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## ASSESSMENT BASED INFORMATION NEEDS IN MANUAL ASSEMBLY

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### Abstract

To handle the complex and flexible manufacturing of today it is vital to have well functional information systems for the operators so that they know when, what and where to assemble. The current designs of assembly work instructions differ much between companies, but also between plants within the same company. The digitalization trends and initiatives such as Industry 4.0 show the manufacturing industry the advantages to incorporate new methods and tools into their businesses. Even though manufacturing IT systems are designed to be adaptive to product and volume changes, they are still widely characterized by their rigid structures. Making large changes to manufacturing IT systems with comprehensive structures is complex and requires large amounts of resources. Therefore, it is important for the manufacturing companies to make the correct investments. In previous studies, two current state analyses have been conducted with the aim to map manufacturing engineering processes and IT systems producing assembly work instructions in a mass customization context. This paper presents results from the third part of a longitudinal study which focuses on identifying operators' information needs in manual assembly of heavy vehicles. This third study aims to identify the information gap between the current state and the wanted state by assessing information needs at 13 assembly stations in three plants belonging to a global production network. The purpose is to identify design requirements for future assembly information systems enabling the practical use of the digitalization.

### Keywords:

Manufacturing systems, assembly information systems, cognitive automation, cognitive ergonomics, digitalization, Industry 4.0

## 1 INTRODUCTION

Industry 4.0 has become well known as a concept of the digitalization of the manufacturing industry. As technology becomes mature, the manufacturing industry has started to see the advantage of implementing this concept in practice. Despite the rapid changes in technology, there are still large challenges that need to be solved, e.g. standards/interfaces, data security, data quality, visualization, requirements engineering etc. [1,2]. To enable the ideas of industry 4.0, the industry requires a technology upgrade focusing on network technology to enable robust communication throughout the plant and the enterprise [3].

When it comes to the automotive industry, heavy duty trucks are characterized by low volumes and high customization levels which make it challenging to perform manufacturing preparation in a cost efficient way [4]. Previous research has shown that product variety is increasing [5,6] which affects productivity [7,8], the complexity in production [9] and production quality negatively [10]. These factors are difficult to handle in present manufacturing infrastructures. Manufacturing companies that have conducted heavy acquisitions in the past are at greater risks in terms of integration of business entities as well as processes and systems [11–13]. To be able to implement promising digitalization concepts in practice, the manufacturing companies need to be mature and susceptible for such changes. Therefore, it is important to understand the structural needs of these companies. Previous studies have focused on how assembly work instructions are produced in multi-nationals [14] and how these assembly work instructions are used in practice [15]. Furthermore, these studies have also shown that there are large improvement potentials in current assembly information systems.

This paper presents results from the third part of a longitudinal study which focuses on identifying operators'

information needs in manual assembly of heavy duty trucks, engines and transmissions.

This paper is organized as follows: The first section presents an introduction to research area elaborating about the digitalization trend; the second section presents the frame of reference for this study; the third section presents the methodology used in this study; the fourth section presents the result; the fifth section discusses the key findings; the sixth and final section presents the main conclusions of this study and proposes suitable future research activities.

## 2 ASSEMBLY INFORMATION SYSTEMS

An information system is designed to "get the right information to the right people at the right time in the right amount and in the right format" [16]. In assembly processes, the information system plays an important role as it contains all vital data for executing the assembly. All data in such a system is originated from the manufacturing engineering process which covers material handling, process development, process planning and other preparatory activities taking place before start of production [17]. Together, the information system and the manufacturing engineering process form the assembly information system which is in this research used to define the information flow through the manufacturing engineering process and throughout production.

### *Information support to operator in manual assembly*

Assembly errors increase if the components or the assemblies are complex and difficult to join [18]. Therefore, it is necessary to have support functions in place to guide the operator in the work. In manual assembly, the key to achieve high production quality is to enable a proper knowledge sharing from product design to production through assembly work instructions as part of the assembly information system. The challenge with such instructions is

that operators are highly different in terms of skills, experience, age, language etc. which make it difficult to design instructions that match the diversity of the operator workforce [19]. When deciding which support tools to use in assembly, it is from recent studies suggested that it is important to consider the time space flexibility meaning that different support tools have different strengths depending on which performance measures that are in focus [20].

