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Design concept towards a human-centered learning factory

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Abstract

Learning factories play an important role when studying multi-disciplinary problems. Such a problem is to support operators in multi-variant assembly. Multi-variants cause problems with product quality, production time as well as cognitive load and therefore it is important to find ways to support operators in this context. To assess the effects of multi variants, a design concept were developed in a learning factory environment (SIILab, CPPS-testbed). The concept was constructed at a conveyer belt with three assembly stations using Casat software for instruction presentations. The following aspects were included in the human-centered learning factory: studying the introduction of advanced automation, managing product variety, supporting operators in finding information and supporting existing human-automation interactions.

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1. Background

Digitalization and Industry 4.0 trends are transforming operators' traditional working environment through increased symbiosis with higher levels of automation and an increased number of different work tasks [1-4]. These trends will increase the complexity of the production system and the need for understanding the operator in such a system [5-7]. Assembly systems are complex partly due to a high product variety [8-11] and since operators are flexible and can manage fast and dynamic changes [12-14] the operator is an invaluable resource [7]. High demands are placed on the operator [15] and therefore companies need to be attentive to operator perceptions and work environment [16,17].

Advances in cognitive automation due to digitalization are e.g. digital tools [18,19], VR glasses [20], visual computing [21] and an increased number of cobots and human-robot collaboration [22-24]. Cognitive automation is defined as “*technical solutions helping the operator, e.g. HOW and WHAT to assemble and situation control*” [25]. The use of Information and Communications Technology systems in manufacturing increases rapidly as these

systems become more capable and inexpensive [26]. However, although these smart technologies exist, they are not fully adapted to the manufacturing industry [27].

Production companies are encouraged to start industrial projects to enable implementations of smart factories [28]. Smart factories include supply networks and warehousing systems, decision-making support for both machines and the production, better control of the engineering processes and a dynamic business models [29]. Since many new smart technologies are emerging, there is a need to test and show implementations of these solutions in industry [27,30,31]. One way to do this is to develop learning factories where companies can, together with academia develop scenarios that are similar to their own production facilities [32]. This way personnell can also train in a realistic manufacturing environment.

The aim of this paper is to develop a learning factory concept that can be used to investigate relevant human-centered issues in complex assembly. The concept is tested in a separate article, focusing on the experiment set-up, in Li et al. [33]. Important issues are presented in the following section.

2. Learning factory concept

Important issues connected to multi-variant assembly are adaptive automation and decision-making [2-4] and the learning factory should therefore consider the following:

- *The introduction of advanced automation.* Levels of automation should be adapted to the operator so that the human will perform tasks that are best adapted to the human (and not given left-over automation such as loading a machine) [25,34]. In addition, it is important to consider interoperability [35].
- *Production complexity.* Increasing product variety also increases the importance of the role of humans [36] since they are flexible and can handle the complex and dynamic context [13,14]. In addition, there are high demands on flexible workstations, which means that there are many different types of tools on the same station. One way to manage complexity is to reduce or simplify [37,38].
- *Finding information.* In today's systems it is difficult to find the information. This is partly due to information overload and the operator is therefore less informed than before [39].
- *Existing interactions* between human and automation needs support [40] due to that it is frequently seen to cause problems [41,42]. Since it is difficult to know what are the cause and effects of interactions [43], relevant factors should be assessed.

To handle these issues in future systems, a human centered approach is needed [44,45]. *Human-centered design* (HCD) places the human in center when designing a system. A human centered system should support both physical and cognitive aspects of work [34,46], which make the system more usable so that the operator can function at the highest and safest possible level [47,48]. The advantages of having a usable system are: increased productivity, reduced errors, reduced training and support, improved acceptance, enhanced reputation, improved satisfaction and motivation [49]. The ISO 9241-210 defines HCD as “an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques”[50]. A learning factory provides an opportunity for testing various HDC approaches with focus on Industry 4.0 operator.

In assembly, cognitive capabilities are often not considered [51-53], and one consequence of that may be that usability factors, which are not included in the production system design. To manage production complexity, complexity can be reduced or avoided through simplifying information presentation [37,38]. Information should therefore be presented according to the operators' active cognitive processes [53]. When the operator is assembling the active cognitive process is intuition and no demanding problem-solving or searching for information should be carried out. This means that text-instructions will not support assembly work. Further task-based information should be presented when and where the operator needs it [54,55], thereby simplifying information presentation.

Today work instructions are often text-based and not connected to the operators learning phase [56,57]. Although studies point towards that an increased learning can be seen with digital tools [18,58-61], learning is often done by tutors or mentors at production companies.

2.1. Assessed variables

As part of the CPPS-testbed environment established at the SII Lab at Chalmers University of Technology, an assembly system design was set up. The concept consists of a continuous assembly line, connected through a conveyor belt, with three stations that could be manually operated or operated by a cobot (collaborative robot), see Figure 1. Each station is equipped with a touch screen monitor that is used for displaying assembly instructions. The work instructions are displayed through Casat software via a web browser. The web browser is also used for data acquisition through Casat software. The aim of the concept is to support research and secondly to serve as a test environment for operators. The learning targets are to support mainly cognitive capabilities. The cognitive capabilities are connected to how instructions can aid the operator in a multi-variant assembly context. The following aspects should therefore be included in the concept: effect of multi-variants (a randomized order), different information contents, diverse experience levels and different types of assembly stations (where cycle times and types of components vary).

