Enhancing Future Assembly Information Systems – Putting Theory into Practice

(article starts on next page)

28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018), June 11-14, 2018, Columbus, OH, USA

Enhancing Future Assembly Information Systems – Putting Theory into Practice

Pierre E. C. Johansson[a,b,]*, Lennart Malmsköld[c], Åsa Fast-Berglund[b], Lena Moestam[a]

[a]Volvo Group Trucks Operations, Gothenburg 405 08, Sweden
[b]Chalmers University of Technology, Gothenburg 412 96, Sweden
[c]University West, Trollhättan 461 86, Sweden

Abstract

The manufacturing industry is in a changing state where technology advancements change the mindset of how manufacturing systems will function in the future. Industry 4.0 provides manufacturing companies with new methods for improved decision-making processes and dynamic process control. Despite this ambition, the manufacturing industry is far away from implementing this approach in practice. Assembly information systems will play an even more vital role enabling information transfer from product design to shop floor assembly in the future. To prepare the industry for these changes that are foreseen and for those that are yet to be discovered, a learning factory environment is vital. Such an environment is intended to support the industry during the development of assembly information systems. This paper presents an industrial demonstrator which incorporates well-known methods for improving assembly work stations with the perspective on assembly information systems. These methods are still not widely used in manual assembly intense manufacturing companies. This demonstrator illustrates how established theories can be practically used when designing future assembly information systems. The demonstrator will be used to validate functionalities and requirements for future assembly information systems.

Keywords: Assembly Information Systems; Learning factories; Digitalization; Assembly systems

1. Introduction

The transition towards digitalized manufacturing organizations has changed the way manufacturing will be conducted in the future. With Industry 4.0, the manufacturing industry will gain from improved decision making and dynamic process control based on digital models and collected process data [1,2]. To support the manufacturing industry to adhere to the concept of Industry 4.0, a maturity index has been established which presents six stages that the manufacturing company need to accomplish [2]. These stages include stage 1 – computerization, stage 2 – connectivity, stage 3 – visibility, stage 4 – transparency, stage 5 – capacity prediction and stage 6 – adaptability. Despite this ambition, the manufacturing industry is far away of taking such large steps. Several problem areas have been identified in the manufacturing industry where the problems that strongly limits the ability to fully incorporating the concept of Industry 4.0 [3,4].

The manufacturing industry is strongly characterized by the philosophy of continuous improvements to improve work standards and methods [5]. Systematic improvements in the manufacturing industry has allowed the industry to handle an ever increasing product variety with high quality but to a low cost [6]. The consumer market is rather quick to adapt to new technologies and smart services. As the digitalization is currently redefining the manufacturing industry, one might wonder – *why do we not facilitate technology and services at work as we do at home*? New technology has the benefit of augmenting knowledge and skills and make complex tasks easier to conduct [7].

In manual assembly, operators are facing the impact of highly customized products. Highly customized products increase option content and the number of options the operator needs to choose from during an assembly task. The difference in option content has negative impact on productivity [8]. While the product variety continues to increase [9,10], the complexity at the work station has started to get more and more attention [11,12]. In order to handle such complexity, the operator needs sufficient support in terms of assembly information in sufficient format [13].

As an ambition to support the industry, focus areas have been identified to address current issues in the manufacturing industry such as instruction errors, updating of instructions, on-the-job training and feedback and follow up [3,4]. The focus areas cover assembly information match, individualized and dynamic and structure and visualization which are intended to make processes more robust and to assure that the business is prepared for the transition towards a digitalized manufacturing industry. As part of these focus areas are identified stakeholder requirements for future assembly information systems (AIS) which address current assembly challenges and assure that future AIS are flexible and adaptable. One of the problems with radical innovation within manufacturing is that it is difficult to demonstrate the true value of the innovation in an existing manufacturing context. Therefore, industrial demonstrators are developed which facilitate real manufacturing in a small scale.

During 2011, an industrial demonstrator was developed with the purpose to show how a Manufacturing Execution System functions within a manufacturing company [14]. The practical use of such a demonstrator is to train different stakeholders both within and outside the manufacturing context. During 2015 an additional industrial demonstrator, influenced by the design of the previous one, was developed with the purpose to be used as an educational arena focusing on digital assembly work instructions using 3D data models [15]. These industrial demonstrators serve an educational purpose on different levels, both for management and operations. Industrial demonstrators have large potential to demonstrate new functionalities and emerging technologies.

