LAB University of Applied Sciences

Virtual Commissioning in Industrial Automation

LAB University of Applied Sciences
Bachelor of Engineering, Mechanical Engineering and Production Technology
2023
Borislav Hristov

Abstract

Author(s) Borislav Hristov	Publication type Thesis, UAS	Completion year 2023
	Number of pages 20	
Title of the thesis **Virtual Commissioning in Industrial Engineering**		
Degree, Field of Study Bachelor of Engineering (UAS), Mechanical Engineering and Production Technology		
Organisation of the client LAB University of Applied Sciences		

Abstract

Virtual commissioning is a relatively new approach in the field of industrial automation, which uses simulation and virtual reality technologies to test and optimize control systems before they are deployed in real-world industrial environments. This approach has the potential to improve the quality and reliability of control systems while reducing the time and costs associated with traditional physical commissioning. In this thesis, the author explores the concept of virtual commissioning in industrial automation, including its benefits and challenges, and the current state of the technology. The author also reviews the existing literature on virtual commissioning, including academic papers and industry reports. Finally, a discussion about the future of virtual commissioning in industrial automation and the potential for further research in this area.

Keywords

Automation, industrial, virtual, commissioning, software

Contents

1 Introduction 1
1.1 Introduction to virtual commissioning 1
1.2 Background and context 1
1.3 Objectives and research questions 2
1.4 Scope and delimitations 2
2 Literature review 4
2.1 Main research topics 4
2.2 Definition and principles of virtual commissioning 5
2.3 Benefits and implementation of virtual commissioning 5
2.4 Challenges and limitations of virtual commissioning 8
2.5 Best practices and tools for virtual commissioning 10
3 Methodology 12
3.1 Research design and approach 12
3.2 Data Collection and Analysis 12
3.3 Limitations and ethical considerations 13
4 Results and Analysis 14
4.1 Overview of the collected data 14
4.2 Analysis of the benefits and challenges of virtual commissioning 14
4.3 Comparison of virtual commissioning with traditional commissioning 15
5 Conclusion 17
5.1 Summary of the main findings 17
5.2 Recommendations for future research 18
6 Sources 20

1 Introduction

1.1 Introduction to virtual commissioning

The use of automation in the industrial sector has grown rapidly in recent years, providing significant benefits in terms of efficiency, accuracy, and cost-effectiveness. However, the commissioning of these automation systems can be a complex and time-consuming process, requiring significant resources and expertise. This is where virtual commissioning comes in, offering a solution to these challenges by allowing the commissioning process to be performed in a virtual environment, before being implemented in the actual production.

Virtual commissioning in Industrial Automation refers to the simulation and testing of control systems, including programmable logic controllers (PLCs), human-machine interfaces (HMIs), and robots, in a virtual environment before implementation in the actual production process. This innovative approach to commissioning has proven to be a cost-effective and efficient way to improve the quality and reliability of automation systems, reduce downtime, and minimize commissioning costs.

1.2 Background and context

Industrial automation has become increasingly important in modern manufacturing, as it enables higher levels of efficiency, productivity, and quality in production processes. One of the critical phases in industrial automation is commissioning, which involves testing and verifying the functionality and performance of the automated systems before they are put into operation. Traditionally, commissioning has been done by physically connecting the devices, sensors, and controllers and testing them in the real environment. However, this approach is time-consuming, costly, and prone to errors and safety risks.

To overcome these limitations, virtual commissioning has emerged as a promising alternative that allows engineers and technicians to simulate and validate the control logic and communication protocols of the automated systems in a virtual environment before they are deployed to the real plant. Virtual commissioning can reduce the time and costs associated with traditional commissioning, enhance the accuracy and quality of the testing, and improve the safety of the personnel and equipment involved.

However, despite the potential benefits of virtual commissioning, there are also challenges and limitations that need to be addressed. These include the complexity and diversity of the industrial automation systems, the lack of standardization and interoperability of the virtual commissioning tools and models, the need for skilled personnel and resources, and the requirement for continuous updates and maintenance of the virtual models.

1.3 Objectives and research questions

The main objective of this thesis is to investigate the concept of virtual commissioning in industrial automation and evaluate its benefits, challenges, and limitations. To achieve this objective, the following research questions will be addressed:

- What is virtual commissioning and how does it work?
  This question aims to provide a conceptual framework for virtual commissioning in industrial automation, including its definition, principles, and processes. The answer will be based on a thorough review of the relevant literature and standards.

