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Digital Tools for Supporting Production Preparation: Reflections Related to Designing Human-Robot Collaboration Layouts

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Abstract. Accelerating technological developments and increasing competition make it important to secure the development of production solutions that allows for resource efficient layouts and continuous improvements. When developing production solutions, the usage of digital tools is an important asset that supports production preparation engineers in their work. However, the emerging possibilities to design production layouts where the operator and a robot collaboratively share a task, add more challenges for production preparation engineers. The production layout become more complex, with more parameters to analyze for a safe and secure working environment, supporting a safe interaction between technologies and operators. The design of human-robot-collaborative (HRC) layouts, with ever shorter product life cycles, could benefit from an increased use of digital tools, as ever more powerful simulation and design tools are available on the market. This paper will explore digital tools (such as simulation, emulation, visualization) and their potential contribution for different HRC layout designing steps. Based on this, the needs to be reflected in a guideline for a digitalized production preparation process will be explored from the perspective of developing a human-robot collaborative layout..

Keywords. Digital tools, Human-Robot Collaboration, Production system, Production preparation, Industrialization

Introduction

Accelerating technological developments and increasing competition make it ever more important to secure the development of production solutions that allows for resource efficient layouts and continuous improvements. When developing production solutions, the usage of digital tools is an important asset that supports the production preparation engineers in their work. Brunoe et al. [1] argue for the impact on several performance metrics through integration of digital tools within a product realization process, such as cost, flexibility, standardization, and efficiency. The trend in industry is increasing assembly volumes of customized products. Mostly, this is related to many operators and manual assembly, with challenges related to i.e. ergonomic issues, takt time, production

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cost, diversity in final product quality, productivity and material supply etc., especially relevant in an automotive assembly line with a cycle time typically in the range of 60 to 90 seconds [2]. In the automotive industry it is also common to organize the final assembly lines according to a Mixed Model Assembly line [3] – where each product can be unique.

Design for Automated Assembly is an approach [4], where product development, production preparation and production development is interlinked. This can be further developed to analyze the possibility to facilitate solutions for humans and robots to collaborate when assembling products designed for assembly (DfA). But it is important to plan the assembly manufacturing process, to reduce the number of operator mistakes [5]. However, to analyze what to automate, how to assemble, etc there is a lot of different software and digital tools on the market, such as simulation, visualization, and emulation tools. On the other hand, there are a lot of other perspectives on this as well, such as digital twins, cyber physical systems, and digital shadows, etc. All this is also related to the smart manufacturing paradigm as well as the Industry4.0 approach [6].

The emerging possibilities to design production layouts where the operator and a robot collaboratively share a task, add more challenges for production preparation engineers. The production layout becomes more complex, with more parameters to analyze and optimize for a safe working environment that also manage security and are designed for a safe interaction between technologies and operators [7]. The possibilities for continuous improvements and optimization also increase as new and improved digital technologies for measuring, control, analysis, and coordination of resources, are commercially available. The design of human-robot-collaborative (HRC) layouts, responding to the industrial trend of shorter product life cycles, could gain from an increased use of digital tools [8], since ever more powerful simulation and design tools are available on the market. Having a holistic view of the design of a production system layout, over time, can therefore be crucial.

This paper will explore digital tools (such as simulation, emulation, and visualization) and their potential contribution to different HRC layout designing steps. Based on this, the routines related to risk assessments for developing and implementing automation technology in a production system will be reflected upon in relation to different digital tools.

1. Method

First, literature has been explored from mainly three different perspectives in the context of final assembly in an automotive industrial setting. These are (1) KPIs related to value related to a human-robot collaboration (HRC) perspective, (2) production preparation, and (3) virtual technologies. This was combined with trend studies within virtual support for product realization processes, especially related to production preparation activities, as well as the emerging trends in the automotive industry, such as an increased interest in automated-assisted assembly.

Interactive workshops with support from demonstrators in research projects together with industrial partners have been performed. During these projects (2 projects during a 5 year period 2016 – 2021) the authors have interacted and participated in different workshops where virtual as well as physical demonstrators have been show-cased. The interaction and reflections during these sessions have contributed to an iterative development of the demonstrators between the different workshops as well as the different cases – one for assembling flexible components on a moving line, one for assembling soft material, like tubes or cables, in narrow spaces on a moving line and one assembly station for customized electronic products that was assembled, incl. downloading of selected software.