In general, operators do have the necessary information available during the assembly work; however, such information is not always formulated in a suitable manner which affects the operator's ability to correctly navigate through provided assembly work instructions. As a consequence, the operator loses its focus and miss important information which affects production quality [21]. In theory, it is suggested that focus should be put on the information quality rather than on the amount of information. Such information needs to be accurate, complete, current, timely and relevant. In terms of communicating the same information, it is important to choose an adequate information carrier and to assure that the information is communicated on the correct detail level and clarity [22]. Such information is also designed and structured accordingly to the principles of cognitive ergonomics, meaning that the it provides the necessary feedback to minimizing incorrect actions [23].

According to Rasmussen [24], skill-, rule-, and knowledge based performance are three common levels of performance which emerge when assessing behavior of an human operator. Therefore, it is needed that assembly information is structured in such a way that it reflects the cognitive process of the operator. If the information is reflecting the cognitive processes of the operator, performance and satisfaction could be increased which also affects cycle time and cost reduction in production [25]. When it comes to the design of information in an assembly information system, the design requirements are different depending on system constraints such as cycle time length and variety levels and others. The more complex work situation, the more instructional information would be required by the operator. This have implications on both content and carriers in terms of assembly work instructions [26].

#### *Manual assembly and the digitalization focus*

The focuses on the digitalization in governmental strategic plans across the world reflect the ongoing activities both in academia and industry. As researchers suggest that cyber-physical assembly systems can provide improved production performance [27], there are new possibilities of implementing new technology to support operators in manual assembly. Already a decade ago, industry started to implement smart sensors in their production to improve traceability which in earlier research has been suggested to increase the collaborative, flexible and responsive characteristics of manufacturing systems which continuously become more complex every day [28].

To better cope with variety and frequent updates in the assembly information systems, digital assembly work instructions would be better suited for such circumstances. Furthermore, to be able to increase mobility and flexibility in assembly work, mobile devices are well suited information carriers [26]. This has also been shown in previous research which indicated improved production quality when assembly work instructions were presented on mobile devices instead of on fixed computer screen. One suggested reason behind this result is that the operator is keen of using the supplied information if it is more accessible at the work cell [29].

Additionally, technology development has come far in order to create new methods to perform virtual training [30],

virtual simulation [31] and other activities within the area of virtual manufacturing. These methods contribute to make production more flexible, efficient and more reliable as the chain between product design and production becomes more intact. These methods do also contribute to improvements of the work cell as they include the operator as a parameter in the process. Virtual manikins have in at least one study been used to test automatically generated assembly work instructions through simulating the assembly sequence. One benefit of such an approach is to be able to set production parameters in much earlier phases than today [32].

Devices enabling technologies such as augmented reality (AR) and virtual reality (VR) provide the possibilities to present assembly information to operators in new ways, expanding the opportunities to provide cognitive support. Some studies have been conducted [33], but there is still much research needed to fully incorporate the potentials from virtual technologies in the manufacturing industry. Moreover, as the introduction of new information technologies increases, there are needs for new information systems which can contribute with structure and efficiency to enable the fully potential of the technology [34].

### **3 METHODOLOGY**

This study has been carried out at a global case company with a global production network, GPN, consisting of 40 producing units. The case company produces heavy duty trucks under different brands with extreme customization levels as well as engines and transmissions. The investigation focuses on identifying main enablers and functionalities for future assembly information systems. The study follows a qualitative approach where operators, production technicians and other functions belonging to the manufacturing engineering organization at the case company have been interviewed. To be able to choose a suitable number of assembly and preassembly stations, both the global and local manufacturing engineering organization participated in the study:

1. Relevant assembly activities that are characteristically for assembly of heavy vehicles and heavy vehicles components have been identified.
2. On basis of the assembly activities, 13 assembly and preassembly stations have been chosen in three different plants within the same GPN.

The three chosen plants in the GPN are:

- Plant A - Cab & Vehicle assembly
- Plant B - Engine assembly
- Plant C - Transmission assembly

In total, 25 operators have been interviewed using a semi structured interview strategy. Furthermore, 7 production technicians, production leaders and other manufacturing engineering roles have also been interviewed to be able to capture different aspects of the information needs in manual assembly, see Table 1.

Table 1. In total, 32 persons have been interviewed. One of the interviewees is working in a global function and therefore not listed in the table.

Plants	No. of Stations	No. of Operators	No. of White-collars
Plant A	6	12	3
Plant B	4	7	2
Plant C	3	6	1

The interview data have later been summarized and organized as general process enablers and proposed focus areas for improvements and information detected during the interviews. The following section presents the collected data and analysis.

