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Virtual Commissioning and the Use of Extended Reality and Automated Testing: A Survey of Industry

Virtuelle Inbetriebnahme und die Nutzung von Extended Reality und Automatisiertem Testen: Eine Umfrage in der Industrie

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Abstract: Virtual Commissioning (VC) is seen as an important technology for managing the complexity of production systems. While it is demonstrated that VC can reduce commissioning time, defect rates and costs, the rate of industrial adoption is below expectations. In this paper, we present the results of a survey conducted to investigate the use, expectations, and barriers to the use of VC with an additional focus on Virtual Reality (VR), Augmented Reality (AR) and Test Automation (TA) in this context. The survey results reveal that just over half of the respondents use VC, albeit rarely to occasionally. Barriers to the use of VC are not technological. VR and AR technologies are used in many companies, but not frequently. The results indicate that the potential benefits of using these technologies are not clear enough to justify further investment in what is seen as a somewhat immature technology. TA can only be found in large companies. The main barriers are the amount of effort required to create and maintain automated tests and a general lack of know-how and resources. Respondents agree that all three technologies will become more important in the future.

1 Introduction

In order to economically manage the increasing complexity of production plant design, it is necessary to identify issues as early as possible. One solution is the use of Virtual Commissioning (VC), which consists of testing and validating partial or full automation systems during the engineering phase using simulation models and methods (VDI/VDE 2018a). The main fields of application are the engineering and commissioning phase of complex automation systems in logistics, manufacturing and assembly (Lechler et al. 2019). As simulation capabilities and tools have improved, the use of VC has increased in recent years, but remains below its perceived potential.

Some notable technologies related to VC are Extended Reality (XR) and Test Automation (TA). XR is an umbrella term for the technologies and concepts surrounding virtual reality (VR), augmented reality (AR) and mixed reality (Çöltekin et al. 2020). XR systems can provide visualisations of automation systems in realistic dimensions. This can improve the decision-making process in the engineering phase by providing a better shared basis for discussion, especially in multi-user environments, and enabling virtual testing of ergonomics and accessibility for production and maintenance.

In general, the term VC encompasses three layers, plant level VC, cell level VC and machine level VC (Reinhart and Wünsch 2007). This publication focuses on the machine level whose main aspect is the testing of control programs on a virtual model of the automation system as would be performed during the actual commissioning of the plant. At present, these tests are typically performed manually. Manual testing involves setting up the starting conditions for the test, manually initiating the test, monitoring the 3D visualisation, behaviour simulation, variables, and PLC program and documenting the results. Due to the required effort, the performed tests mostly cover sections of the program that are considered critical or susceptible to failure. Therefore, there is a risk that parts of the program are forgotten or misjudged and the extent of test coverage is often unclear (Sub et al. 2016). Automated testing has the potential to alleviate these issues. It generally refers to the automation of one or more parts of: test planning and control, test analysis and setup, test execution, test evaluation and test documentation (VDI/VDE 2018b). The concept is commonly utilized in many areas of software development and has been shown to achieve decision coverage comparable to manually created tests for PLC code while saving up to 90% of the time required (Enoiu et al. 2017).

The goal of the survey presented in this paper is to gather feedback from the industry on how VC, VR and AR, and TA in the context of VC are applied and what the main barriers impeding more widespread application are. Based on the results, future focus areas for research and development are derived. First, an overview and distinction from similar studies is given (section 2), followed by an introduction of the survey design and conduct (section 3). The results of the survey are then presented and discussed (section 4). Finally a summary and an outlook are given (section 5).

2 Overview of and Distinction from Similar Studies

Other authors try to answer similar questions using studies and questionnaires. In Shahim and Moller (2016), the goal is to evaluate the tangible and intangible economic benefits of VC through expert interviews and a procedure called Fuzzy Analytic Hierarchy Process. The results indicate that “Deadline control”, “Risk of delay and interruption during ramp up” and “Software quality in relation to future operation” are the three most significant drivers in automation industry with impact on value creation. The study in Reimann (2017) focuses on simulation and visualization. Its results indicate that simulation is mostly used in the concept phase and alongside construction. Close to 50% of participants state they are using simulation for virtual prototypes. 57% expect growth for VC. The main findings of the study looking into the use of simulation in process and discrete industries in Bruckner et al. (2020) are that safety and quality are the main drivers within these industries, simulation has gained acceptance and simulation is used a lot in all life cycle phases of a production plant.

