and Training Employees

After integrating digitalization into the process, all involved departments have to be informed and trained to fully implement the techniques and obtain their benefits. This requires creating suitable training methodologies, training teaching personnel, and ensuring that the employees are willing and capable to adopt the new methods.

The focus to help the project and its team members should not be lost. Correct training is essential to assign the correct people to a given project. The documentation for this can be as simple as an excel sheet, containing requirements such as *PLC planning and programming experience* or *knowledge in the employed simulation tools*. On a less technical level, topics such as an understanding of the company's processes and the economical aspect are required. This will allow the assigned experts to competently decide when digitalization can be useful and when it can be too costly.

Not all trainings can be carried out in the same way. A suitable method for ensuring effectiveness has to be devised, but structuring and tracking trainings and required competencies is an important first step.

4.3 Technical Changes

Besides the comparatively soft process-related and human-related factors, it is also necessary to find the right technical tools. There are many different software tools available, making a careful assessment of their strengths and weaknesses necessary. A benchmark has to be devised with a fitting reference machine and suitable criteria. The results have to be representative, so they can be translated and extrapolated to upcoming projects. Ensuring that the basic technical framework runs smoothly can then lead to increased and successful automation.

4.4 Use Cases

To make the proposed solutions tangible and how they can be implemented, this section presents two concrete use cases from production planning. One of the most straightforward approaches for implementing process related solutions is to develop suitable tracking documents. This can range from simple tables to complexly linked and automated documents that provide an overview of the entire project at any given point. As a first step, it is sufficient to create and maintain a tracking document in MS Word or Excel to track subprocesses and the respective progress. To ensure acceptance, it is important to start such processes small and grow the gradually over time.

Another approach is to implement training processes to ensure the necessary knowhow is present in every project. For this to succeed, expert knowledge is essential in order to break the field down into teachable parts. Hiring experts to create and give occasional training seminars does not add significant cost, bust allows to gradually accustom employees to the new workflows.

Hardware and licenses are easy to buy, but setting up a business plan for this endeavor should be given sufficient attention as well.

5 Conclusion and Outlook

This paper investigated, why tools such as virtual commissioning are still lagging behind other digital technologies. We identified the main problems as lack of synchronization, lack of flexibility in current processes, the human factor, and challenges for management. We categorized potential solutions into three groups and outline how a process can be optimized to facilitate digitalization, namely by a complete process integration, training for employees, and by a thorough assessment of potential technical tools.

While we believe these measures are a first step towards establishing digitalization, several limitations remain. Creating expert knowledge and changing team structures requires significant time and resources. Even with such a commitment, the right people have to be found, which is a challenge with a general global shortage of technical personnel. A technical benchmark requires extensive documentation and continuous updates to remain relevant. Finally, the determined use cases have to match actual business cases. While digital twins can reduce costs, creating an internal team for this purpose might not always be the more efficient that relying on external resources.

With this work laying the foundation, there still remains work to be done. The next step should be to continue gathering expert information by launching a wide range of interviews to get a broad view of how industry experts see the processes, what problems they identify and how they judge the proposed solutions. Additionally, the proposed solutions have to be implemented in practice to obtain real-life feedback, so that the proposed concept can be further improved iteratively. In summary, this work identified the main problems and proposed first steps towards solving them, serving as a starting point towards fully establishing the smart digital factory.

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