The following questions have been used as a guide when analyzing and selecting the literature for this work, related to production preparation and virtual tools:

1. How can all different types of virtual or digital tools contribute to the engineering work required for preparation of a production layout for human and robot collaborative assembly?
2. Which resources (the digital systems, automation solutions or humans) have which role or responsibility or similar, when utilizing digitalization?
3. How are different digital tools designed – visualization, emulation, simulation, or other tools?

The following questions have been used as a guide when observing and interacting with the industrial representatives in workshops supporting the production preparation engineers in their operative work of designing a collaborative assembly layout for human and robots:

1. Resource allocation and skills in relation to time and quality?
2. Expert competence versus virtual tools with embedded knowledge and capacity?
3. Compatibility between different virtual tools, risks and aspects related to shared data?
4. Information versus communication in relation to different types of virtual tools?

2. Theoretical framework

2.1. Value and Resource parameters for a HRC setting

Key Performance indicators (KPIs) are a defined set of parameters that supports targets within an organization. The specification of these is critical for performance support when making decisions [9]. When designing a layout for human-robot collaboration (HRC) there are several value and resource parameters to reflect upon. Our study indicates that most of them are connected to economical parameters (1) cycle time and productivity [10], (2) utilization of equipment and throughput [11] and (3) average assembly time [12]. However, there is a trend towards parameters that are related to environmental indicators, such as energy consumption and emissions [13, 14]. In a HRC setting it is also important to evaluate the most cost-efficient way to organize the layout where the operator and the robots can work safely together [15]. When analyzing utilization of digital tools for production preparation we define an ‘efficient’ utilization as utilization that increases created Value (V), or decreases the consumption of Resources (R) that are required for the Value creation, over time, i.e. increases the V/R fraction [16]. V and R are then vectors of KPIs.

2.2. Production preparation

Production preparation is an important activity in a product realization process, including analysis of the producibility of a product as well as the development of the production system. By implementing and using digital manufacturing it is possible to link the product development, the production planning and the facility planning [17]. Wöhlke and Schiller [17] describe the possibilities to validate both the product and the production system by utilization of digital manufacturing support. The assembly sequence and the accessibility can be validated station by station in a more product-oriented perspective. More detailed process-oriented simulation can explore the use of equipment, cycle time, ergonomic aspects, and the stations layout [17]. However, the development of new emerging technologies is accelerating which challenges the organization to manage the skills to be up-to-date, related to the employment of Industry 4.0 technologies such as digital simulation and use of innovative ICT [18].

Accelerating development of capability of emerging technologies can challenge the way companies are able to keep up the skills within their organizations, for full potential use of the software and/or technologie's capabilities. However, it is still challenging to develop a simulation model that manage the manual operations in detail, such as assembly of parts and fixtures [19]. Furthermore, a production preparation engineer act in a transdisciplinary context during the industrialization process, where the grade of success is dependent on the quality of the integration of the product and production development [19]. These transdisciplinary activities can be compared to challenges within an interorganizational relation, where three learning processes can be supportive: learning to collaborate, learning to share and learning to create knowledge through interorganizational collaboration [20]. Here, several opportunities as well as challenges with implementation and utilization of digital tools for facilitating industrialization activities have been identified [21].

2.3. Virtual tools

There are several different types of digital approaches that are possible to use in a more digitalized production preparation process, such as simulation, emulation, and visualization. These emerging technologies demonstrates the possibilities to support decision-making for manufacturing companies [22], with the mission to reduce errors and improve the design of the production system layout. A simulation model is designed to support decisions, and therefore the models should mimic behaviors which contribute to important insights [23]. When the simulation is running it should show how a system or product works overtime, but there is a need to further develop the simulation models, especially discrete event simulation into new application areas [24], which is still valid if the applications are related to human and robots in collaboration [25]. It is also challenging to evaluate energy consumption through simulation when designing and improving manufacturing systems [26].