- What are the benefits and challenges of virtual commissioning compared to traditional commissioning?
  The question aims to compare virtual commissioning with traditional commissioning methods in terms of time, cost, quality, safety, and other relevant factors. The answer will be based on a systematic analysis of case studies and expert opinions.

- What are the best practices and tools for virtual commissioning, and how can they be applied in industrial automation?
  This question aims to identify and evaluate the existing tools and methodologies for virtual commissioning, including simulation software, communication protocols, and testing frameworks. The answer will be based on a comparative study of the available options and their suitability for different types of industrial automation systems.

The answers to these research questions will enable a comprehensive understanding of the concept of virtual commissioning in industrial automation and provide insights into its benefits, challenges, and best practices. These insights will be useful for industrial automation practitioners and researchers who are interested in adopting or advancing virtual commissioning in their projects.

1.4 Scope and delimitations

The scope of the thesis is to investigate the concepts of virtual commissioning in industrial automation and evaluate its benefits, challenges, and limitations. The thesis will provide a comprehensive definition of virtual commissioning, its underlying principles, and its application in industrial automation. The aim is to establish a clear understanding of the concept and its potential benefits.

The thesis will compare and contrast virtual commissioning with traditional commissioning methods, including their advantages and disadvantages. The aim is to provide a thorough analysis of the benefits and limitations of virtual commissioning.

The final scope will be identifying and evaluating the best practices and tools for virtual commissioning, including simulation software, communication protocols, and testing frameworks, providing practical recommendations for industrial automation practitioners and researchers.

The thesis's main delimitations will be in the technological approach. The study will focus on simulation-based virtual commissioning, focusing on understanding the benefits and limitations of the method. Another type of virtual commissioning is model-based virtual commissioning, where mathematical models are used to predict how a system would perform. This method will not be part of the scope of the research since its complexity would require dedicated research.

The thesis will focus on industrial automation systems, such as manufacturing plants, process industries, and robotics, and will not address other types of automation systems, such as building automation or home automation.

The research focus will be trends set by large multinational corporations; therefore, the focus on small and medium enterprises will be minimal. The limitation comes from the fact that the challenges and opportunities for virtual commissioning are based on different business contexts.

2 Literature review

2.1 Main research topics

Virtual commissioning is a relatively new concept that has gained significant academic attention in recent years. This section provides a comprehensive review of the existing literature on virtual commissioning in industrial automation, including definitions, benefits, challenges, and limitations. The literature review is organized as follows:

- Definition and principles of virtual commissioning
  This section provides an overview of the definition and underlying principles of virtual commissioning, as described in the existing literature. The aim is to establish a clear understanding of the concept and its application in industrial automation.

- Benefits and implementation of virtual commissioning
  This section reviews the existing literature on the benefits and implementation of virtual commissioning, including improved productivity, reduced costs, increased flexibility, and enhanced safety.

- Challenges and limitations of virtual commissioning
  This section reviews the existing literature on the challenges and limitations of virtual commissioning, including the complexity of simulation models, the need for accurate data, and the potential for simulation errors.

- Best practices and tools for virtual commissioning
  This section reviews the existing literature on the best practices and tools for virtual commissioning, including simulation software, communication protocols, and testing frameworks.

Overall, the literature review provides a comprehensive overview of the existing research on the topic. By synthesizing the existing literature, this section will inform the research questions and objectives of this thesis and provide a foundation for the empirical research to follow.

2.2 Definition and principles of virtual commissioning

Virtual Commissioning is defined as the early development and validation of programmable logic controller (PLC) code using a simulation model (Wünsch G., 2008). While virtual commissioning finds its application in different fields, this thesis will focus on virtual commissioning as a tool for optimization and validation in industrial automation.

Commissioning is a critical stage in the development process, but it is often implemented during the final stage. Although commissioning only takes up 25% of the total development time, it is the phase where most of the delays occur (Hoffmann et al. 2010). It is predicted that up to 70% of delays are a consequence of errors in the control software (Reinhart and Wünsch, 2007).

The aim of utilizing virtual commissioning is to enable the validation of machine code at an early stage, which significantly minimizes the possibility of deploying a program that contains errors (Beilby). The virtual model is useful for training and testing different scenarios in a safe and controlled environment.

Virtual commissioning could save up to 75% of the time required for commissioning (Zäh et al. 2006). For virtual commissioning to be effective, the virtual model must be an exact and precise representation of the actual system. Even though virtual models were commonly used in the aerospace and automotive industries, until recently they were not widely adopted in industrial automation due to the lack of integration with the PLC design methods (Beilby).