This paper presents an industrial demonstrator which is developed to demonstrate some of the aspects which have been identified during intensive case studies made [3,4,16–19]. The purpose of the demonstrator is to validate the outcome of the case studies and to evaluate if there are positive links between usability of assembly information during assembly and production quality. The industrial demonstrator will function as an educational arena for future manufacturing systems. The demonstrator scope is based on the IS Success Model focusing on information system quality, information quality and service quality [20,21]. The paper presents the design of the demonstrator, the use cases of the demonstrator and the end user tests to be conducted.

2. Transition towards digitalization

The complexity of an assembly work station is defined by many attributes. There are three complexity sources related to an assembly work station – task complexity which includes the assembly work instruction, equipment and facilities complexity e.g. robots, and management coordination complexity e.g. line balancing. There also four sources of complexity which in general lie out of the control of the plant – product complexity, number and similarity of products in the plant, marketplace complexity and supply chain complexity [22]. To handle this amount of complexity, proper data and information is required throughout the product realization process.

Information is data which has reached the state of providing the user some meaning e.g. who, what, where etc. [23]. The information system defined as getting "the right information to the right people at the right time in the right amount and in the right format" [24] is vital in a manufacturing context. It contains the assembly information which is used to create assembly work instructions to the operator. In situations where components are complex to assemble, the probability of occurring assembly errors increases [25]. Therefore, it is needed that proper assembly information is presented to the operators in the most effective way. Assembly work instructions on paper tends to be difficult to interpret based on the amount of information in the shape of text and numbers [4,26]. As a consequence, operators neglect the instructions as they find it too time consuming to find information that provides any added value to the specific assembly situation. Instead they trust their own experience [11]. A framework of instruction information quality problems have been presented [27] where the "intrinsic" problems such as deficiency, ambiguousness, neediness, incorrectness and repetitiveness will be addressed further ahead in this paper.

A learning facility could be useful for demonstrating an example of a future assembly work station with active complexity handling such as dynamic assembly information towards the operator.

2.1. Learning factories

Learning factories is a popular terminology used by institutes and research organizations to describe their labs where research in the fields of digitalization and industry 4.0 takes place. In 1995 the first learning factory was established at Penn State University with the purpose to integrate product development and manufacturing issues [28]. The concept of a learning factory consists of two parts, the educational environment and the manufacturing environment [29]. Furthermore, the learning factory should focus on the attributes of the learner and adapt the learning process accordingly [30]. There are six different applications of learning factories [31]:

- Industrial application scenario,
- Academic application scenario,
- Remote learning scenario,
- Changeability research scenario,
- Consultancy application scenario,
- Demonstration scenario.

Even though learning factories are much often focused on the digitalized manufacturing process, Haghighi et al. [30] argue that a totally virtual learning factory is not feasible due to the lack of representation of physical attributes such as touch and feel and concepts such as teamwork etc. The virtual learning factory should therefore be a supplementary tool to the physical learning factory. Reducing the gap between the real and digital world makes the factory environment more flexible, more adaptive, but also demands broader skills of human workers [32]. *A Cyber Physical Production Testbed (CPPS)* is established at Chalmers University as a hybrid learning factory, which combines physical, digital and virtual environments [33]. The Industry 4.0 concept anticipates that Internet technologies will find their ways into future factories replacing traditional components by dynamic and intelligent cyber-physical systems (CPS) that combine the physical objects with their digital representation. This paper represents an industrial application scenario using a physical environment combined with digital solutions for assembly instructions. Such a scenario is suitable for bridging the knowledge gap between current assembly information strategies and future assembly information systems.

3. Industrial application scenario

Despite the rapid technology transformation in society, the manufacturing industry is a conservative sector and is not as technology mature as it could be. The overall complexity within a global production network makes it difficult to make large transformations which each producing unit can benefit from. To prevent supplied assembly information from not being used [4,11,34], the aim of the demonstrator is to evaluate, demonstrate and educate operators and management in how an assembly workstation can be equipped and designed in the future. With an enhanced assembly information system, it would be possible to utilize new functionalities not only towards operators, but to all stakeholders within the manufacturing process. Today, lots of technologies have matured and are ready for implementation in the manufacturing industry. The intention of the industrial demonstrator is to accelerate such implementations and to show the benefits of using new technologies in the manufacturing processes. As seen in many cases, obstacles for innovation in the manufacturing industry, often lies in unawareness of new technologies and lack of holistic perspective when planning investments in the global production network. There are several conditions for the manufacturing industry to meet to be ready for Industry 4.0 [2]. Despite the non-controversial conditions, the manufacturing industry is far away from fulfilling them. This demonstrator serves the purpose of showing how such conditions will practically function. Additionally, by focusing on the attributes of the tester, the demonstrator will provide a better learning outcome [30].