#### 4 RESULTS: INFORMATION NEEDS IN FUTURE ASSEMBLY INFORMATION SYSTEMS

The objective of this study has been to identify what the information needs are in manual assembly work. By interviewing operators and different functions within manufacturing engineering, improvement potentials and enablers for future assembly information systems have been collected. The data has been analyzed and categorized to form focus areas which are needed to improve assembly information quality in future assembly information systems. Some of the collected data covered problems in current processes and has been categorized on basis of the problem types. These problems need to be emphasized to improve the assembly information system and to utilize its fully potential. The following sub sections will present the identified process problems in the current setup of the assembly information system and focus areas based on the interviews held.

##### 4.1 Process problems in current setup

During the interviews, some of the gathered information has been categorized as process problems, see Figure 1. To be able to achieve the intended functionality of the cognitive support in future assembly information systems, these problems need to be solved. The information from the interviews has been categorized in four categories; Instruction errors; updating of instructions; on-the-job training; feedback and follow-up.

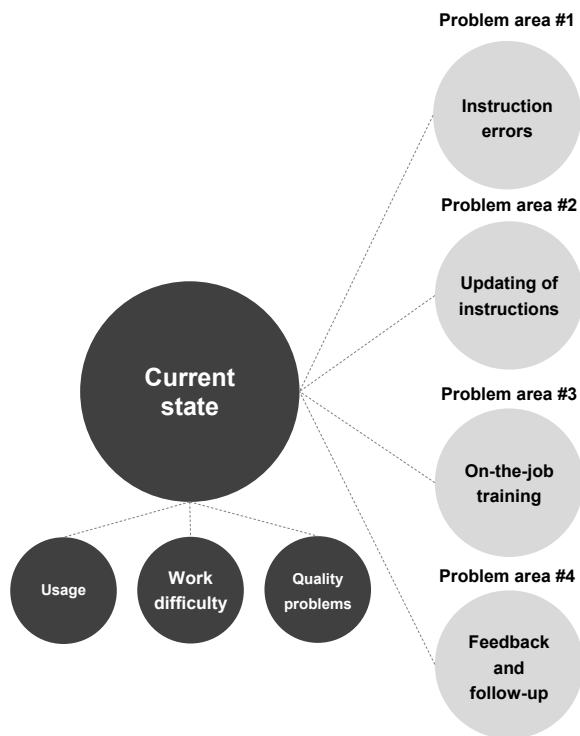


Figure 1. Four problems areas are identified on basis of the data analysis, which are classified as enablers of future assembly information systems.

##### Instruction errors

One of the issues that have been brought up by the operators is errors in assembly work instructions. 44 % of the operators across the three plants stated that the instructions sometime contain errors, especially for rare product configurations. Even though the amount of errors has decreased during the last years, only 56 % of the interviewed operators state that they mostly trust the information in the assembly work instructions. Additionally, errors in instructions tend to increase during rebalancing. Most of the interviewed operators state that they feel included in the development and correction of instructions.

##### Updating of instructions

When updating instructions, both for improvements in terms of adding comments and for correcting errors, it has during the interviews become evident that at one of the plants it takes three weeks before a correction is possible to see in the assembly work instruction. This is due to a system constrain. This delay cause unnecessary assembly errors because of errors in the instructions, which have already been corrected in the assembly information systems. At all plants, it takes, in general, too long time until errors are corrected in the assembly work instructions. Consequently, the amount of temporary instructions is increasing.

##### On-the-job training

On basis of the interviews, education, on-the-job training and knowledge are important factors when talking about assembly work and assembly work instructions. All interviewed operators stated that their initial training has been provided at the production line where they worked closely with another operator. No training is provided before an operator can perform any kind of work on the production line. Most operators find this as unsatisfactory. 48 % of the operators stated that there is a variety in how the training is conducted, since operators on the production line train novice operators. 56 % of the operators said that they obtain different knowledge because of this variation. 56 % of the operators did also state that operators lack general knowledge about the work they conduct. This lack of knowledge affects production quality negatively as suggested by one of the interviewees who had made assembly errors which unconsciously affected an operator some stations later in the production line.

##### Feedback and follow-up

According to the general assembly process, when assembly errors have occurred, the operator should be notified and be provided with feedback on the incident; however, at Plant B, 58 % of the operators stated that this feedback is not provided or is very sporadic.