2.3 Benefits and implementation of virtual commissioning

To understand the benefits of virtual commissioning it is important to define why it should be used. Calles et al. describes the reasons why virtual commissioning should be implemented in five steps:

- Early simulation and validation of machine code by using different simulation approaches – Hardware-in-the-Loop, Software-in-the-Loop, and Model-in-the-Loop (HiL, SiL, MiL) without impacting production.
- Higher quality software and optimized controls architecture and programming.
- Faster change implementation while maintaining quality and reducing risks.
- Shortened overall commissioning time.
- Decrease manufacturing system lead time.

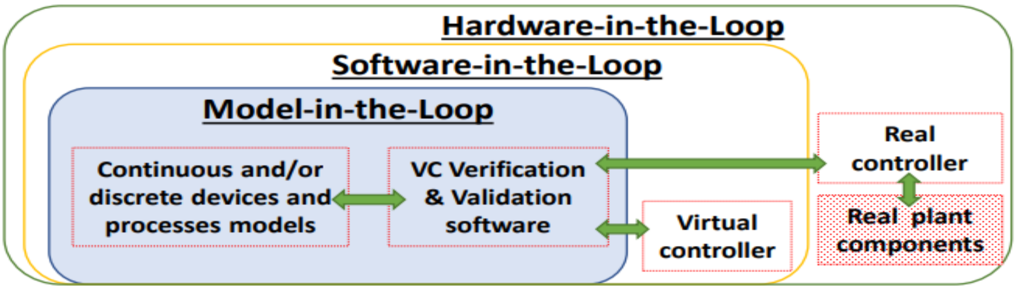

Figure 1. Virtual Commissioning Loops

Figure 1 shows that all virtual commissioning approaches are based on a virtual model linked to a PLC. When conducting virtual commissioning, a Hardware-in-the-Loop (HiL) simulation involves using an actual hardware controller, such as a PLC, which can later be integrated into the production system (Oppelt et al. 2015). A Software-in-the-Loop (SiL) simulation can be used, where an emulated PLC is deployed, eliminating the need for hardware (Lee and Park).

Additionally, a Reality-in-the-Loop simulation can be performed by combining an emulated PLC with the production system to test certain real components (Lee and Park). The virtual model can also be integrated with real machine components to test their future function, resulting in hybrid simulation (Lee and Park).

Figure 2 shows the difference between the engineering process with and without virtual commissioning. The first step in virtual commissioning is to create a model of the production system. It is advisable to begin the task during the engineering process to identify inconsistencies and errors in the construction early on (Auris et al. 2017).

Virtual commissioning can be performed simultaneously with the production and assembly process, which can help save valuable time during the commissioning phase by allowing for optimization loops during those processes (Brökelmann, 2014). Additionally, virtual commissioning allows for a safer commissioning process because any errors detected during the virtual commissioning can be resolved prior to the actual commissioning (Brökelmann, 2014).

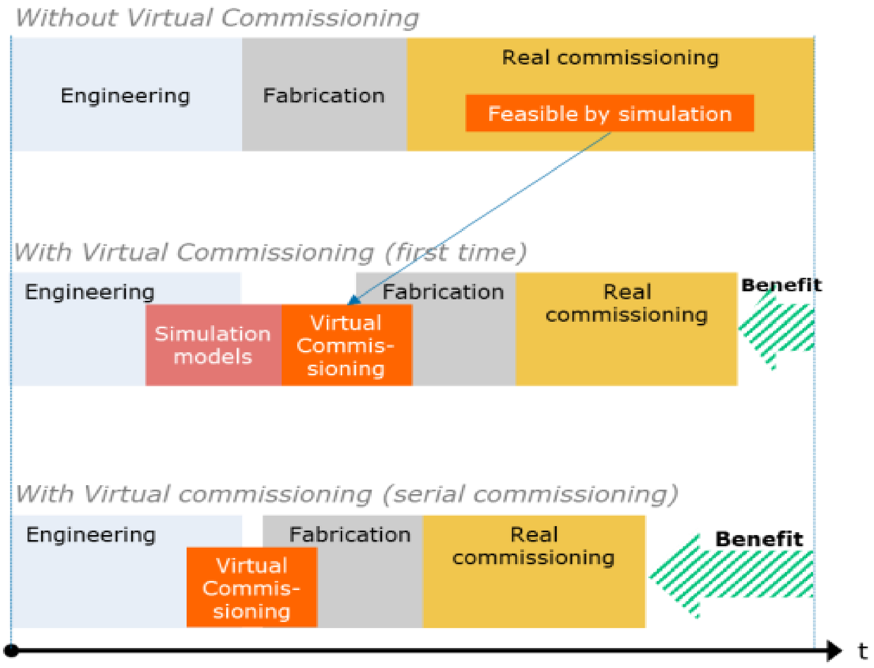

Figure 2. Comparison of Virtual Commissioning and traditional commissioning

A study done by Shahim and Møller provides the perspective of an industry expert regarding economic benefits of virtual commissioning:

