Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 9 (2017) 143 – 150

Procedia MANUFACTURING

7th Conference on Learning Factories, CLF 2017

Planning and Evaluation of Digital Assistance Systems

Philipp Hold[a,b,*], Selim Erol[b], Gehard Reisinger[a,b], Wilfried Sihn[a,b]

[a]*Fraunhofer Austria Research GmbH, Theresianumgasse 27, 1040 Vienna*
[b]Technische Universität Wien, Institute of Management Science, Theresianumgasse 27, 1040 Vienna
*Philipp Hold: Tel.: +43-676888-616-30; *E-mail address:* philipp.hold@fraunhofer.at

Abstract

Education and training for industrial engineering focus on developing professional competence for the design, analysis and optimization of work systems, characterized mostly by either manual or automated processes and include determination of process, tasks and equipment based on given product requirements. In future production scenarios, human work can be assisted by digital information in regard to create work systems which remain flexible towards changing products and volatile demands through human adaptability while still making use of cost-efficient improvement potentials. Planning and evaluation of digital assistance systems in the context of cyber-physical assembly systems requires both classical industrial engineering competencies but also basic knowledge of information systems design. The paper proposes a learning design for a course in Cyber-Physical Assembly Systems Design which will be offered within the environment of the Industry 4.0 Pilot Factory at TU Wien where students can learn the basics of Cyber-Physical Assembly Systems Design both on a theoretical and practical level.

Peer review under responsibility of the scientific committee of the 7th Conference on Learning Factories

Keywords: technical assistance service, visual assistance service, shop-floor management, assistance service planning method

1. Cyber-Physical Assembly Systems and Digital Assistance Systems

Manufacturing companies with a strong focus on assembly processes are facing the challenge of rising product and process complexity. The rising process complexity is a consequence of individualization of customer needs and the acceleration of fulfilment processes. An increasingly aging and diverse workforce poses additional challenges on management of process complexity. State-of-the-art assembly systems in industry reach their economic and technical limits when encountering these challenges. However, a new generation of assembly systems is currently on its way that is based on the concept of cyber-physical systems (CPS) [1]. CPS realize the connection between the physical and the digital world. CPS are composed of embedded systems, which detect physical objects directly by sensors and interact with physical processes via actuators. These systems are linked through digital networks and exchange data

Peer review under responsibility of the scientific committee of the 7th Conference on Learning Factories
doi:10.1016/j.promfg.2017.04.024

and services globally. CPS are not (technically) closed units, they are defined as open socio-technical systems, which are characterized by a high degree of cross-linking of the physical, social and virtual world as well as by the intelligent use of information and communication systems [2]. By integrating CPS into assembly systems new forms of assembly processes will be possible [3].

So called Cyber-Physical Assembly Systems (CPAS) are expected to meet the challenge of flexibility towards volatile customer demand and workforce diversity [4, 5]. Flexibility regarding product and process variations (“lot-size 1”) will lead to frequent changes of work content and respective information needs and will impose excessive physical and mental stress on the operator [6]. As a consequence, similarity of assembly tasks will decrease and building up of relevant work routine will not be possible anymore. Erroneous material and tool are an inevitable consequence. The risk of unmanageable work situations for the operator are likely to increase [7].

Within a CPAS digital assistance systems (DAS) are the primary interface to optimally integrate human agents into the assembly system during task execution. Thus, DAS compensate the gap between required competencies at the work place to perform a work task (performance requirements) and the capability of a human worker (worker capability). The primary objectives of DAS are the increase of productivity [8], e.g. reduction of training time, search times, operating errors and supporting the work force in stressful situations [9, 10].

Features of modern DAS come far beyond a sheer representation of information. They provide situational support through process-aware assembly periphery (tools, material, work piece etc.). Work instructions are automatically provided in accordance with physical work progress and without any manual interaction with the system, e.g. through adequate sensory equipment [3]. Order specific assembly instructions facilitate the worker in choosing the correct work place set-up, materials, tools and tool configurations. In case of assembly mistakes, a DAS suggests activities in order to have the mistake corrected at the right moment and at the right location to achieve product quality as desired [11].