The results of the 2019 study in IDG Business Media GmbH (2019) indicate that 40% of probed German companies already use VR or AR with an additional 33% planning to implement it in the next 12 months. The authors of Ugarte-Querejeta et al. (2021) investigate the use of and challenges in traditional commissioning (TC), VC, and automated testing for Spanish companies. The most prevalent challenges identified for TC are little margin for error correction, unexpected issues due to errors from previous development stages and time to market. The results also show that most tests in the context of VC are performed manually. The most commonly automated tests are for the validation of PLC, automated at 45% of practitioners' companies.

In summary, the authors of other studies mostly focus on broader applications of digital factories, digital twins or on simulation in a more general sense rather than on the use, benefits and barriers for VC. Furthermore, data on the application of VR and AR in the context of VC and production planning has not been published. Up until now, the pervasiveness of automated testing in VC has only been examined for Spanish companies. Therefore, this study expands the general understanding of the current application of VC in industry particularly of the use of VR, AR and TA.

3 Survey Design and Conduct

Based on the research questions and presented surveys, a questionnaire is created consisting of 31 multiple choice and multiple select questions. A free text option is added where suitable. Overall, the survey is divided into four sections. The first segment contains general questions about the use of VC, followed by questions on the application of VR and AR and automated testing in the context of VC. The final section collects demographic information on the respondents and on their companies. The design of the survey and questions is verified with feedback from several trial participants from research and industry.

The German-language survey was accessible during January and February of 2023. The target group is practitioners from industry which are involved in commissioning or VC as part of their work as system manufacturers, system integrators or manufacturers. Participants in the survey are industry experts from various sectors who were contacted via the authors' mailing lists and social media channels as well as industry newsletters. A total of 30 experts participated especially from machinery and equipment engineering (40%), automotive manufacturing (23%), electrical engineering industry (20%), medical technology sector (17%) and other (13%).

The participating companies are mostly large companies (77%) with some medium (10%) and small companies (13%). Categorized by segment of the supply chain of production plants, these companies are component suppliers (43%), system suppliers (43%), plant operators (30%), engineering service providers (17%) or software companies specialized in PLC or robot programming (10%). The participants themselves are managers (31%), software developers (19%), development engineers (15%) with 33% in the age range of 18-29, 50% aged 30-49 and the remainder 50 or older.

4 Survey Results and Interpretation

The content of the survey is divided into three main sections along which the survey results are analysed and interpreted below. First, the general use of VC is examined in detail (section 4.1), followed by the use of VR and AR in the context of VC (section 4.2). Finally, the application of TA in VC is evaluated (section 4.3).

4.1 Results on Virtual Commissioning

Of the respondents to the survey, 55% apply VC and a further 17% are planning to use it. Here, a medium correlation between the company size and the use of VC can be observed (Cramer-V: 0.482; contingency coefficient: 0.563). Software-in-the-Loop (SIL) (69%) is more common than Hardware-in-the-loop (HIL) (31%) and Model-in-the-Loop (MIL) (31%). Out of the participants using VC most apply it rarely (47%) or occasionally (24%) and few apply it often (18%) or always (12%). The most influential factors which decide whether VC is used or not are plant complexity (68%), availability of resources and personnel (44%), pilot projects (28%) and instructions issued by management (28%).

The participants observed benefits of employing VC fall slightly short of their expectations, see Figure 1. Especially the medium- and long-term savings and improved cause analysis for faults deviate considerably. At the same time, these measures are the most difficult to quantify. In general, the reduction of faults (76%) and time required for commissioning (71%) are observed as the most important benefits, followed by the improved visualisation of the system functionalities (47%).

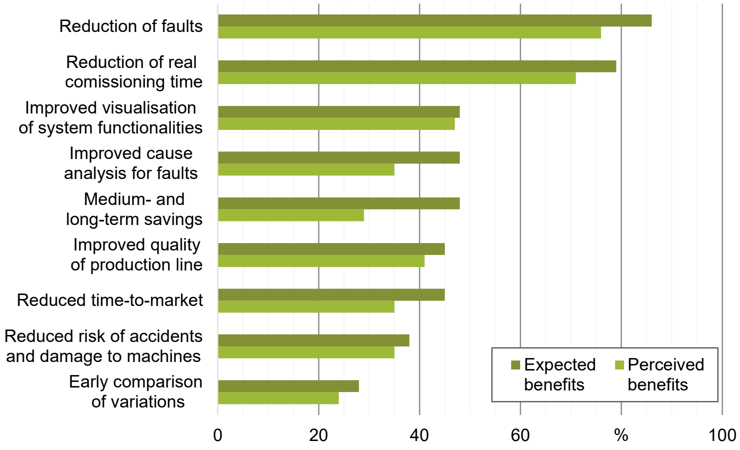

Figure 1: Expected (dark) and perceived (light) benefits of using VC.