3.1. Demonstrator design

The demonstrator has been designed to enable flexible manufacturing systems that handles high levels of product customization. The demonstrator consists of flexible modules in terms of material racks, product fixtures and both analog and digital tools. The demonstrator allows part securing as well as kitted and sequenced material. The demonstrator does also use an electric nutrunner which allows enhanced control over tightening quality, production quality as well as overall productivity. All assembly information is digital, order specific, dynamic and adaptable to the experience level of the operator as well as the operator's own preferences in terms of assembly instruction layout, language and text size. For this demonstrator commercial off-the-shelf software has been chosen since the current version of the software already qualifies for several of the functions required. The software consists of two modules, one module functioning as the manufacturing engineering part and one module used as an HMI showing assembly work instructions as well as other interactive functions. Since the HMI is enabled by responsive web design throughout a web browser [35], the layout of the assembly information is adjusted to the screen size of the information carrier allowing assembly information to be optimally displayed on both stationary displays as well as on mobile devices.

By a close collaboration with the software supplier more of the defined requirements could be implemented in the demonstrator, e.g. changing the layout of the assembly information. The design requirements of the demonstrator are in line with the two first stages of the Industry 4.0 Maturity Index [2]. Fig. 1 provides an illustration over the developed assembly work station (demonstrator).
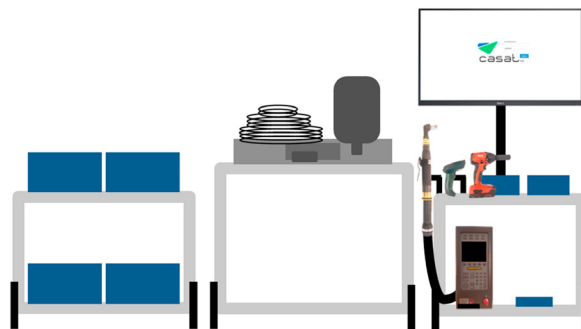

Fig 1. Demonstrator for future assembly work stations.

In Table 1, the demonstrator functionalities (requirements) are presented.

Table 1: Functionalities for the demonstrator are linked with Industry 4.0 Maturity Index and other references.

Functionalities (requirements)	I 4.0 Maturity Index	References
Digital assembly work instructions	Stage 1	[26,36–39]
Dynamic assembly work instructions	Stage 2	[3,38]
Product variant driven assembly work instructions	Stage 1	[3,40]
Responsive assembly information layout	Stage 1	[35]
Mobile assembly information	Stage 1	[34,41]
Experience based assembly information	Stage 2	[3,41]
Operator optional settings as text size, language and layout	Stage 1	[3,41]
Real time reporting on assembly disruptions	Stage 2	[3]
Traced reading receipts on change notices, warnings and other messages during an assembly cycle	Stage 2	-
Connected tools through easy set up (plug & produce)	Stage 2	[2,42]

The idea of having digital assembly work instructions instead of paper-based instructions have been discussed over a long period of time. In the automotive industry there are great examples of using digitized assembly work instructions. Digitized assembly work instructions as well as dynamic ones have large benefits compared to analog ones [26,36–39].

By having too much information available it becomes difficult for the operators to distinguish relevant information from peripheral information [27,43]. Therefore, the information content should be adjusted to fit the experience of the operator as well as personal preferences. Experienced operators will be provided with brief information focusing on explicit information such as variant driven components rather than general procedures, while novice operators will be guided by procedural information (WHAT, HOW, and WHY) and supportive images. Additionally, the layout of the assembly work instruction will also be adapted to the experience level of the operator. For the experienced operators, the instruction will mainly focus on the part list containing part names and numbers, while the instruction for the novice operator will focusing on step wise instructions with supportive images. The assembly information will be available in two languages (English and Swedish) and is adapted to the preferences of the operator.