> *No exact numbers but we are convinced it is a good investment. Shorter ramp up means less time spent on site and less time used on capital investment lock up, so we are having people testing at home instead of testing on site, which means that cost of the testing will be very low. Moreover, higher software quality with less bugs mean decreased manpower and saving money. (Shahim & Møller 2016)*

The implementation of virtual commissioning can provide a competitive advantage to companies by managing project lead times. This advantage can be seen in different ways such as faster product launch, shorter lead time quotations compared to competitors, and quicker realization of internal benefits. Additionally, companies can reduce their labor costs per project by delivering more projects with the same resources (Shahim and Møller).

Per Shahim and Møller's study, the main drivers for controlling or shortening lead time include:

- Increase predictability: reducing variability in lead time will allow consistently knowing and committing when something can be delivered. Delivering consistently will help to increase trust within the system. One of the very beneficial outcomes from increasing trust in the system is that it leads to a dramatic reduction in expending.

Once the system becomes predictable, the business may be able to make new offers to customers based on the high level of predictability.

- Faster feedback: reducing lead time duration results in faster feedback. Faster feedback can result in increased quality. There are a number of reasons for this. Less work is done based on work items that require rework. Shorter cycles result in better fit since the feedback can be gathered and applied frequently. Also, faster feedback means that the team can minimize the work required to meet the objectives.
- Flexibility and responsiveness: shorter lead times and trust based on predictability increases options for flexibility. You can delay some decisions until very late – deciding just before you pull into the system the details of a solution. Expediting now means putting an item into the queue as the next item. Also, you can make new promises to customers based on this increased level of flexibility and responsiveness.

Furthermore, Shahim and Møller identify that high degree of uncertainty is the root cause of why projects are often late or over budget. Original due dates are not met, changes to scope or timing, unavailable resources, or too much rework, are all issues that can be resolved with the implementation of virtual commissioning (Reinhard and Wünsch).

2.4 Challenges and limitations of virtual commissioning

A study done by A. Lidell et al., "The Current and Future Challenges for Virtual Commissioning" has conducted interviews with three interviewees that are directly involved in the industrial automation field. The interviewees are connected to the business or the academic world.

> *"The first interviewee is mainly connected to the business world, while still influenced by the academics through working life with the University of Skövde. According to this expert, the most common practice is not using Virtual Commissioning. Another highlighted obstacle for the development and use of Virtual Commissioning is related to the cultural and social aspects of implementing new technologies and work methods. Some other interesting thoughts raised by the interviewee are the paradox of using Virtual Commissioning efficiently and reducing the real commissioning time, and thus working more in the office can fool the customers to think that the assignment is easier than they are paying for."*

> *"In the second interview, where the interviewee is completely in the business world and focused on marketing. This expert views Virtual Commissioning as a standard*

procedure for at least two or three companies working with system integration. The interviewee was very clear with not being too interested in Virtual Commissioning anymore since he taught the process was adequate and wanted to focus on the rest of the lifecycle. As in other business areas, the interviewee suggested that there could be organisations to certify the Virtual Commissioning process of companies in order to harmonise approaches and verify the Virtual Commissioning process. Finally, a possibility from using Virtual Commissioning is improving the social sustainability of the workplace. By increasing the time spent in the office and for normal work hours while reducing the time needed for the real commissioning, the work conditions of the employees of system integrators are improved. Some are forced to quit due to the private life clashing with the work of real commissioning on site."

"The third and final interview, in which the interviewee is purely academic and therefore could not give very detailed or specific answers regarding Virtual Commissioning technology and methods. The interviewee notes that in some companies it is not the engineers who drive the use of Virtual Commissioning, and therefore the approaches and methods in those cases can often be ad hoc or improvised. Another interesting issue raised by this expert regards the role of higher education as the rate of the technological and digital evolution increases. In addition, the shift in competence demands from process knowledge to competences in technological and digital tools, which can create a competence gap in the labour market."