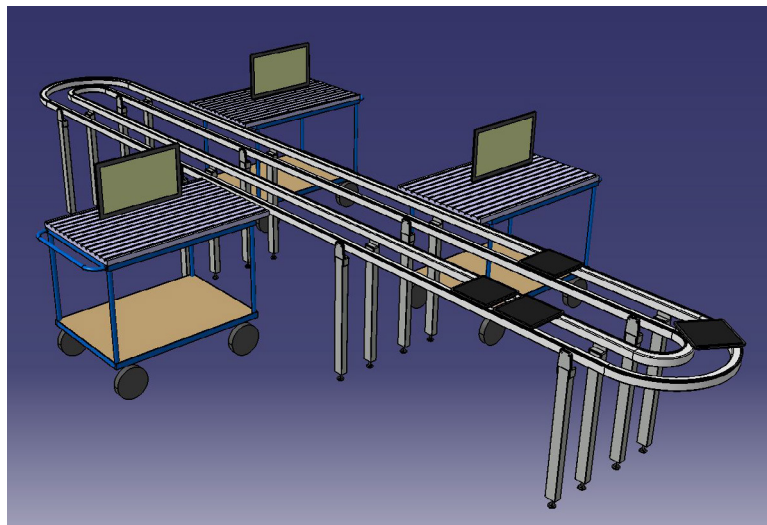


Fig. 1. Learning factory concept set up with three assembly stations.

To be able to study how operators are affected by different product variants presented in different ways (text and picture) the following output variables are suggested: Number of Parts Assembled Correctly (NPAC), cycle time, CXI, information quality, NASA TLX and physiological data. *NPAC* was used as a measurement to assess the quality of assembly work, which considers how well the assembly operator manages to assemble the products (was also used in previous experiments e.g. in [62]). The *NPAC* values, which are non-negative integers, are calculated by deducting the incorrectly assembled parts from the total number of parts for each assembly station. Efficiency is assessed through Number of Parts Assembled Correctly (*NPAC*), cycle time and number of disturbances (small and bigger). *Cycle time* is the total time taken to produce one unit from start to finish. For experimentation purpose, cycle time at each station is used for assessing impact of operator performance on overall performance of the system. *CXI*, information quality and NASA-TLX [63] can be captured through a survey filled in after the assembly. *CXI* is a method used to assess perceived production complexity at a station level [64]. Some of the questions, previously used to investigate the impact of disturbance handling were used to study the complexity level at each of the stations. The *information quality* of the provided information, i.e. instructions, as perceived by the operators, are mainly assessed by a survey filled out by the participants after the experiments, focused on these aspects of information quality [65]: comprehensiveness, validity, timeliness, accuracy, relevance and accessibility. Physiological data is assessed through Empatica's device E4 which measures skin conductance, blood pulse volume (derived from heart rate variability), heart rate and skin temperature. The E4 was previously used to assess operator

wellbeing and empirical results pointed to that a combination of electro dermal activity and blood pulse volume were reliable and useful in industrial applications [66].

2.2. Work instructions and products

The work instructions are created using Casat software, which has a built-in function for methods-time measurement (MTM) and station balancing. The MTM approach prompted that all of the intended movements made by operators during assembly, as a standardized assembly method, were assessed with regards to time and entered as a row in the Casat software. One or several of these rows combined constitute a task that is represented with picture and text in the work instructions. These factors influenced the creation of the work instructions. Further, the Casat software also facilitates viewing of work instructions through a web browser, which can be used during experiments or tests.

The chosen product was a LEGO gearbox, which can be seen in Fig. 2. This gearbox has been used in previous experiments and is therefore a relevant product e.g. 50 experiments were carried out to investigate how emotions and cycle time and affected operator performance and experience [62,66,67] and then 10 additional experiments were then carried out and it was seen that productivity and satisfaction were increased. Additional experiments have been carried out studying what type of instruction is connected to the lowest learning time and maintained quality [68].

The product variants for the learning factory concept were designed to be similar to each other with regards to assembly method in order to retain comparability between variants, but contain some differences, enough to create a cognitive challenge in order to be able to evaluate the possible support effects of the work instructions.

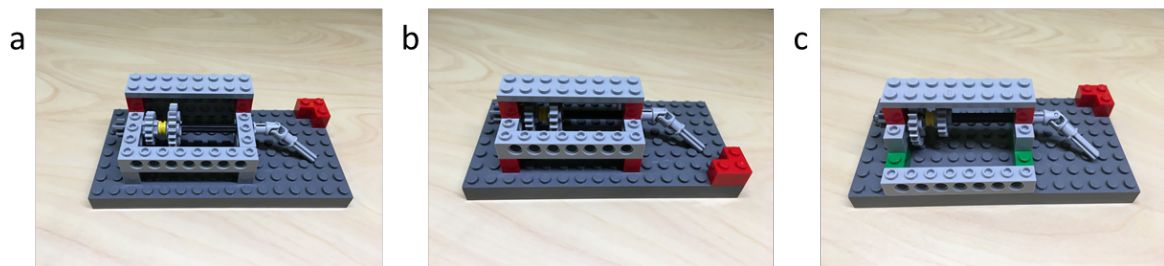


Fig. 2. The products used in the experiments, LEGO gearboxes: (a) variant A; (b) variant B; and (c) variant C.