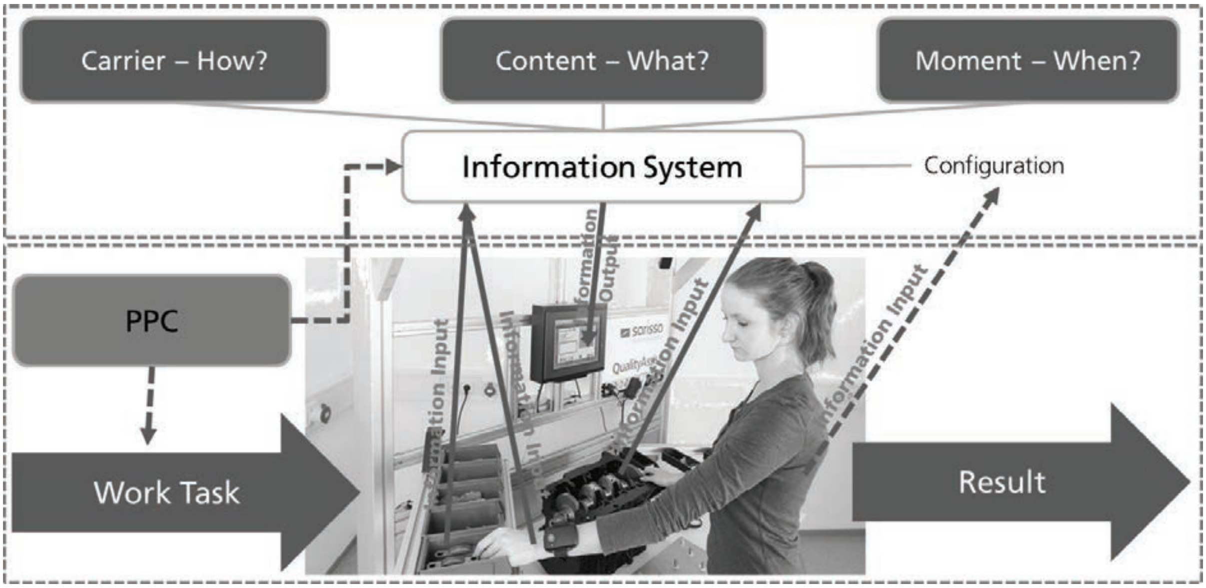

Figure 1: Digital Assistances in CPAS

In addition to the above outlined general features of DAS also domain and process-specific requirements of assembly processes must be addressed. Advantageous features of DAS must be determined already during the planning phase of an assembly system. It is necessary to systematically identify specific needs, to derive requirements for appropriate technical systems, and to evaluate the productivity impact of single digital assistance features on the entire assembly system.

2. Planning and Evaluation of Digital Assistance Systems

Methods and tools currently used in the context of industrial engineering are targeted to improve and evaluate the productivity of existing work systems. However, they demonstrate substantial weaknesses with regard to in advance planning and evaluation of work systems. An aspect that is largely missing in state-of-the-art industrial engineering research is the systematic identification of information needs, the design of appropriate information and assistance systems and their evaluation with regard to productivity impact [5, 12, 13]. A recent review of literature reveals that planning and evaluation of DAS has not been addressed properly in research [14, 15, 16, 17, 18, 19]. In particular, we identified a lack in the systematic analysis of relations between the characteristics of assembly tasks, the qualitative and quantitative evaluation of their complexity and the derivation of requirements for DAS [19, 20, 21].