Comparing companies that use VC and those that do not, it is clear that the companies that do not use VC expect significantly fewer benefits. It therefore seems as if they are either not aware of the advantages of VC or that VC is not as relevant for their specific business. As shown in Figure 2, the most common barriers to applying VC are resource constraints, i.e. large effort for creating models (89%), lack of resources and staff (61%) and lack of standardization (50%). The majority of the participants agree (60%) or mostly agree (33%) with the statement "VC will gain in importance in the future". The remaining 7% answered with "neither agree nor disagree".

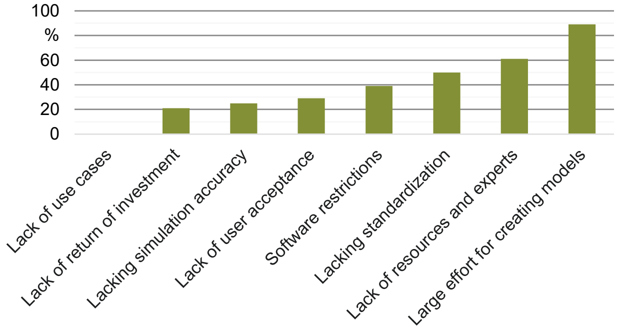

Figure 2: Barriers to applying VC.

In summary, just over half of the respondents use VC. Of these, SIL is the most common, probably due to transferability to the actual hardware. The majority of respondents use VC only rarely to occasionally, with plant complexity, availability of resources and pilot projects as the main motivation. The main expected benefits for applying VC are the reduction of faults and of commissioning time. Barriers to the use of VC are generally related to resource constraints, rather than technological in nature.

4.2 Extended Reality in Virtual Commissioning

Out of the participants' companies, 64% are using VR or AR technologies. 14% of the remaining companies plan to implement them while a further 14% have no plans to do so. 7% have used at least one of the technologies but discarded it. Here too, a medium correlation with the size of the company can be observed (Cramer-V 0.367; contingency coefficient: 0.461). The majority of respondents using either of the technologies apply them rarely (46%) or occasionally (46%). Only few employ them frequently (4%). VR and AR are mostly applied for the creation of CAD or simulation models of production plants (42%) and training (35%), also compare Figure 3.

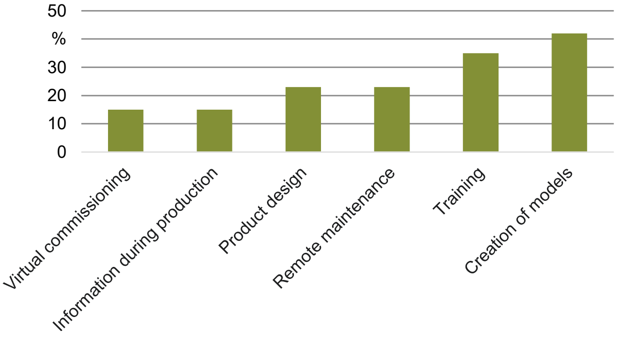

Figure 3: Processes for which AR or VR is used for respondents using either.

The use of VR and AR devices is relatively evenly split between VR-Headsets (46%) AR-Headsets (38%) and handheld AR (38%), i.e. using AR with smartphones or tablets, with some using unspecified other devices (8%). Figure 4 contrasts the expected and perceived benefits of using VR and AR technologies. In general, the technologies meet the expectations. The largest expected benefits are time savings (52%), collaboration without on-site presence (48%) and an accelerated decision-making process (45%). The observed benefits of the former two remain significantly below expectations.

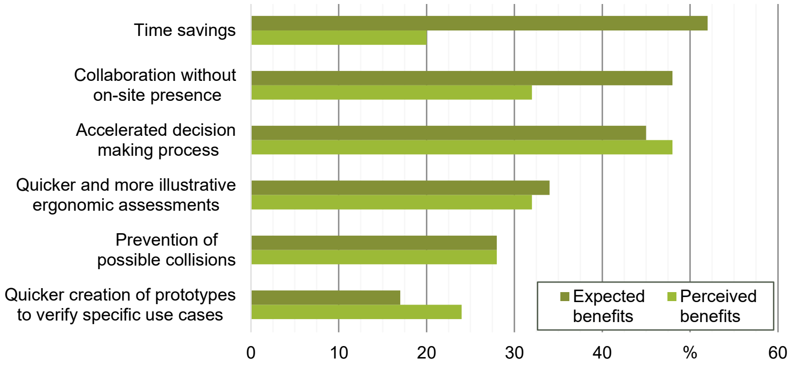

Figure 4: Expected (dark) and perceived (light) benefits of using VR and AR technologies.