There has been a growing interest in the topic of Virtual commissioning, but there has been limited work done in terms of classification. Both the available literature and interviews indicate a need for standardization, not only in defining the terminology but also in designing Virtual commissioning and establishing data exchange and communication protocols. This lack of standardization presents challenges in creating a cohesive description of Virtual Commissioning. The analysis of various papers shows that the ISO 23247-1 standard could provide much needed clarity and definitions. It is difficult to predict the exact outcomes of the standard before its publication, but it should establish an accepted definitions and data exchange protocols for connectivity and automated data flow. These aspects and technologies will simplify and improve the use of Virtual Commissioning and promote the use of virtual tools and methods in general. (A. Lidell et al)

Managing software in the context of machinery development can be challenging as it is often not integrated with hardware and electronic definitions until late in the development process. Since machinery has long lifecycles, software updates need to be well-documented and managed throughout its lifetime. Furthermore, finding support for electronics and embedded software can be difficult. Testing the modified and extended code is crucial to ensure that it is free of errors. In Virtual Commissioning, software is a part of the configuration, which requires multidomain configuration management to include embedded software in the as-built configuration and track updates through the as-maintained configuration. Multiple upgrades and changes are common during a machine's life, including hardware and software upgrades, control system changes, and additional modules to support customer product mix changes. Having a comprehensive digital twin enables validation of these changes, saving significant amounts of machine downtime. (Siemens)

2.5 Best practices and tools for virtual commissioning

Virtual Commissioning involves the use of software tools that are linked to physical items (known as hardware in the loop of HiL) to simulate and validate various aspects of a product, such as fit, function, safety compliance, control, and performance. With the help of actual hardware and human operators, modern virtual commissioning tools can simulate most, if not all, validation testing that is required for the product. This approach enables quicker testing and the ability to perform tests that may be difficult or destructive to execute in the physical world, resulting in a better understanding of the product. Additionally, data obtained from physical products through IoT can be used to drive the virtual models, ensuring that real-world scenarios are utilized for verification and validation purposes. (Siemens)

Early uses of virtual commissioning were limited to assessing the physical fit and function of products. However, recent advancements have allowed for more extensive validation and verification (V&V) processes by combining hardware in the loop (HiL), software in the loop (SiL), and human in the loop (HITL). Human in the loop involves connecting hardware devices like PLCs and safety switches to the digital twin, which is a model that encompasses software, electronics, and mechanical design. This allows for simulation and testing of the complete machine's operational characteristics. HITL is another method used where humans interact with simulated software controls and hardware to ensure that the machine behaves as expected. (Siemens)

One of the primary benefits of implementing V&V in Virtual Commissioning is the ability to simulate the functional behaviour of the machine using software PLC and HMI inputs. The functional behaviour is represented by an intelligent 3D model that responds to various inputs initiated by the PLC code or user interaction with input devices such as a mouse. This model allows users to interact with the machine's components, such as opening and closing doors and engaging with the HMI and other user interfaces. The model responds to these inputs by changing the position of components and causing the to actuate. By sequencing these events and registering the responses to signal-generating components like limit switches, the simulation can predict what will happen during machine operation. This sequence of operations can be fed into a PLC code authoring tool, allowing the control system to know how to respond when the machine is operational. The code can then be validated by feeding it back into virtual PLC and HMI emulations. By starting up the machine with the emulation, any collisions or code changes can be resolved immediately, and almost all machine use cases can be executed much faster than with a physical machine, without any risk of damage. (Siemens)

In addition to V&V, Virtual Commissioning provides opportunities for early and remote training, which has become particularly valuable during the COVID-19 pandemic and the shift towards remote work. This means that operators and technicians can practice using software and control concepts in a virtual or hybrid virtual and real environment by operating a physical control to drive a virtual machine or using a virtual control to operate a physical machine. This flexibility allows for testing of ideas at an early stage, which can improve the quality of the product, and for training to be conducted before the machine is ready for production, thereby reducing the time needed for startup and increasing productivity. (Siemens)

Mechatronics Concept Designer is a crucial component of Siemens Advance Machine Engineering software, allowing Virtual Commissioning by creating a functional model of the machine with reusable data such as joints, sensors, and actuators. This model can simulate the machine’s behaviour, executing controller code in real-time. The model is compatible with other Siemens tools, such as NX, Simcenter, Capital, Polaron, and Teamcenter, which enables the creation of a comprehensive digital thread and actionable digital twin. The model can be virtually tested to validate machine functions quickly and efficiently, reducing the time needed for V&V. (Siemens)

3 Methodology

3.1 Research design and approach

The research design for this thesis will be primarily qualitative in nature, with a focus on collecting and analysing data from existing literature and expert interviews. The purpose of this research design is to gain a deeper understanding of the implementation and effectiveness of virtual commissioning in industrial automation.