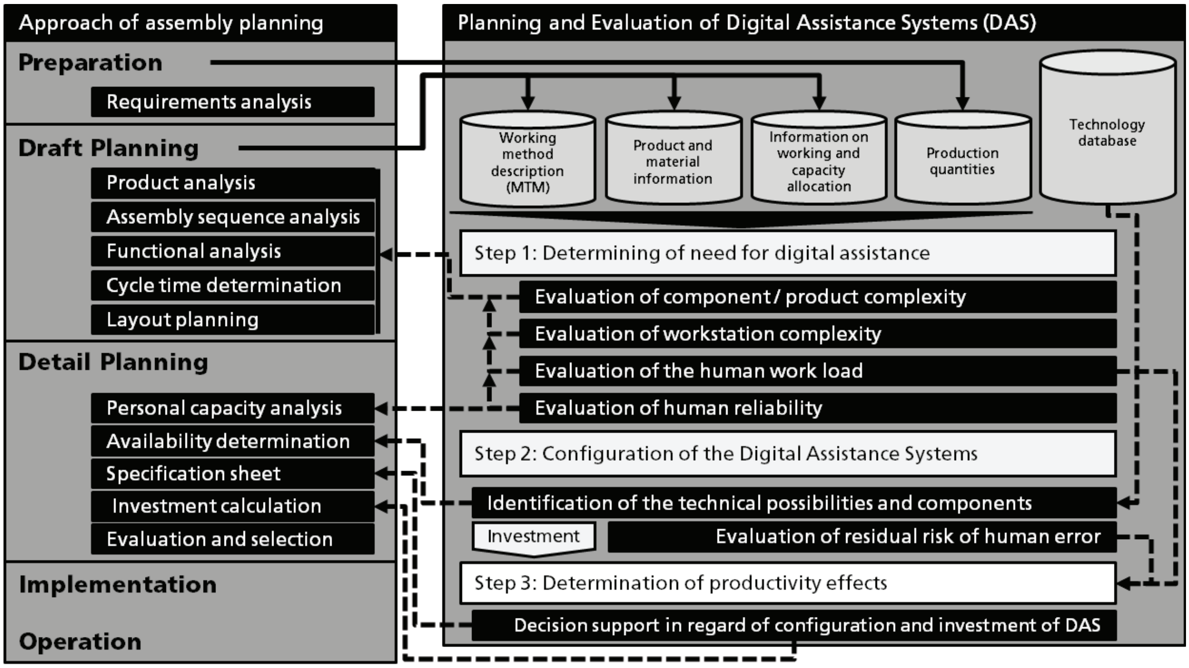

Figure 2: Method for Planning and Evaluation of Digital Assistance Systems

In the course of prior research, we developed a method for planning and evaluation of DAS for complex Cyber-Physical Assembly Systems. The method takes into account individual work tasks as well as operators' individual skills, qualifications and performance levels. Based on this information the method supports the identification of technical and functional requirements for the conception and design of a DAS and the evaluation of respective system features with regard to expected productivity effects on the assembly process. In this way the method complements both technical planning and economic evaluation of DAS to ensure their optimal integration with Assembly Systems.

The method for planning and evaluation of DAS builds upon a classification of work tasks and their detailed description by using for example Methods-Time Measurement methodology (MTM). The advantage of using methods like MTM methodology is that apart from standard time of a work task also information on the positioning of the work piece, its orientation, weight, length, gripping and the extent of human work load is given [10]. Based on this information work task complexity and human error probability measures [22] are computed. For computation of task complexity measures we consider as well work piece complexity and work place complexity [18, 19, 23]. For the computation of error probability, we apply the method of "Human Error Probability" [24].

Based on the qualitative information about assembly tasks and the quantitative information like complexity and human error probability requirements for DAS can be derived. The derivation of requirements is carried out for different task levels – from single low-level tasks to sequences of tasks (high-level processes). In addition to extrinsic requirements (driven by the task at hand) we consider as well intrinsic requirements [19, 25, 26] such as the skills, knowhow, dexterity.

Given the requirements adequate features of DAS will be determined and are evaluated for their economic impact (labor productivity and unit costs). To adequately structure and evaluate DAS features an approach similar to Quality Function Deployment (QFD) [27] has been chosen. Through an integrated assembly technology database, required features of DAS and related system components to implement them are determined. The technology database contains different kinds of digital assistant system components which are described by the type of assistance (instruction, additional information etc.) they provide, the time of assistance (on explicit demand of the operator or automatically), the form of assistance (mobile, semi-mobile and fixed) [28] and the costs of a component shows the tool that supports the method. The first column represents work tasks, subsequent columns are used to show the magnitude of complexity and other influencing factors for the identification of requirements and features.

The method is primarily intended to extend classical approaches of assembly system planning with a systematic evaluation of DAS impact on productivity. In this sense, we also developed a learning and training concept for holistic assembly systems planning with a special focus on DAS planning and evaluation.