Mobile information provides better production quality than stationary information at the work station [34], therefore, mobile information will be an alternative to the stationary monitor in the demonstrator. To fulfill the connectivity condition in the maturity index [2], an electric nutrunner will be connected to the demonstrator HMI using a provided gateway. As several interviewees have stated during the recent studies, it is seen as important to assure that messages from engineering to the operator, as of changes notices, quality messages, warnings etc., are traced to assure that operators always have the latest information during assembly.

3.2. Demonstrator use cases

The demonstrator covers four real pre-assembly stations within base module assembly for heavy-duty trucks. The four stations are in sequence where crossbeam members are being assembled. The crossbeam member is positioned in between the two frame rails that constitute the main part of the base module (truck body). The crossbeam member is placed over the rear axles (bogie) position as seen in Fig. 2. In the demonstrator, the crossbeam member is positioned on a fixture and material racks are interchanged as the assembly goes along the scope of the individual assembly work station. In total, two product variants are assembled. The first product variant consists of one crossbeam member belonging to heavy-duty truck with three-wheel axles (6x4) (Fig. 2). The second product variant consists of two crossbeam members belonging to a heavy-duty truck with five-wheel axles (10x4). The reason for

choosing these two product variants is to demonstrate two use cases with different amounts of work content and complexity levels.
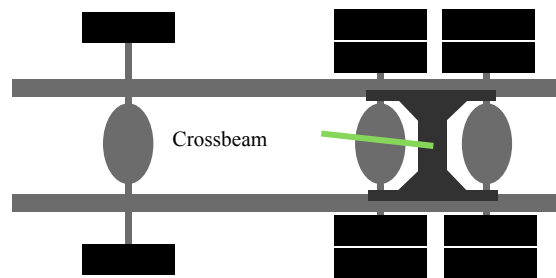

Fig 2: The crossbeam member is positioned at the rear axle installation in the truck base module.

3.3. Demonstrator user tests

During the spring of 2018 and forth, the demonstrator will be tested by real operators in a real production environment. The tests will be carried out with both non-experienced operators, novice operators and experienced operators. The operators chosen for the tests are following paper-based assembly work instructions on daily basis. The assembly information will be altered during the tests from current assembly information content to assembly information content based on the experience level of the operator as previously addressed. The main hypothesis for the tests is that the enhanced assembly information and HMI will improve the user satisfaction, increase the usage of provided assembly information and overall production quality (reduced amount of assembly disruptions). This setup is aligned with the IS Success Model which addresses system quality, information quality and service quality which are directly linked to the intention to use/actual use and user satisfaction which in turn are directly linked to the net benefits (the performance such as production quality) of the system [20,21]. In the latest update of the IS Success Model, determinants of IS Success are presented focusing on task characteristics, user and social characteristics and project and organization characteristics [44]. The characteristics of the demonstrator design and user tests are aligned with these determinants. These tests will be used to validate the requirements for future assembly information systems.

The use cases of the demonstrator have been defined on basis of previous studies made [3,4,16–19]. The four consistent assembly work stations provide realistic use cases and relevance to industrial workers. Tests in older demonstrators have often limited complexity in the use cases to enable control of the parameters during the experiments [45,46]. However, the drawback of such tests is that the differences between an experimental surrounding and real assembly environment are large. As this demonstrator uses real use cases and the setup of real assembly work stations, the differences between the real factory and the demonstrator should be limited. Additionally, it is sufficient to add increased product variety and to add more complexity to the experiment to make it realistic [45,46]. The two use cases do not only increase the product variety but also the time to assemble the customer orders. Additional numbers of use cases are possible to add to the demonstrator if needed in the future.

The tests will be conducted in a real assembly environment assuring that surrounding attributes as noise, light etc. will be similar as during regular assembly work. Since operators have different preferences in terms of displaying assembly information in an assembly work instruction, different setups will be tested with operators with different experience levels. The intention is that an increased user satisfaction will have a positive effect on production quality and the real use of provided assembly information. As previously stated, to measure the real impact of the provided assembly information, the information currently provided in the real production environment will be used by some operators to compare with the new version of the assembly information provided. In such a way, it will be possible to measure the effect on the information quality as in the framework of instruction information quality problems [27]. After all, there is little use in altering the work station and information systems if the information quality is not in focus. The test data will be used to improve the construct of the design for future assembly information systems.