##### 4.2 Focus areas to improve information quality

Based on the interview data, three focus areas have been defined during the data analysis, see Figure 2. The data from the three plants differ as the products they produce differ in terms of complexity. Additionally, the cycle times are much higher for truck assembly than engine and transmission assembly which also affect the operator needs of cognitive support. The truck assembly plant uses one assembly information system where the assembly work instructions are paper based, while the engine and transmission plants uses another assembly information system which also presents the assembly work instructions in a digital format.

##### Assembly information match

One of the main questions during the interviews has been to identify what assembly information operators need to conduct their assembly work. Since the plants produce different product types, the data from the interviews differ.

In general, the assembly information demands at the truck assembly plant (Plant A) are higher due to longer cycle times and high product variety. In general, there is miss match between usage of information and the need of information. Too much information is presented to the operators. In Plant A, 83 % of the interviewed operators stated that they are only searching for specific information while at Plant A and Plant B the number is lower at 54 %.

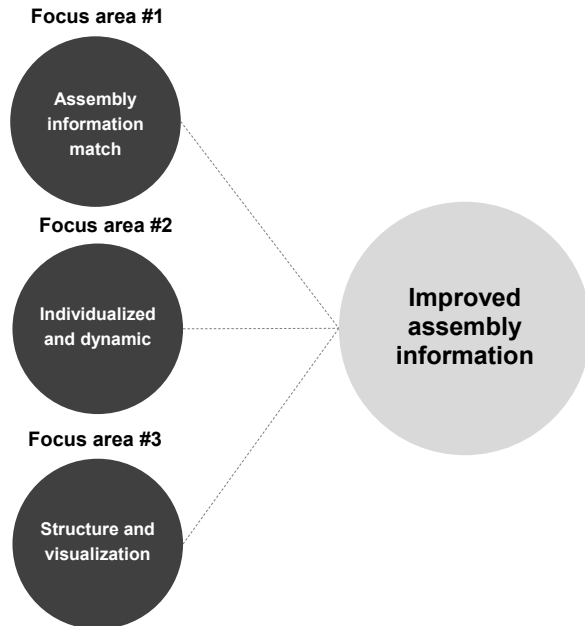


Figure 2. Three focus areas are defined on basis of the data analysis, which contributes to improved assembly information.

Today, basic assembly information, containing attributes such as Product ID, part number, part name, quantity, is provided in the assembly work instructions together with comments and descriptions are provided to the operators. However, in a recent study based on the same sample of assembly stations, it has been shown that much of the provided information in the assembly work instructions is rarely used, especially in Plant A [15]. information that is real-time based, sequenced, indicating where to assemble, how to assemble, changes, common problems with solutions, general knowledge about the assembly task and increased mobility, are requested in future assembly information systems. The right amount of information, when it is needed, is the most fundamental need stated during the interviews. The main part of the current assembly information provided is text based. Operators did also request higher availability of pictures in their assembly work instructions that could be used for quality control and educational purposes. Additionally, operators asked for improved feedback functionality from the assembly information system e.g. electric nutrunners which send feedback on actual torque value.

#### *Individualized and dynamic assembly information*

The need for assembly information varies due to different experience among the operators and has been stated during the operator interviews. One operator stated that *"the instructions are too extensive for experienced operators and too poor for novices"*. Therefore, the satisfactory level of the assembly information is generally low. Several operators suggested that there should be a possibility for the operator to choose the detail level of the

information provided in the assembly work instructions. Experienced operators suggested that standard information that mostly is the same for each product should not be shown. Instead, the focus should be put on the information belonging to the varying part numbers. Adjustable information amounts in the assembly work instructions would decrease the unnecessary time spent searching for needed information and reduce the amount of assembly errors in terms of missed/wrong part which is stated as one of the most occurring issue. Individualized and dynamic assembly information is also support by several of the interviewees from manufacturing engineering.

#### *Structure and visualization*

In Plant A, most interviewed operators raised concerns about the structure, logic and visualization of the assembly work instructions. In this plant, the assembly work instructions contain large amounts of information that are seldom or never used by the operators. Therefore, it becomes difficult for the operators to navigate through the assembly work instructions. Nearly half of the interviewed operators in Plant A suggested that the language in the instructions is too technical and difficult to comprehend. Therefore, assembly work instructions are difficult to use by novice operators. In Plant B and C, the operators are in general satisfied with the structure of their assembly work instructions which are short and lack the unnecessary information provided in Plant A. The operators, did however agree to the fact that the instructions are difficult for novice operators to interpret and use.