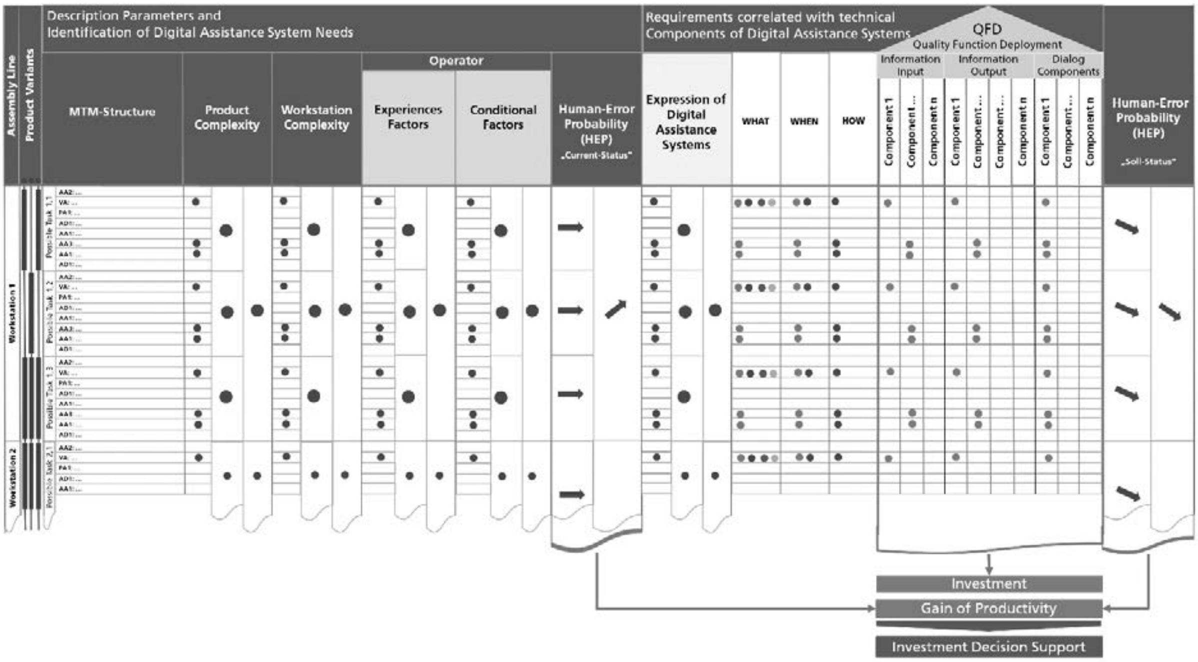

Figure 3: Schematic Structure of the Method

3. Learning Design for Planning and Evaluation of Digital Assistance Systems

The learning design presented in the following describes a seminar that particularly aims at teaching engineers to design complex assembly systems. The seminar has been redesigned to include the above discussed method for planning and evaluation of digital assistance systems in the context of cyber-physical assembly systems. The seminar will be held within the recently established Industry 4.0 Pilot Factory at TU Wien. In the following we describe the learning design by the target audience, the learning objectives, the learning materials and the course format.

3.1.1. Target audience

The target audience of our seminar are primarily students enrolled in the Master program of Industrial Engineering at TU Wien. However, we are also planning to offer a similar course for professionals from industry. The following considerations focus on the primary target group of Master students. Master students of Industrial Engineering at TU Wien typically have a profound education in mechanical engineering and management subjects.

3.1.2. Learning objectives

The objectives of the course are formulated by using Bloom's taxonomy of learning objectives [29]. Figure 3 illustrates the different levels of learning objectives. At level 1 knowledge about the basic theories and principles of assembly systems design is the objective. For example, comprehension of task analysis (according to MTM) and understanding the basics of digital assistance systems design are concrete learning objectives on this level. On level 2 the application of these theories and methods to assembly systems design is the objective. Level 2 refers to the first