4. Conclusion and future work

This paper presents an industrial demonstrator with the scope of validating requirements for future assembly information systems. The demonstrator is based on flexible design where the assembly information content can be altered in relation to experience levels and personal preferences of the operators. Furthermore, the design of the demonstrator allows altering of the number of connected tools as well as the amount of use cases. The demonstrator will be tested during 2018 by real operators in a real assembly environment. A future publication will focus on the result of the operator tests and an improved design construct of future assembly information systems. Furthermore, a virtual representation of the industrial demonstrator is planned to be designed enabling virtual training and introduction for the operators in the virtual world before performing the real assembly work on the production line.

Acknowledgement

References

[1] A. Gilchrist, Industry 4.0, Apress, Berkeley, CA, (2016). doi:10.1007/978-1-4842-2047-4.
[2] G. Schuh, R. Anderl, J. Gausemeier, M. ten Hompel, W. Wahlster, Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY), Herbert Utz Verlag, Munich, (2017).
[3] P.E.C. Johansson, G. Eriksson, P. Johansson, L. Malmsköld, Å. Fast-Berglund, L. Moestam, Assessment Based Information Needs in Manual Assembly, DEStech Trans. Eng. Technol. Res. (2018) 366–371. doi:10.12783/dtetr/icpr2017/17637.
[4] P.E.C. Johansson, M.O. Enofe, M. Schwarzkopf, L. Malmsköld, Å. Fast-Berglund, L. Moestam, Data and Information Handling in Assembly Information Systems – A Current State Analysis, Procedia Manuf. 11 (2017) 2099–2106. doi:10.1016/j.promfg.2017.07.335.
[5] H. Holtskog, E.G. Carayannis, A. Kaloudis, G. Ringen, Learning factories the Nordic model of manufacturing, Palgrave Macmillan, (2017). https://books.google.se/books?id=16M5DwAAQBAJ&dq=learning+factories&hl=sv&source=gbs_navlinks_s (accessed December 19, 2017).
[6] B.J. Pine II, Mass Customization - The new Frontier in Business Competion, Harvard Business School Press, (1993). https://books.google.se/books?id=Seli55Gt-sEC&dq=mass customization 93&hl=sv&source=gbs_book_other_versions (accessed November 29, 2017).
[7] B. Joseph Pine II, B. Victor, A.C. Boynton, Making Mass Customization Work, Harv. Bus. Rev. 71 (1993) 108–118. doi:Article.
[8] J.P. MacDuffie, K. Sethuraman, M.L. Fisher, Product Variety and Manufacturing Performance: Evidence from the International Automotive Assembly Plant Study, Manage. Sci. 42 (1996) 350–369. doi:10.1287/mnsc.42.3.350.
[9] S.J. Hu, X. Zhu, H. Wang, Y. Koren, Product variety and manufacturing complexity in assembly systems and supply chains, CIRP Ann. - Manuf. Technol. 57 (2008) 45–48. doi:10.1016/j.cirp.2008.03.138.
[10] S.J. Hu, Evolving paradigms of manufacturing: From mass production to mass customization and personalization, in: Procedia CIRP, Elsevier B.V., (2013): pp. 3–8. doi:10.1016/j.procir.2013.05.002.
[11] Å. Fast-Berglund, T. Fässberg, F. Hellman, A. Davidsson, J. Stahre, Relations between complexity, quality and cognitive automation in mixed-model assembly, J. Manuf. Syst. 32 (2013) 449–455. doi:10.1016/j.jmsy.2013.04.011.
[12] S. Mattsson, M. Tarrar, Å. Fast-Berglund, Perceived production complexity – understanding more than parts of a system, Int. J. Prod. Res. (2016) 1–9. doi:10.1080/00207543.2016.1154210.
[13] J.P.C. Verhoosel, M.A. van Bekkum, Recipe-Based Engineering and Operator Support for Flexible Configuration of High-Mix Assembly, in: Adv. Prod. Manag. Syst. Path to Intelligent, Collab. Sustain. Manuf., (2017): pp. 363–371. doi:10.1007/978-3-319-66923-6_43.
[14] P.E.C. Johansson, R. Oliveira, Manufacturing Execution Systems Demonstrator Platform, Chalmers University of Technology, (2011). https://publications.lib.chalmers.se/publication/146438.
[15] M. Khoshnevis, E. Lindberg, Development of a Demonstrator in the Aerospace Industry for Visualization of 3D Work Instructions Mahan Khoshnevis, Linköping University, (2015).
[16] Å. Fast-Berglund, M. Åkerman, S. Mattsson, P.E.C. Johansson, A. Malm, A. Pernestål Brenden, Creating Strategies for Global Assembly Instructions – Current State Analysis, in: Sixth Swedish Prod. Symp., (2014). http://publications.lib.chalmers.se/publication/202979-creating-strategies-for-global-assembly-instructions-current-state-analysis (accessed January 30, 2015).