## 5 DISCUSSION

This study has investigated current assembly information systems with the purpose of identifying change requests in what information that should be provided to the operators in manual assembly and how future assembly information system should be designed to offer better cognitive support to the operators. The identified problem areas limit the possibility to successfully develop a future assembly information system and needs to be solved prior to such an implementation. The focus areas defined, are suggested to improve assembly information in manual assembly and production quality.

Today, production quality is affected by incidents caused by missed/forgotten parts, wrong parts, assembly on wrong positions, assembly errors, negligence and technical issues. Additionally, since the product variety is high in the plants, there is limited time for adjustments throughout the assembly cycle.

At one of the plants, most of the operators stated that there is too much information provided in their assembly work instructions. This affects the ability of the operators to quickly identify the needed assembly information for that assembly task. As the amount of information in the assembly work instructions A in general is too high, an optimal structure of the instructions is therefore even more important to provide the cognitive support as intended. On the other hand, at the other plants in the sample, the structure and visualization of the assembly work instructions are not well-suited for novice operators as they provide no guidance on how the task should be executed. This is one of the reasons many operators choose to rely on their experience and other operators' experience and not continuously read the assembly work instructions. This is supported in literature which suggests that all necessary information most often is provided, but does not necessarily stimulating attention and the so called information seeking process [21]. To improve the usage of the instructions, they need to be better structured and visualized to support the operator when needed rather than

being an additional disturbance in their assembly work. From a recent study, a list of attributes presenting available assembly information at the same sample stations showed that a majority of the information presented is rarely or never used in practice [15]. This indicates the future assembly information systems need to better incorporate better information sharing in terms of information carrier and suitable information detail level [23,24]. Additionally, future assembly information systems need to be flexible towards the choices of how information should be presented to the operators depending on the constraints of the assembly situation. Current assembly information systems are difficult to adjust to changed circumstances due to the complex infrastructures.

In literature it has been suggested that instead of focusing of the amount of information, the information quality should be in focus [22]. The data from this study shows that information quality needs to be improved in the assembly work instructions to regain the operators' trust in provided assembly information. Furthermore, the process handling information errors also needs to be improved, shortening the lead time for problem solving.

Operators did also request more individualized and dynamic assembly work instructions which is also supported by manufacturing engineering. The idea of providing individualized information would decrease non-value adding activities in the assembly cycle as the experienced operator is only requesting assembly information for rare product configurations and hence, unfamiliar circumstances. This would indeed support the fact that cognitive support should be provided on basis of the complexity of the work station [26] and reflect the experience of the operator. For the novice operator, this would imply that assembly information is more detailed in the beginning and reduced when becoming more experienced.

During the interviews, much information has been focused on process problems. Most the operators stated that current on-the-job training is not preparing the operator for the specific assembly work to be carried out. To take the advantage of future assembly information systems, adequate training needs to be implemented which considers not only the assembly task itself, but also quality and product knowledge. This has been suggested by both operators and from manufacturing engineering, to improve general knowledge and accountability in work. The training as such, should be verified through some form of certification procedure. Training has in literature been shown to better prepare experienced operators for new vehicle introductions. Furthermore, virtual training improves performance compared to traditional operator training [35]. Additionally, the implementation of virtual training could be used to individually adjust the information content to match the training records of the operator. Those results clearly show that proper training processes are vital for stable and high production quality.

When assembly work instructions contain errors, it affects the operators' trust in information. Additionally, if instructions contain errors, operators tend to rely more on their experience or coworkers experience. If the lead time between error correction and updated instructions is too long, operators do also tend to rely on their experience. Such consequences undermine the idea of the assembly information system and the work with cognitive support to the operator. Future assembly information systems need to enable feedback from operators throughout the assembly process in real-time. Additionally, such information needs to be used in proper follow-up processes to successfully work with continuous improvements.

The mentioned problem areas and suggested focus areas which possibly would improve assembly information quality

are important when developing framework and standards for future assembly information systems. As the initiatives as the digitalization and industry 4.0 will continue to receive much focus, it is important to incorporate the industrial requirements in such initiatives. In such a way, the suggested performance improvements in cyber-physical assembly systems [27] can be achieved.