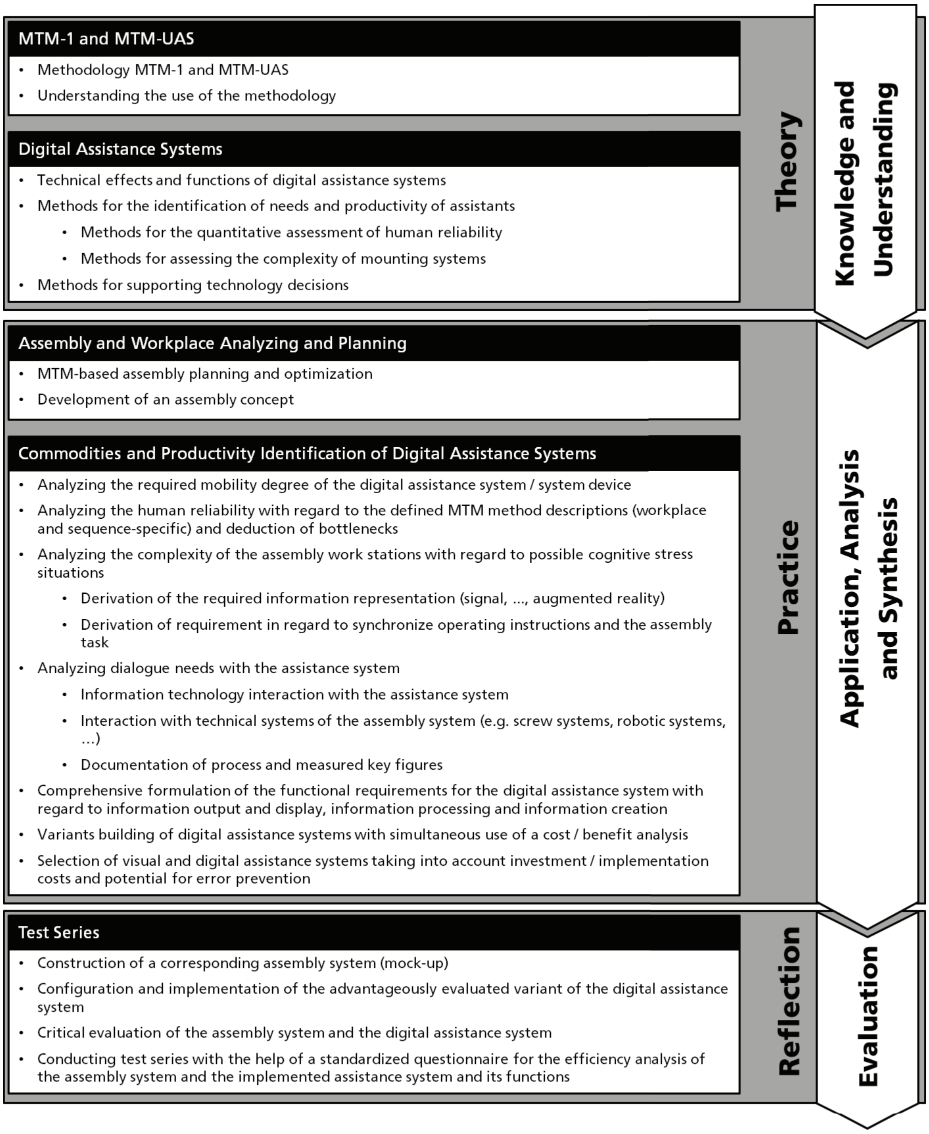

Figure 4: Description of Learning Objectives

step in our method for planning and evaluation of DAS. It comprises the analysis of work tasks by using MTM methodology, the computation of complexity measures and error probabilities. In addition, requirements for digital assistance are derived based on the theoretical input. Subsequently also features of DAS are identified that potentially meet the requirements. Finally, evaluation of features in terms of economic measures, e.g. productivity is performed. A complete description of learning objectives can be seen in the following figure.

3.1.3. Learning materials and environment

Study materials for Level 1 learning objectives will be provided mainly through our e-learning platform TUWEL [30] which is based on Moodle [31] open-source software. Study materials include text books and also several Excel based tools to perform the planning of tasks (MTM-based analysis) and the subsequent steps of the method for planning and evaluation of DAS.