To achieve this, the thesis will utilize a systematic and organized approach to data collection and analysis. Data collection will involve a review of relevant research papers, articles, and publications, as well as interviews with industry experts. The data will be analysed using qualitative methods such as content analysis, thematic analysis, and pattern recognition to identify common themes and patterns in the data.

The approach taken in this thesis will follow established research protocols and guidelines to ensure the validity of the research. However, it is important to acknowledge the potential limitations of this approach, including potential biases and limitations in the scope of the research due to time and resource constraints. To mitigate these limitations, the research will strive to use a diverse and representative sample of research and experts, and clearly define the scope and objectives of the research.

3.2 Data Collection and Analysis

The data for this thesis will be primarily collected from research papers, articles, and publications related to the implementation and effectiveness of virtual commissioning in industrial automation. The data will be gathered using a systematic and thorough search process of relevant academic databases and industry publications.

The data analysis will involve qualitative methods such as content analysis, thematic analysis, and pattern recognition. These methods will be used to identify common themes and patterns in the data, as well as to gain a deeper understanding of the findings. The analysis will be conducted systematically and rigorously to ensure that the results are valid and reliable.

3.3 Limitations and ethical considerations

The limitations of this study are mainly related to the scope of the research and the available resources. As this thesis will mainly rely on secondary sources of information such as research papers, articles and publications, there is a possibility of information bias. Furthermore, the thesis will only focus on virtual commissioning in industrial automation and may not cover all aspects of the subject. Another limitation of this thesis is the lack of primary data that could provide more detailed and specific information. Additionally, the thesis will be limited to the time and resources available, which may affect the depth and breadth of the analysis.

In conducting the thesis, ethical considerations will be taken into account. The sources of information used in this thesis will be cited appropriately to avoid plagiarism. The study will also be conducted in accordance with the ethical guidelines and protocols established by the academic institution. Furthermore, the research findings will be presented in an objective and unbiased manner.

4 Results and Analysis

4.1 Overview of the collected data

The data in this thesis was primarily obtained from three sources: internet sources, research papers, and interviews retrieved from the research papers. Internet sources refer to publicly available information gathered from sources such as websites, online databases, and other digital platforms. Research papers were obtained from academic journals, and interviews were retrieved from the abovementioned research papers.

The data collection involved a comprehensive literature review of relevant research papers and internet sources. The literature review helped identify key sources and gather information related to the research questions. The retrieved interviews were analysed for relevant perspectives for the topics researched in the thesis.

The collected data consists primarily of qualitative information. It includes text data extracted from internet sources, research papers, and interviews. The data contains descriptions, explanations, and opinions related to the research topic. Quotes from interviews are used to provide direct evidence and support the research findings.

To ensure the validity and reliability of the collected data, only reputable and credible sources were used. The inclusion of peer-reviewed research papers was prioritized. The interviews were evaluated for the expertise and qualifications of the interviewees.

The data selection process aimed to include a diverse range of relevant sources, although it is important to acknowledge that the data can include potential biases. This limitation should be considered when interpreting the research findings and drawing conclusions.

4.2 Analysis of the benefits and challenges of virtual commissioning

Virtual commissioning offers the opportunity to carry out commissioning activities simultaneously with production and assembly processes, leading to time savings. This approach enables optimization loops during these processes, as highlighted by Brökelmann. Virtual Commissioning improves safety during the commissioning phase by allowing for the identification and solution of errors prior to actual commissioning.

The adoption of Virtual Commissioning can provide a competitive edge for companies by effectively managing project lead times. This advantage can happen in several ways, such as accelerated product launches, shorter quotation lead times compared to competitors, and faster realization of internal benefits. Companies can optimize their labour costs per project by accomplishing more projects with the same resources.

Additionally, Virtual Commissioning can provide improve consistency by reducing variability in lead time, allowing companies to successfully predict their delivery schedules. This predictability leads to the reduction of wasteful expenditures.

Shortening lead time durations enables faster feedback from loops. This feedback contributes to improved quality as it reduces the need for rework. The ability to receive feedback quickly also minimizes the effort required to meet objectives.

Decreasing lead times and establishing trust through predictability opens possibilities for greater flexibility. With a shorter lead time, certain decisions can be deferred until later stages of the project, allowing for more adaptive and customized solutions.