[17] P.E.C. Johansson, L. Moestam, Å. Fast-Berglund, Use of Assembly Information in Global Production Networks, in: C.F. Oduoza (Ed.), Proc. 25th Int. Conf. Flex. Autom. Intell. Manuf., The Choir Press, Wolverhampton, (2015): pp. 258–265. doi:10.13140/RG.2.1.1264.4244.

[18] P.E.C. Johansson, F. Delin, S. Jansson, L. Moestam, Å. Fast-Berglund, Global Truck Production – The Importance of Having a Robust Manufacturing Preparation Process, Procedia CIRP. 57 (2016) 631–636. doi:10.1016/j.procir.2016.11.109.

[19] P.E.C. Johansson, S. Mattsson, L. Moestam, Å. Fast-Berglund, Multi-variant Truck Production - Product Variety and its Impact on Production Quality in Manual Assembly, Procedia CIRP. 54 (2016) 245–250. doi:10.1016/j.procir.2016.05.062.

[20] W.H. DeLone, E.R. McLean, Information Systems Success: The Quest for the Dependent Variable, Inf. Syst. Res. 3 (1992) 60–95. doi:10.1287/isre.3.1.60.

[21] W.H. Delone, E.R. Mclean, The DeLone and McLean Model of Information Systems Success: A Ten-Year Update, J. Manag. Inf. Syst. 19 (2003) 9–30. doi:10.1080/07421222.2003.11045748.

[22] N. Huang, R. Inman, Product quality and plant build complexity, Int. J. Prod. Res. 48 (2010) 3105–3128. doi:10.1080/00207540902810551.

[23] R.L. Ackoff, From Data to Wisdom, J. Appl. Syst. Anal. 16 (1989) 3–9.

[24] R.K. Rainer, C.G. Cegielski, Introduction to information systems, John Wiley & Sons, (2011).

[25] K.G. Swift, J.D. Booker, Assembly Systems, in: Manuf. Process Sel. Handb., Elsevier, (2013): pp. 281–289. doi:10.1016/B978-0-08-099360-7.00010-0.

[26] A. Brolin, P. Thorvald, K. Case, Experimental study of cognitive aspects affecting human performance in manual assembly, Prod. Manuf. Res. 5 (2017) 141–163. doi:10.1080/21693277.2017.1374893.

[27] A. Haug, Work instruction quality in industrial management, Int. J. Ind. Ergon. 50 (2015) 170–177. doi:10.1016/j.ergon.2015.09.015.

[28] J.E. Jorgensen, J.S. Lamancusa, J.L. Zayas-Castro, J. Ratner, The Learning Factory - Curriculum Integration of Design and Manfacturing, in: Proc. Fourth World Conf. Eng. Educ., (1995): pp. 1–7. https://pdfs.semanticscholar.org/feec/6aee8134ef124e5db19e5b10041dda41c3fd.pdf (accessed December 20, 2017).

[29] U. Wagner, T. AlGeddawy, H. ElMaraghy, E. MŸller, The State-of-the-Art and Prospects of Learning Factories, Procedia CIRP. 3 (2012) 109–114. doi:10.1016/j.procir.2012.07.020.

[30] A. Haghighi, N.S. Zadeh, G. Sivard, T. Lundholm, Y. Eriksson, Digital Learning Factories: Conceptualization, Review and Discussion, in: J. Stahre, B. Johansson, M. Björkman (Eds.), Proc. Sixth Swedish Prod. Symp., Göteborg, (2014). http://conferences.chalmers.se/index.php/SPS/SPS14/paper/viewFile/1729/401 (accessed December 21, 2017).

[31] E. Abele, J. Metternich, M. Tisch, G. Chryssolouris, W. Sihn, H. ElMaraghy, V. Hummel, F. Ranz, Learning Factories for Research, Education, and Training, Procedia CIRP. 32 (2015) 1–6. doi:10.1016/j.procir.2015.02.187.