## 6 CONCLUSION

As the complexity in assembly process continuous to increase because of longtime increased product variety, new assembly information systems need to be developed to address these challenges in a proper way as well as to be flexible towards future challenges. This study contributes to the development of future assembly information systems by investigating information needs in manual assembly in high product variety environments. This study has resulted in four identified problem areas:

1. Instruction errors
2. Updating of instructions
3. On-the-job training
4. Feedback and follow-up

which are identified to limit the performance of assembly systems. The identified problem areas highlight process problems which need to be solved to be able to implement the full potential of future assembly information systems.

Moreover, three focus areas have been identified:

1. Assembly information match
2. Individualized and dynamic assembly information
3. Structure and visualization

which are suggested to contribute to improved assembly information quality, better cognitive support and a better designed assembly information system. With such a system in place, the possibilities to provide optimal cognitive support functionality and assembly information to operators in manual assembly will be significantly improved.

### 6.1 Future work

This study has gathered much data from operators and engineers which contributes to the understanding of process problems and information needs in manual assembly of products which contain unique configurations. Future work will focus on how other global manufacturing companies work with assembly information systems and what challenges they face in their manual assembly processes.

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## 8 REFERENCES

- [1] Thoben K., Wiesner S., Wuest T., 2017, "Industrie 4.0" and Smart Manufacturing – A Review of Research Issues and Application Examples, *Int. J. Autom. Technol.*, 11, pp. 4–16.