Despite all the benefits of Virtual Commissioning, there are a number of challenges that experts face. Virtual Commissioning has gained significant attention, but experts acknowledge the lack or classification and standardization withing the field. Both existing literature and interviews indicate a pressing need for standardization, not only in terminology used but also the design of virtual commissioning systems and the establishment of communication protocols for data exchange. The absence of standardized practices creates challenges in developing a unified understanding of virtual commissioning.

The management of software is another challenge the industry faces, particularly in terms of integration with hardware and electronic components during the later stages of the development process. Software is an integral part of the overall configuration of virtual commissioning. It is necessarily to have the ability to provide constant updates, including software and hardware upgrades, modifications to the control system, and the addition of modules to accommodate changes in customer product requirements.

4.3 Comparison of virtual commissioning with traditional commissioning

Virtual Commissioning offers significant efficiency gains compared to traditional commissioning. By utilizing digital models and simulations, virtual commissioning allows for the identification and resolution of design flaws and errors at an early stage. This results in reduced rework, shorter commissioning times, and faster time-to-market solutions. Traditional commissioning involves sequential testing and troubleshooting, which can lead to delays and extended project time schedule.

Compared to traditional commissioning, Virtual commissioning provides an enhanced risk mitigation. Through virtual simulations, potential risks and performance issues can be identified and resolved before the physical implementation. This approach minimizes the chances of errors, safety hazards, and equipment damage during the commissioning phase. Traditional commissioning is also addressing the risks, but it relies more on real-time troubleshooting and problem-solving.

For any business, cost is of great priority. Virtual commissioning offers the potential for greater cost savings in comparison to traditional commissioning. The early detection of errors minimizes the need for rework, reducing material waste, labour costs, and downtime. Virtual commissioning also allows for more efficient optimization of control systems, resulting in improved efficiency and operational cost savings. In traditional commissioning, the higher costs are usually due to prolonged testing, rework, and expenses caused by physical modifications.

Virtual commissioning also offers greater flexibility and provides better testing opportunities. The digital models and simulations can be easily modified and adjusted, allowing for rapid testing and validation of alternative configurations, control strategies, and operation scenarios. This approach allows for fine-tuning and optimization, leading to improved performance and operational effectiveness. Traditional commissioning may involve more challenges and costs when making significant modifications or changes to the physical system.

In conclusion, Virtual commissioning provides advantages over traditional commissioning. It offers efficiency gains, risk mitigation, cost reduction, and flexibility by utilizing digital models and simulations. While Traditional commissioning is still the more common option, virtual commissioning proves to be a good alternative, especially in industries where efficient commissioning, reduced risks, and shorter time-to-market are crucial factors.

5 Conclusion

5.1 Summary of the main findings

Virtual commissioning is commonly defined as the process of developing and validating programmable logic controller (PLC) code using a simulation model (Wünsch. G., 2008). Commissioning is a crucial phase in the development process and it is typically implemented towards the end of the project. Even though commissioning takes only 25% of the total development time, commissioning often experiences significant delays (Hoffmann et al., 2010). It is estimated that up to 70% of these delays can be attributed to errors in the control software (Reinhart and Wünsch, 2007).

The primary objective of virtual commissioning is to facilitate early validation of machine code, minimizing the risk of deploying a program with errors. By utilizing virtual models, different scenarios can be trained and tested in a safe and controlled environment, offering valuable insights, and enhancing overall system performance. (Beilby)

Virtual commissioning presents the opportunity to do commissioning activities simultaneously with production and assembly processes, resulting in time savings. This approach allows for optimization loops during these processes, as mentioned by Brökelmann. Safety during the commissioning phase is enhanced through virtual commissioning by enabling the identification and resolution of errors before the actual commissioning takes place.

The implementation of virtual commissioning can give companies a competitive advantage by effectively managing project lead times. This advantage can provide faster product launches, shorter quotation times compared to competitors, and faster realization of financial gains. Companies can optimize their labour costs per project and successfully deliver more projects using the same resources.

Despite the numerous advantages of Virtual Commissioning, experts encounter several challenges in its implementation. While Virtual Commissioning has become more popular, experts recognize the lack of classification and standardization within the field. The absence of standardized practices presents difficulties in developing a unified understanding of virtual commissioning.

In the past, the application of virtual commissioning was primarily limited to evaluating the physical compatibility and functionality of products. Recent advancements have expanded its capabilities, enabling more comprehensive validation and verification processes. These advancements involve integrating hardware in the loop, software in the loop, and human in the loop methodologies.