[32] F. Quint, K. Sebastian, D. Gorecky, A Mixed-reality Learning Environment, Procedia Comput. Sci. 75 (2015) 43–48. doi:10.1016/j.procs.2015.12.199.

[33] E. Abele, G. Chryssolouris, W. Sihn, J. Metternich, H. ElMaraghy, G. Seliger, G. Sivard, W. ElMaraghy, V. Hummel, M. Tisch, S. Seifermann, Learning factories for future oriented research and education in manufacturing, CIRP Ann. 66 (2017) 803–826. doi:10.1016/j.cirp.2017.05.005.

[34] P. Thorvald, A. Brolin, D. Hogberg, K. Case, Using Mobile Information Sources to Increase Productivity and Quality, Proc. 3rd Int. Conf. Appl. Hum. Factors Ergon. (2010) 450–459.

[35] M.H. Baturay, M. Birtane, Responsive Web Design: A New Type of Design for Web-based Instructional Content, Procedia - Soc. Behav. Sci. 106 (2013) 2275–2279. doi:10.1016/j.sbspro.2013.12.259.

[36] G. Schuh, B. Franzkoch, J.-P. Prote, M. Luckert, F. Sauermann, F. Basse, Analysis of the Potential Benefits of Digital Assembly Instructions for Single and Small Batch Production, in: Adv. Prod. Manag. Syst. Path to Intelligent, Collab. Sustain. Manuf., (2017): pp. 346–353. doi:10.1007/978-3-319-66923-6_41.

[37] P. Hold, W. Sihn, Towards a model to identify the need and the economic efficiency of digital assistance systems in cyber-physical assembly systems, in: 2016 1st Int. Work. Cyber-Physical Prod. Syst., IEEE, (2016): pp. 1–4. doi:10.1109/CPPS.2016.7483914.

[38] A. Syberfeldt, O. Danielsson, M. Holm, L. Wang, Dynamic Operator Instructions Based on Augmented Reality and Rule-based Expert Systems, in: Procedia CIRP, Elsevier B.V., (2016): pp. 346–351. doi:10.1016/j.procir.2015.12.113.

[39] T. Fässberg, Å. Fasth, J. Stahre, A classification of carrier and content of information, in: J.S. Hu (Ed.), Proc. 4th CIRP Conf. Assem. Technol. Syst., (2012): pp. 1–4. http://cirp.me.engin.umich.edu/CIRP_CATS_2012_Proceedings_small.pdf.

[40] A. Claeys, S. Hoedt, H. Van Landeghem, J. Cottyn, Generic Model for Managing Context-Aware Assembly Instructions, IFAC-PapersOnLine. 49 (2016) 1181–1186. doi:10.1016/j.ifacol.2016.07.666.

[41] S. Mattsson, Å. Fast-Berglund, D. Li, Evaluation of Guidelines for Assembly Instructions, IFAC-PapersOnLine. 49 (2016) 209–214. doi:10.1016/j.ifacol.2016.07.598.

[42] T. Arai, Y. Aiyama, Y. Maeda, M. Sugi, J. Ota, Agile Assembly System by "Plug and Produce," CIRP Ann. 49 (2000) 1–4. doi:10.1016/S0007-8506(07)62883-2.

[43] J. Lindblom, P. Thorvald, Towards a framework for reducing cognitive load in manufacturing personnel, Adv. Cogn. Eng. Neuroergonomics. (2014) 233–244.

[44] S. Petter, W. DeLone, E.R. McLean, Information Systems Success: The Quest for the Independent Variables, J. Manag. Inf. Syst. 29 (2013) 7–62. doi:10.2753/MIS0742-1222290401.

[45] D. Li, S. Mattsson, Å. Fast-Berglund, M. Åkerman, Testing Operator Support Tools for a Global Production Strategy, Procedia CIRP. 44 (2016) 120–125. doi:10.1016/j.procir.2016.02.089.

[46] M. Lušić, C. Fischer, K.S. Braz, M. Alam, R. Hornfeck, J. Franke, Static Versus Dynamic Provision of Worker Information in Manual Assembly: A Comparative Study Using Eye Tracking to Investigate the Impact on Productivity and Added Value Based on Industrial Case Examples, Procedia CIRP. 57 (2016) 504–509. doi:10.1016/j.procir.2016.11.087.