To share specific insights about a product design it is possible to highlight or filter out different layers in a CAD model for visualization, which can facilitate collaboration in a multidisciplinary way [27]. Furthermore, the usage of emulation is also increasing in the library of implementation of virtual support for production engineers, where the emulation supports the test of control systems or control code in virtual models of the product, such as programming a virtual robot, which facilitates a test under practical conditions [28]. The trend in virtual support tools for engineering activities throughout a product realization process is demonstrated by Wagg et al. [29], and their W model, where the first iteration is a virtual prototyping stage, and the second cycle is the usage of the virtual models into a digital twin supporting data and workflow analysis.

As explored above there are several types of virtual tools and to summarize, it can be concluded that simluation softwares mimics the environment based on models, such as CAD models. Emulation software, however, mimics the hardware and the software features such as robot movements that can be used as an offline programming. And visualization can be described as a picture or sketch without the functionality as described for simulation and emulation softwares have.

3. Reflections from the industrial interaction

In the workshops for the three different virtual demonstrators, the authors participated in the discussions with the ambition to facilitate industrial reflections related to challenges and possibilities regarding the use of virtual tools during production preparation activities. During these workshops the following challenges summarize the overall observations from all three demonstrators:

- Challenging to quantify the improvements when using virtual tools and how they contribute to improvements – especially, to quantify whether tool utilization contribute to a faster process development from idea to practically implemented improvement.
- Both the virtual tools, and secured competence to interact with them in an efficient way, need to be in place. – ’In place’ should be viewed from the engineering, as well as from the information user perspective.
- Virtual tools need an organization that continuously maintain, upgrade, and secure relevant system user competence.
- From an engineering perspective, virtual tool support decisions related to conceptual design can reduce the need to build initial physical demonstrators.
- The virtual tools can be used to support decisions related to identified needs for redesign of components and/or products to achieve a better assembly task, especially if the assembly is to be supported by a robot.
- The virtual tools can be used to support layout design analysis before rearranging the factory floor as well as understanding the needs for floor space. This was particularly noticed when the layout should reflect a safe human-robot collaborative setting.
- The observations showed the importance of understanding the difference in capability between virtual tools, such as tools for visualization, emulation, and simulation.
- Virtual tool software algorithms must be developed for industrial analysis purposes.

4. Needs for a digitalized production preparation support for HRC layout design

4.1. Guideline for implementation of digitalized production preparation

There is an identified need for developing a supportive guideline for digitalization of production preparation, which supports decision-making [9] which contribute to improvements of the organizational KPIs. The KPIs needs to be related to critical aspects relevant for the production development situation, especially when it is related to human-robot collaboration layouts. Virtual tools can support, inspired by Mariotti [20], the collaboration in the transdisciplinary production preparation process [21], share information and knowledge between roles and needs [27] and learning to create knowledge through interorganizational collaboration by utilizing virtual tools in an efficient way [29]. In the industrial interactive workshops, it was identified a need to manage needs related to organization, technology, and personal skills. Based on this a conceptual guideline supporting a digitalized production preparation is presented in Table 1.

Table 1. Aspects to consider in a guideline for digitalized production preparation

Area of perspective	Needs
Organization	• Develop skills in digital tools, how they are used, interfaces, and which software for which application or need • Managing set-up time as well as learning curves in relation to upgrades of software tools
Technology	• Communication interfaces between different software's • Method forcontinuous upgrading as well as securing back-up and traceability between versions • Infrastructure for digitalized, and secure support
Skills	• Continuous traningto keep upwith the software development • Agility in adapting to new interfaces and technologies • Maintaning knowledge about older technologies still in use • Managing a continuously changing environment , where more and more information and data is searchable, which includes countinuous training of staff to understand what to search for, when and why

4.2. Aspects related to software support for the HRC layout design

When designing an HRC layout it is important to analyse the degree of interaction between the human and the robot [30]: (1) Independent – the human and the robot work separately on a workpiece without actual collaboration, (2) Synchronous – the human and the robot has a sequential task scheme, (3) Simultaneous – the human and the robot work at the same time on the same workpiece but on separate tasks, and (4) Supportive – the human and the robot work cooperativley on the same workpiece. These interaction aspects must be combined with a risk assessment procedurem adhering to existing standards, to identify hazards and safety risks in the layout design [8]. A generic procedure for designing a HRC layout are illustrated in Figure 1.