The course will take place both in lecture halls (see learning objectives on level 1) and in our Pilot Factory [29] where we have an ideal practical training environment for assembly systems design. The cyber-physical assembly line in the Pilot Factory is currently composed of several connected mobile assembly stations. Within the assembly line various products will be assembled according to customer requirements (lot-size 1). We use a consumer class 3D-printer as a demo product for our assembly line. The assembly worker is supported in terms of managing complex assembly tasks as well as in managing physical, cognitive and psychological stress situations. On the one hand, the operator is supported through digital assistance systems, and on the other hand is supported through collaborative robotic systems. The work piece itself is assembled directly on driverless transport systems and adaptive work benches that are able to identify work pieces and track the progress of assembly tasks. The following figure illustrates the different features of digital assistance systems, which are available within the Industry 4.0 Pilot Factory at TU Vienna.

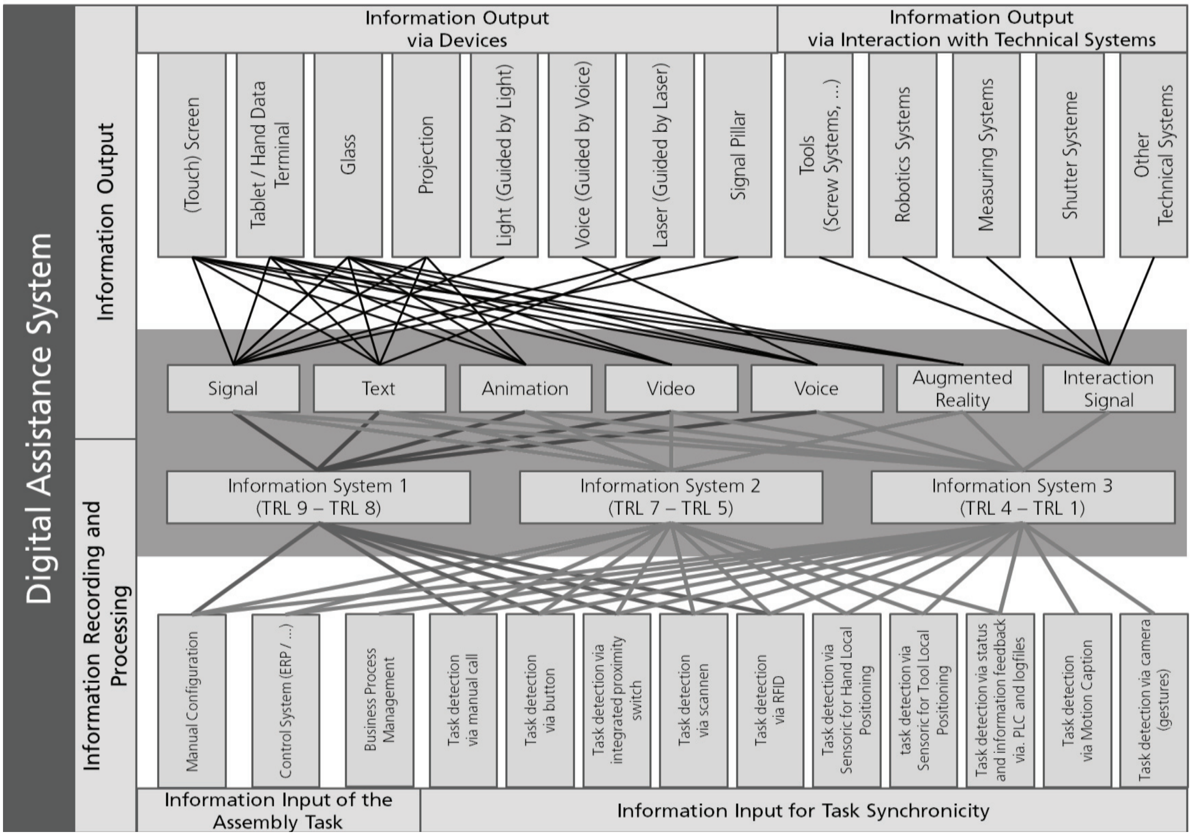

Figure 5: Different Features of Digital Assistance Systems

3.1.4. Course format

The course will be held partly as a lecture to transfer basic knowledge of theories, methods, concepts of industrial engineering and digital assistance systems design. The largest part of the course will be held as a practical training right within the above described environment of our Industry 4.0 Pilot and Learning Factory. Students are able to use the study rooms available at the Pilot Factory and at the same time have possibility to see a real assembly system in action. Both the assembly system itself and the different available technologies for digital assistance can be used to validate the planning outcomes.