Further, the product variants should be modular enough to be able to be balanced across three workstations, and still maintain the possibility to assess the quality of assembly work for each of the three stations, i.e. it should be able for operators at later stations to assemble correctly even if operators at earlier stations have made mistakes. The balanced distribution of the three assembly stations can be seen in Fig. 3, where variant A stands as an example. variants B and C are balanced similarly. It is noteworthy that station 2 has a slightly longer nominal assembly time in comparison to the other stations.

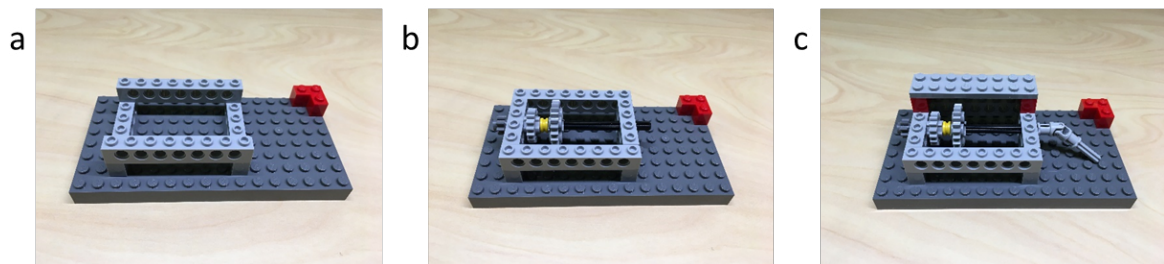


Fig. 3. The balanced distribution of product variant A across the three assembly stations: (a) station 1; (b) station 2; and (c) station 3.

In the learning factory concept physical aspects are considered in terms of height and reachability. The assembly station is adapted to the operator height and also the screens are placed in such a way so that information is presented in line of sight.

3. Discussion

In this paper a concept for human-centered learning factories was developed. The results from experiments performed with students were that the Casat software is useful for presenting work instructions although some bug fixes are needed [33]. In addition, the number of variants were few in the experiment and should be increased to assess differences in the effect of multi-variants. Now the number of variants was three and the assembly work was considered as moderately complex assessed using parts of the CXI method.

In the experiments it was seen that cognitive load was connected to work instruction content. This indicates that the NASA-TLX assessment, CXI and information quality is useful in assessing human-centered aspects of learning factories.

By considering usability and HCD the workstation a higher efficiency and better ergonomics for the operators can be achieved [47,48]. Applying HCD solutions that personalize a working environment could help attract new work force as well as handle problems with short-term working personnel and long-term sick leaves. To avoid that companies invest in solutions that does not fit them, learning factories can be used to increase knowledge of the best appropriate solution.

A concept design for human-centered learning factories should include the following:

- Investigations of the *introduction of advanced automation* [25,34]. This can be studied through using survey tools such as CXI, NASA-TLX, interviews and the Information quality.
- *Management of the increasing product variety* [36]. Perceived production complexity should be investigated and managed in a learning factory e.g. by CXI or interviews. Since it is difficult to avoid complexity due to that a high product variety cannot be reduced complexity can instead be reduced through balancing tasks so that the assembly content is fewer at each station. In the concept presented in this paper the product variety was supported through presenting three variants balanced at three stations.
- Support in *finding information* [39]. A learning factory should present information according to the operators' cognitive processes [53]. This could be done by using both pictures and text and reduce and simplify the instructions so that only the necessary information is presented. This was supported through real-time information presentation. In addition, instructions for learning should include additional information e.g. why the assembly is carried out in that manner [70].
- Support of *existing interactions* between humans and automation [40-42]. The interaction between humans and automation in the learning factory should be supported through real-time information support and visual feedback. In the learning factory concept pick-and-place operations were supported through cognitive automation support (through text or screen) and operators could see each other, which increases their communication possibilities.

The suggested concept design thereby supports aspects of human-centered design. Specifically, the cognitive aspects were in focus in the development that could increase the support of cognitive capabilities (which are seen lacking today [51-53]).

4. Conclusions

To optimize the output from future learning factories experiments, it is important to be sure what companies want and need. Since the test environments can be designed to capture many aspects of production work this is crucial in order to produce relevant experiment results. In this paper a human-centered learning factory concept was developed that specifically focused on cognitive capabilities. With introduction of Industry 4.0, challenges and difficulties faced by operators in production are also changing. The learning factory environment provides a good platform to

overcome these new challenges. Moreover, learning factories can also be used for testing new methods and design concepts that can be used for human-centered production.

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