In order to assess the barriers for using VR and AR technologies a 5-point Likert scale ranging from “strongly disagree” to “strongly agree” is employed. The answers are translated into numbers ranging from 1 to 5, the mean of which is depicted in Figure 5. The results are mixed. It seems, the economic benefits are not sufficiently clear enough. Furthermore, a lack of know-how and experts persists and the technologies are perceived as somewhat immature.

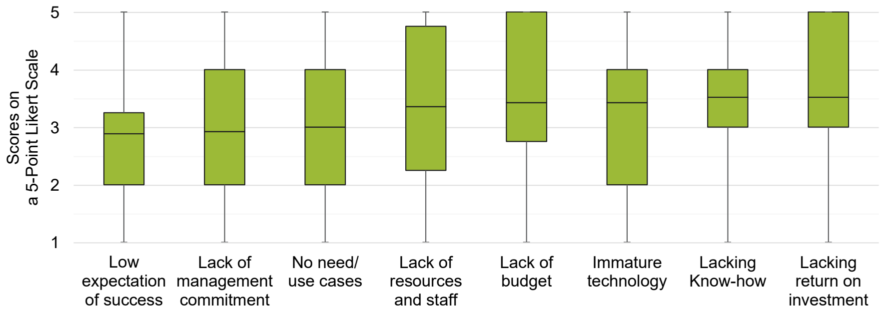

Figure 5: Mean scores on a 5-point Likert scale for barriers to using VR and AR technologies in the context of VC with indicated quartiles and minima and maxima.

30% of the participants agree with the statement “The use of VR and AR technologies in the context of VC will become more significant in the future”, while 47% mostly agree with the statement. Another 20% neither agree nor disagree and 3% mostly disagree. Respondents whose companies already use VR or AR agree more often.

To summarize, XR technologies are already being used in many organisations, albeit infrequently. The results indicate that many do not use them outside of trials. Expectations for time saving and virtual meetings are not met whereas expectations regarding the support of decision-making processes are. A likely explanation for the former is that it is often difficult to estimate the time savings properly which is underlined by the fact that the faster creation of prototypes to verify specific use cases exceeds expectations. The discrepancy between expectations and observations regarding virtual meetings can be explained by the fact that the technologies have not yet reached the level of sophistication portrayed in media and marketing materials. There are no distinct barriers to the application of VR and AR technologies. However, it seems that the potential benefits are not clear enough to justify investing in technologies that have not fully matured.

4.3 Automated Testing in Virtual Commissioning

Although testing is an important part of VC, only 43% of respondents partially or fully automate tests in the context of VC, while 39% do not. The remainder are unsure whether testing is automated at their company. The responses show that only large companies automate testing. All of the participants who automate testing partially or fully automate test execution (100%). Test evaluation (55%) and test documentation (45%) are also frequently automated, in contrast to test creation (27%), see Figure 6.

Figure 6: Degree of automation of test elements by respondents who automate testing.

Table 1 shows the results for the question of whether the different types of tests are performed and the extent to which they are automated. The most commonly performed tests are PLC/CNC configuration validation (85%), PLC code validation and verification (79%) and collision tests (77%). Of the companies performing the tests, HMI tests are most frequently automated to some extent (83%), followed by validation and verification of PLC code (72%) and validation of CNC subroutines (66%). The lowest levels of automation are for verification of the electrical systems (22%) and controller hardware (25%). These results are consistent with the study of Spanish companies in (Ugarte-Querejeta et al. 2021). It is important to note that the relevance of the types of tests listed is highly company specific.

A 5-point Likert scale is used to assess the expected and perceived benefits of partially or fully automating tests, see Figure 7 for a contrast of their mean values. Expected and perceived benefits are all at or close to “agree” and mostly congruent. Only the long-term savings do not quite match expectations.

Table 1: Overview over the types of performed tests and their extent of automation by respondents' companies that automate testing.