4. Conclusion and Outlook

Cyber-physical assembly systems allow to benefit from capabilities of humans and machines in joint production environments. Technological progress has made such systems economically feasible. However, detailed planning and evaluation of such systems, especially with regard to digital assistance systems (DAS), is a prerequisite for increasing productivity and at the same time decreasing unit costs. Industrial Engineers of the future have to be educated with regard to planning and evaluation of such systems.

The learning design presented in this paper describes a recently developed course for Master students of Industrial Engineering. The course takes into account methods to plan and evaluate complex cyber-physical assembly systems and respective digital assistance systems (DAS). Students of the course are taught a method for planning and evaluation of DAS. The Industry 4.0 Pilot Factory is an ideal learning environment that allows students to practically evaluate planning outcomes under realistic conditions.

Acknowledgements

The TU Wien Industry 4.0 Pilot Factory has been partly funded by the public through the Austrian Research Promotion Agency (FFG) and several private industrial firms – our partners in the project.

References

[1] Lu, C., Rajkumar, R., Tovar, E., “Special Section on Cyber-Physical Systems and Cooperating Objects”, IEEE Transactions on Industrial Informatics, vol. 8, no. 2, pp. 378-378, 2012

[2] Geisberger, E. et al., “agendaCPS. Integrierte Forschungsagenda Cyber-Physical Systems”, in: Geisberger, E. et al., “acatech - Deutsche Akademie der Technikwissenschaften“, München, Berlin, 2012.

[3] Dombrowski, U., Wagner, T., Riechel, C., “Analyse eines Konzepts zur Montageplanung auf Basis cyber-physischer Systemmodule“, in: ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb, pp. 344 – 348, 2013

[4] Schlund, C. M., Gerlach, S., “Der Mensch im industriellen Holozän“, in: Erconomic Egineering, pp. 22-26, 2013

[5] Kagermann, H., Wahlster, W., Helbig, J., “Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 - Abschlussbericht des Arbeitskreises Industrie 4.0“, Frankfurt am Main, 2013

[6] Hirsch-Kreinsen, H., “Entwicklungsperspektiven von Produktionsarbeit“, in: Botthof, A., Hartman, E. A. (Ed.). “Zukunft der Arbeit in Industrie 4.0“, Springer, Berlin, 2014

[7] Dombrowski, U., Riechel, C., Evers, M., “Industrie 4.0 - Die Rolle des Menschen in der vierten industriellen Revolution“ in: Kersten, W., Koller, H., Lödding, H. (Ed.), “Industrie 4.0. Wie intelligente Vernetzung und kognitive Systeme unsere Arbeit verändern“, GITO mbh Verlag. Berlin, 2014

[8] Spillner, R., “Einsatz und Planung von Roboterassistenz zur Berücksichtigung von Leistungswandlungen in der Produktion“, Dissertation. Herbert Utz Verlag, München, 2014

[9] Zäh, M. F., Wiesbeck, M., Engstler, F., Friesdorf, F., Schubö, A., Stork, S., Bannat, A., Wallhoff, F., “Kognitive Arbeitssysteme in der Montage. Adaptive Montageführung mittels zustandsbasierter, umgebungsabhängiger Anweisungsgenerierung“, in: ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb, pp. 644-650, 2007

[10] Kuhlang, P., “Modellierung menschlicher Arbeit im Industrial Engineering. Grundlagen, Praxiserfahrungen und Perspektiven“, Ergonomia Verlag Stuttgart, 2015

[11] Hold, P., Sihn, W., “Towards a Model to Identify the Need and the Economic Efficiency of Digital Assistance Systems in Cyber-Physical Assembly Systems“, in: International Workshop on Cyber-Physical Production Systems at CPS Week 2016, Vienna, Austria, IEEE, 2016.