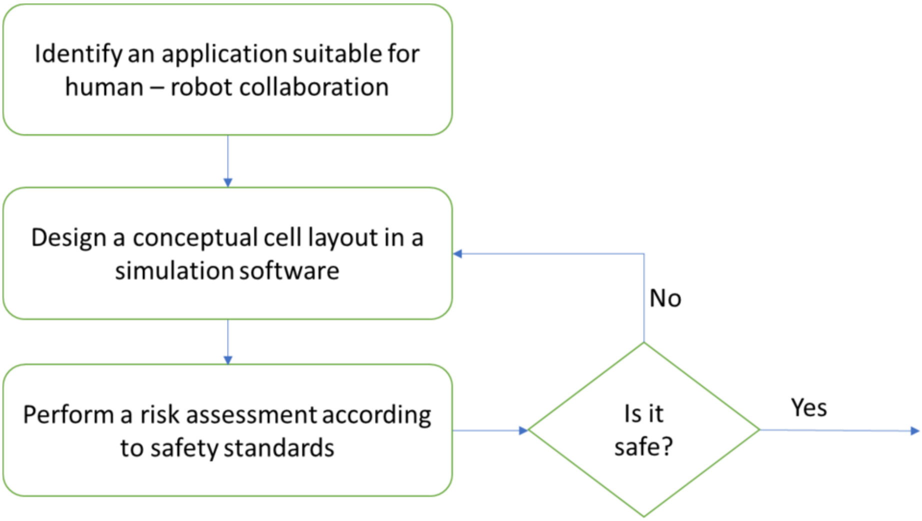

Figure 1. A generic procedure for designing a HRC layout (adapted from [8])

During the phase of designing the conceptual cell layout, usinga software tool (see Figure 1) it is important to reflect on the possibilities to evaluate the safety aspects as well as risks in the layout. Here, some needs are identified, such as understanding the capability of the different types of tools, such as in an early conceptual design using a visualization software for a layout without any functionality to get a view of the concept, using CAD for geometry simulation toanalyse the hazards in potential collisions between the human and the robot, the safety sensors interaction with the movements within the cell while collaborating, the ergonomic analysis of the collaborative tasks, the 3-dimensional challenges within the volume where the human and the robot are collaborating, in a flow simluation software,when analysing the productivity in the application while sharing a task between a human and a robot, or using a software for emulation, and when programming the robot for a safe interaction with a human. However, the challenge is to understand the level of reliability for each software when utilizing these as a support for analysing hazards related to a HRC layout. This is important to manage since the risks needs to be re-evaluated if the application is changed [15].

5. Discussion and conclusion

We have assumed that digital tools are implemented with the intention to improve the product realization process and increase companies' ability to create more Value with fewer Resources, over time. However, we have found that it is not obvious how virtual tools with its cost drivers (maintenance, up-grading, learning, securing interfaces to other users of information, competence, usage, archiving of models, back-traceable models, etc) efficiently can be integrated into existing product realization processes. The need to develop a secure digitalized environment, both from the perspective of cyber-security (information control) as well as from the human-robot collaboration perspective (as the reliability of safety sensors rely on cyber-security) adds to the efficiency challenge.

The findings indicate that it is important to develop a digital tool guideline that supports coordination of companies' resources (people, technology, and organization) to secure timely and cost-efficient decision quality, time-deliverables, and results. The identified aspects relevant for a guideline (see Table 1) needs to be related to the specified KPIs that contributes to the overall organizational strategy. One important challenge is to identify activities where virtual tools efficiently contribute to knowledge and can support analysis related to implementation of new emerging technologies, such as human-robot collaboration.

To conclude, there is a need for efficient and reliable assessment methods related to different activities in a digitalized production preparation process for HRC layout design:

- from the cell designing phase, to active operation
- from intital concepts produced by digital tools, to the re-use of models of older products and layouts
- from a human-machine-interaction perspective – both HRC as well as software interaction
- how to ensure safety in production, and security in software support or control

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