Human in the loop involves the integration of hardware devices, such as programmable logic controllers (PLCs) and safety switches, with the digital twin. The digital twin encompasses software, electronics, and mechanical design, creating a comprehensive model of the machine. This integration enables simulation and testing of the complete operational characteristics of the machine. Human in the loop serves as a method for humans to interact with the simulated software controls and hardware, ensuring that the system behaves as intended and meets the desired expectations.

Overall, Virtual commissioning is a field that would require much further research to achieve it’s potential. The benefits of Virtual commissioning are undisputed, and its integration is becoming more common. With introduction of standardization, the process of virtual commissioning might become the industry norm, allowing for faster and safer commissioning.

5.2 Recommendations for future research

While virtual commissioning has gained attention and shown promising results, there are many areas that require further exploration. By addressing these research gaps, we can advance the understanding and application of virtual commissioning, leading to its broader adoption and continued development.

Standardization and best practices

Future research should focus on developing standardized frameworks, terminologies, and best practices for virtual commissioning. This includes defining common data exchange formats, communication protocols, and interoperability standards. Standardization efforts can help streamline implementation processes, facilitate collaboration, and ensure compatibility among different virtual commissioning tools and platforms.

Validation and verification methods

There is a need for research on robust validation and verification methods for virtual commissioning. This involves developing techniques to ensure the accuracy and reliability of virtual models and simulations, as well as methods for validating the results against real-world performance.

Integration with Digital Twins and Industry 4.0 Technologies

Exploring the integration of virtual commissioning with digital twin technologies and other Industry 4.0 concepts is another area for future research. Investigating how virtual commissioning can leverage real-time data from physical systems and how digital twins can enhance the virtual commissioning process.

Performance optimizations and system resilience

Investigating how virtual commissioning can be used to optimize not only individual components but also the overall system performance, taking into account factors such as energy efficiency and system resilience. This research can contribute to the development of intelligent algorithms and decision support systems for virtual commissioning.

In conclusion, future research in virtual commissioning should address key areas such as standardization, validation and verification, integration with digital twins are Industry 4.0 technologies, human factors, and performance optimization. Developing this type of research can lead to widespread adoption and continued advancement in the field.

6 Sources

Methoden für die virtuelle Inbetriebnahme automatisierter Produktionssysteme. Wünsch G. (2008). Retrieved in February 2023. Available at: https://www.utzverlag.de/assets/pdf/40795les.pdf

Virtual Commissioning of Manufacturing Systems A Review and New Approaches For Simplification. Hoffman, Peter et al. (2010). Retrieved in February 2023. Available at: https://www.sciencedirect.com/science/article/pii/S2288430014500292

Economic application of virtual commissioning to mechatronic production systems. Reinhard, Gunther and Georg Wünsch (2007). Retrieved in February 2023. Available at: https://www.worldscientific.com/doi/abs/10.1142/S0219686702000076

What is Virtual Commissioning. Beilby, Alex. Retrieved in February 2023. Available at: https://virtualcommissioning.com/what-is-virtual-commissioning/

Zero to hero. A generalized virtual commissioning implementation method. Calles et al. (2022). Retrieved in March 2023. Available at: https://www.researchgate.net/publication/364088514_Zero_to_hero_a_generalized_virtual_commissioning_implementation_method

Virtual commissioning – scientific review and exploratory use cases in advanced production systems. Lechler, T. et al. (2019). Retrieved at March 2023. Available at: https://www.sciencedirect.com/science/article/pii/S2212827119305839

Survey on the virtual commissioning of manufacturing systems. Lee, C., Park, S. (2014). Retrieved in March 2023. Available at: https://www.sciencedirect.com/science/article/pii/S2288430014500292

Systematik der virtuallen Inbetriebnahme von automatisierten Produktionssystemen. Brökelmann, J. (2014). Retrieved in March 2023. Available at: https://digital.ub.uni-paderborn.de/hsx/content/titleinfo/1731075

Economic justification of virtual commissioning in automation industry. Shahim and Møller (2016). Retrieved in March 2023. Available at: https://www.informs-sim.org/wsc16papers/212.pdf

Virtual Commissioning: Achieving a Flawless Launch. Siemens (2020). Retrieved in March 2023. Available at: https://www.plm.automation.siemens.com/media/global/en/CIMdata%20White%20Paper%20-%20Virtual%20Commissioning_tcm27-88900.pdf

Virtual Commissioning – A practical guide. Aldrete, S. (2015). Retrieved in March 2023. Available at: https://blogs.sw.siemens.com/tecnomatix/virtual-commissioning-a-practical-guide/