[12] Bokranz, R., Landau, K., “Handbuch Industrial Engineering: Produktivitätsmanagement mit MTM“, Schäfer-Peschel, 2012

[13] Spanner-Ulmer, B., “Humanzentriertes Industrial Engineering im Wirkungsfeld zwischen Stabilität und Flexibilität“, in: Spath, D. (Ed.). “Wissensarbeit - zwischen strengen Prozessen und kreativem Spielraum“, GITO Verlag, pp. 324-344, 2011

[14] Bullinger, H. J., “Systematische Montageplanung. Handbuch für die Praxis“, München, Hanser, 1986.

[15] Lotter, B., “Wirtschaftliche Montage. Ein Handbuch für Elektrogerätebau und Feinwerktechnik“, Düsseldorf, VDI-Verlag, 1992
[16] Konold, P., Reger, H., “Praxis der Montagetechnik. Produktdesign, Planung, Systemgestaltung“, Wiesbaden, Vieweg, 2003
[17] Richardson, M., Jones, G., Torrance, M., “Identifying the task variables that influence perceived object assembly complexity”, in: Ergonomics 47, pp. 945-964, 2004
[18] ElMaraghy, W. H., Urbanic, R. J., “Assessment of Manufacturing Operational Complexity“, Annals of the CIRP 53 (2004) 1, pp. 401-406, 2004
[19] Claeys, A., Hoedt, S., Soete, N., van Landeghem, H., Cottyn, J., “Framework for Evaluating Cognitive Support in Mixed Model Assembly Systems“, IFAC-Pap., 48, No. 3, pp. 924–929, 2015
[20] Reinhart, G., Spillner, R., “Assistenzroboter in der Produktion. In: Intelligente Mechatronische Systeme“, Tagungsband, Winterthur 3.-4. November 2010, Internationales Forum Mechatronik, Winterthur, IMS Institut für Mechatronische Systeme, 2010.
[21] Wiesbeck, M., Zaeh, M. F., Rudolf, H., Vogl, W., “New Media and Technology Support in Manual Assembly“, in: Fischer, X. et al. (Ed.), Research in Interactive Design: Proceedings of Virtual Concept 2006, Playa Del Carmen / Mexico, 26. November - 1. December 200, Paris, Springer, 2006
[22] Kern, C., Refflinghaus, R., “Assembly-specific database for predicting human reliability in assembly operations“ in: Total Quality Management & Business Excellence, Vol. 26, No. 10, pp. 1056 – 1070, 2015
[23] Zhu, X., Hu, S.J., Koren, Y. and Marin, S.P., “Modeling of manufacturing complexity in mixed-model assembly lines“, Journal of Manufacturing Science and Engineering, 130(5), 051013, 2008
[24] VDI 4002, VDI-Gesellschaft Produkt- und Prozessgestaltung (GPP), “Menschliche Zuverlässigkeit. Methoden zur quantitativen Bewertung menschlicher Zuverlässigkeit“, Blatt 2, 2015
[25] Zeltzer, L., Limere, V., Aghezzaf, E.H., Van Landeghem, H., “Measuring the objective complexity of assembly work stations“, in ICCGI 2012, The Seventh International Multi-Conference on Computing in the Global Information Technology, pp. 341–346, 2012
[26] Abad, A.G., Paynabar, K., Jin, J.J., “Modeling and analysis of operator effects on process quality and thoughput in mixed model assembly systems“, Journal of manufacturing science and engineering, 133 (2), 2011
[27] Spath, D., “Forschungs- und Technologiemanagement. Potenziale nutzen - Zukunft gestalten“, München, Hanser, 2004
[28] Fässberg, T., Fasth, Å., Mattsson, S., Stahre, J., “Cognitive automation in assembly systems for mass customization“, in: Proceedings of the 4th Swedish Production Symposium (SPS), Lund, Sweden, 2011
[29] Bloom, B. S., “Taxonomy of Educational Objectives“, Handbook 1, The Cognitive Domain, David McKay Co Inc., New York, 1956
[30] TU Wien, TUWEL, https://tuwel.tuwien.ac.at/?lang=en, 2016
[31] TU Wien, MOODLE, https://moodle.org/?lang=en, 2016