Types of performed tests	**Not Executed**	**Manual**	**Partially Automated**	**Fully Automated**
Validation of CNC sub-programmes	45 %	18 %	27 %	9 %
Verification of controller-hardware	38 %	46 %	0 %	15 %
HMI tests	38 %	15 %	23 %	23 %
Checking of electronics	31 %	54 %	15 %	0 %
Checking of electrical system	31 %	46 %	23 %	0 %
Collision tests	23 %	38 %	15 %	23 %
PLC code validation and verification	21 %	21 %	43 %	14 %
PLC/CNC configuration validation	8 %	50 %	42 %	0 %

The main barriers to the use of TA are not of technical nature, see Figure 8. Rather, they are related to the high cost of creating and maintaining the automated tests, the uncertain lack of return on investment, and the lack of know-how and resources. Nonetheless, the respondents mostly agree (46%) or agree (35%) that automation of tests in the context of VC will increase in importance, with another 15% neither agreeing nor disagreeing and 4% mostly disagreeing with the statement.

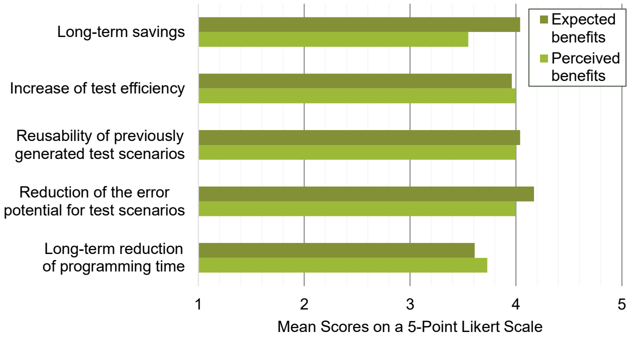

Figure 7: Expected (dark) and perceived (light) benefits of partially or fully automating tests in the context of VC.

TA can only be found in some large companies, with the highest level of automation being for the verification of PLC code and CNC subroutines. The main barriers to further automating tests are not technical, but related to the high effort required to create and maintain automated tests and the lack of know-how and resources. One possible explanation is that bigger companies manage more complex projects which necessitate more extensive testing. At the same time, they have more resources to commit towards experts for TA and more favourable economies of scale. If companies employ TA they commonly use a variety of different types of tests. This could indicate that beginning to automate tests is a big barrier but this justifies further research.

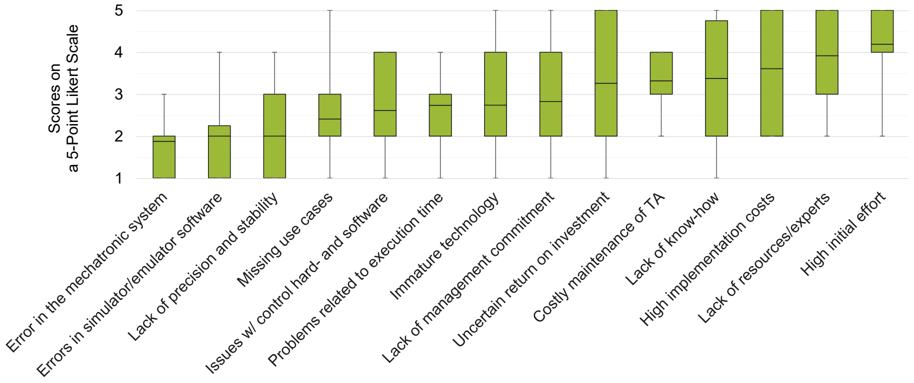

Figure 8: Mean scores on a 5-point Likert scale for barriers to partially or fully automating tests in the context of VC with indicated quartiles and minima and maxima.

5 Summary and Outlook

This study improves the understanding of the current status quo of the use of VC in German companies. Furthermore, it extends the knowledge on prevalence, expectations and barriers of VR and AR as well as TA in the context of VC. Based on the presented results, future research and development focuses can be identified.

For VC, the high effort required to create the models does not always justify the investment. To tilt the scales, further research should focus on reducing the effort to create models and increasing the value of the created models. One possible research avenue for the latter is the extension of VC models to digital twins that can be used to support analysis and decision-making from the concept phase, through design, planning and commissioning, to operation and decommissioning.

In addition to further developing the equipment for VR and AR, the existing benefits and time savings need to be explored and demonstrated more clearly. While many companies have at least trialled the technologies, better integration into existing development processes could help close the gap.

Future investigations in the area of TA in the context of VC should focus on reducing the effort required to create and maintain the automated tests. Assessing how best to support automated test evaluation and documentation, but especially test creation, should be one of the next steps. Furthermore, the knowledge gap in regards to TA in VC needs to be addressed.

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