- [2] Schuh G., Anderl R., Gausemeier J., Hompel M., Wahlster W., 2017, *Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY)* Herbert Utz Verlag, Munich.
- [3] ElMaraghy H., ElMaraghy W., 2016, Smart Adaptable Assembly Systems, *Procedia CIRP.*, 44, pp.4–13.
- [4] Blecker T., Friedrich G., Kaluza B., Abdelkafi N., Kreutler G., 2005, *Information and Management Systems for Product Customization* Springer Science & Business Media, Boston.
- [5] Fisher M., Jain A., MacDuffie J.P., 1995, Strategies for Product Variety: Lessons from the Auto Industry, in: E. Bowman, B. Kogut (Eds.), *Redesigning Firm*, 1st ed., Oxford University Press: pp. 116–154.
- [6] ElMaraghy H.A., 2009, Changing and Evolving Products and Systems – Models and Enablers, in: H.A. ElMaraghy (Ed.), *Chang. Reconfigurable Manuf. Syst.*, Springer-Verlag: pp. 25–46.
- [7] MacDuffie J.P., Sethuraman K., Fisher M.L., 1996, Product Variety and Manufacturing Performance: Evidence from the International Automotive Assembly Plant Study, *Manage. Sci.*, 42, pp.350–369.
- [8] Fisher M.L., Ittner C.D., 1999, The Impact of Product Variety on Automobile Assembly Operations: Empirical Evidence and Simulation Analysis, *Manage. Sci.*, 45, pp.771–786.
- [9] ElMaraghy W., ElMaraghy H., Tomiyama T., Monostori L., 2012, Complexity in engineering design and manufacturing, *CIRP Ann. - Manuf. Technol.*, 61, pp.793–814.
- [10] Fast-Berglund Å., Fässberg T., Hellman F., Davidsson A., Stahre J., 2013, Relations between complexity, quality and cognitive automation in mixed-model assembly, *J. Manuf. Syst.*, 32, pp.449–455.
- [11] Hitt M.A., Ireland R.D., Harrison J.S., 2001, *Mergers and Acquisitions: A Guide to Creating Value for Stakeholders* 1st ed. Oxford University Press, New York, New York, USA.
- [12] Ireland R.D., Hoskisson R., Hitt M., 2008, *Understanding Business Strategy: Concepts and Cases* 2nd ed. Cengage Learning.
- [13] Verbeke A., International acquisition success: Social community and dominant logic dimensions, *J. Int. Bus. Stud.*, 2010, 41, 38–46.
- [14] Johansson P.E.C., Delin F., Jansson S., Moestam L., Fast-Berglund Å., *Global Truck Production – The Importance of Having a Robust Manufacturing Preparation Process*, *Procedia CIRP.*, 2016, 57, 631–636.
- [15] Johansson P.E.C., Enofe M.O., Schwarzkopf M., Malmköld L., Fast-Berglund Å., Moestam L., 2017, Data and Information Handling in Assembly Information Systems – A Current State Analysis, *Accept. to Be Publ. Procedia Manuf.*
- [16] Rainer R.K., Cegielski C.G., 2011, *Introduction to information systems* John Wiley & Sons.
- [17] Scallan P., 2003, *Process Planning* Butterworth-Heinemann.
- [18] Swift K.G., Booker J.D., 2003, Assembly Systems, in: *Manuf. Process Sel. Handb.*, Elsevier: pp. 281–289.
- [19] Menn J.P., Seliger G., Increasing Knowledge and Skills for Assembly Processes through Interactive 3D-PDFs, *Procedia CIRP.*, 2016, 48, 454–459.
- [20] Li D., Mattsson S., Fast-Berglund Å., Akerman M., Testing Operator Support Tools for a Global Production Strategy, *Procedia CIRP.*, 2016, 44, 120–125.
- [21] Bäckstrand G., 2009, *Information Flow and Product Quality in Human Based Assembly*, Loughborough University.
- [22] Beynon-Davies P., 2013, *Business information systems* 2nd ed. Palgrave Macmillan.
- [23] Hollnagel E., Cognitive ergonomics: it's all in the mind, *Ergonomics.*, 1997, 40, 1170–1182.
- [24] Rasmussen J., Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models, *IEEE Trans. Syst. Man. Cybern.*, 1983, SMC-13, 257–266.
- [25] Mattsson S., Fast-Berglund Å., Stahre J., Managing Production Complexity by Supporting Cognitive Processes in Final Assembly, in: *Proc. 6th Swedish Prod. Symp.*, .
- [26] Fässberg T., Fasth Å., Stahre J., 2014, A classification of carrier and content of information, in: J.S. Hu (Ed.), *Proc. 4th CIRP Conf. Assem. Technol. Syst.*, : pp. 1–4.
- [27] Hold P., Ranz F., Sihn W., Hummel V., Planning Operator Support in Cyber-Physical Assembly Systems, *IFAC-PapersOnLine.*, 2016, 49, 60–65.
- [28] Zaeh M.F., Reinhart G., Ostgathe M., Geiger F., Lau C., A holistic approach for the cognitive control of production systems, *Adv. Eng. Informatics.*, 2010, 24, 300–307.
- [29] Thorvald P., Brolin A., Hogberg D., Case K., Using Mobile Information Sources to Increase Productivity and Quality, *Proc. 3rd Int. Conf. Appl. Hum. Factors Ergon.*, 2010, 450–459.
- [30] Malmköld L., 2012, *Virtual Training - Preparatory Training in Automotive Assembly*, Chalmers University of Technology.
- [31] Schulz W., Bischof C., Bobzin K., Brecher C., Gries T., Jeschke S., Kampker A., Klocke F., Kühlen T., Schuh G., Apel M., Arping T., Bagcivan N., Bambach M., Baranowski T., Bäuml S., Beer T., Benke S., Bergs T., Burggräf P., Cabral G., Eppelt U., Fayek P., Fey M., Franzkoch B., Freyberger S., Glasmacher L., Heesel B., Henke T., Herfs W., Jansen U., Kashko T., Kononov S., Kuckhoff B., Laschet G., Linke M., Lohse W., Meisen T., Minoufekar M., Nöcker J., Prahl U., Quade H., Rasim M., Rauhut M., Reinhard R., Rosenbaum J., Rossiter E., Schilberg D., Schmitz G.J., Trieb J., Wegner H., Wesch-Potente C., 2012, *Virtual Production Systems*, in: *Integr. Prod. Technol. High-Wage Ctries.*, Springer Berlin Heidelberg, Berlin, Heidelberg: pp. 241–434.
- [32] Mårdberg P., Carlson J.S., Bohlin R., Delfs N., Gustafsson S., Högberg D., Hanson L., Using a formal high-level language and an automated manikin to automatically generate assembly instructions, *Int. J. Hum. Factors Model. Simul.*, 2014, 4, 233–249.
- [33] Radkowski R., Herrema J., Oliver J., Augmented Reality-Based Manual Assembly Support With Visual Features for Different Degrees of Difficulty, *Int. J. Hum. Comput. Interact.*, 2015, 31, 337–349.
- [34] Akerman M., 2016, *Towards interoperable information and communication systems for manufacturing operations*, Chalmers University of Technology.
- [35] Malmköld L., Örtengren R., Svensson L., Training Virtually Virtual, *Int. J. Adv. Corp. Learn.*, 2012, 5, 29–37.