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Concepts for Digitalisation of Assembly Instructions for Short Takt Times

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Abstract

Operational complexity for shop-floor operators can be reduced with effective presentation of instructions, which in turn improves product quality. While this has been researched for longer takt times, final assembly with shorter takt times requires new approaches to properly support operators. Hence, this paper aims to present findings regarding concepts for digitalised assembly instructions to support shop-floor operators in a mixed model final assembly with shorter takt times. A bottom-up mixed-methods approach was applied in an iterative development process, resulting in concepts for short takt time instructions. The findings indicate how to cognitively support operators in two situations. First, work tasks are preferably taught beforehand, with educational instructions. Second, operators should be supported with simplified instructions, presenting key elements and deviations in real-time. Conclusively, these concepts will increase the likelihood of the instruction to be used by operators, which enables standardised work and contributes to enhanced product quality.

Keywords: Assembly Instructions; Digitalisation; Mixed Model; Final Assembly; Short Takt Times; Industry 4.0; Operator 4.0

1. Introduction

The operational complexity for shop-floor operators in production systems increases as companies in the manufacturing industry competes to meet a wider variety of customer demands [1], affected by factors such as larger product variety to manage [2] and more customised products [3], combined with changing demographics on the labour market [4]. In this complex production systems environment, Industry 4.0 [5], human operators remain as the most valuable resources [6] due to abilities such as flexibility [7], problem-solving [8], and decision-making [9]. Effective sharing of relevant information as cognitive support for operators in this increasingly complex work environment has the benefit of both lowering workload and improve assembly quality [10, 11].

As a result of product variety and customisation demands, a mixed model approach is often applied in final assembly operations [12]. In such work environments, especially in cases with shorter takt times, requirements on assembly instructions concerning its availability and presentation become more important [13]. The conceptualisation of new approaches to present information for operators contributes to developing more socially sustainable workplaces for the future Operator 4.0 [14]. While Industry 4.0 and its enabling technologies facilitate sharing of such information [15], additional efforts are required in promoting their use [16]. This promotion should instil an appropriate level of trust among its intended users, regarding the digitalised instructions' expected reliability and behaviour [17].

Therefore, this paper aims to explore and present findings regarding concepts for digitalised assembly instructions to support shop-floor operators in a mixed model final assembly with short takt times.

2. Design and Presentation of Instructions for Operators

Operators, independent of their experience level, will always encounter unfamiliar situations [18], at these situations the operators need to trust the support from colleagues or available assembly instructions [18]. Assembly instructions have the possibility to define and enhance standardised work, to make operators work according to an optimal and predefined way [19]. The benefits with standardised work are increased quality levels, maintained takt times, and having a basis where improvements can be developed from [20]. Quality deviations

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from experienced operators tend to come from a slip of concentration rather than lacking knowledge [19].

Instructions presented to shop-floor operators need to support different cognitive process depending on the assembly mode at hand, e.g. learning phase and operational phase [21]. When an operator is learning new tasks, technologies or routines, instructions need to support reasoning to the concentrated operator to learn knowledge by heart [22]. In contrast, after the initial learning phase, when an operator enters an operational assembly mode and performs daily assembly tasks, instructions need to support intuition by displaying standardised symbols and highlighting variations [23].

2.1. Assembly Instruction Design

Assembly instructions describe how certain work tasks should be carried out and what components to use [19]. The assembly instructions must be of high quality, otherwise they are useless [24]. A reduced amount of information is preferred for operators working in an environment with short takt times, increasing the possibility for the instructions to be used [25]. The usage of assembly instructions can further be increased if six attributes are fulfilled;

- relevance or necessity [24, 26, 27]
- timeliness [24, 26]
- accuracy or correctness [24, 26, 27]
- accessibility [24, 26]
- comprehensiveness or completeness [24, 26, 27]
- format [24].

An effective approach of showing information is through symbols if the symbols are well-known and easy to understand [23]. Unlike texts, symbols can be seen from a further distance, making it possible to perceive the information more quickly and with fewer errors [23]. A successfully designed symbol can be recalled with minimal cognitive effort and symbols can also work in an international environment [23]. The short-term working memory for a human can store 7 ± 2 entities [28], which also should be considered when developing work instructions for shorter takt times.

If illustrations are used, they need to have a strong connection to reality [3]. Further, they need to be distinct, with high contrast, avoid shadows, use text, arrows, numbers and enlargement to make the illustrations more informative [3].

2.2. Information Presentation

When high-quality assembly instructions are presented to operators at the right time and place, the quality outcome of the products will increase [29]. Therefore, working in stressful environments sets higher demands on the visual presentation of information [23]. By using redundancy of information formats, such as combining colour and placement of the information, it helps the operator to interpret the information in a preferred way [23]. When using a display to present information, operators often scan for information through the diagonal, from the upper left corner to the lower right [3]. Therefore, it is important to develop an interface that presents the work instructions smartly and effectively, to not burden the operator's short-term memories [23].

3. Development of Assembly Instructions

To be able to create concepts for digitalisation of assembly instructions an empirical study was performed at a manufacturing company within the automotive industry. The company was selected due to its short takt times of about one minute.

The research started with an initial state analysis and was followed by developing specification of requirements for the assembly instructions. Thereafter, concepts were created, followed by subsequent improvements. This sequence of methods is outlined in Fig. 1.

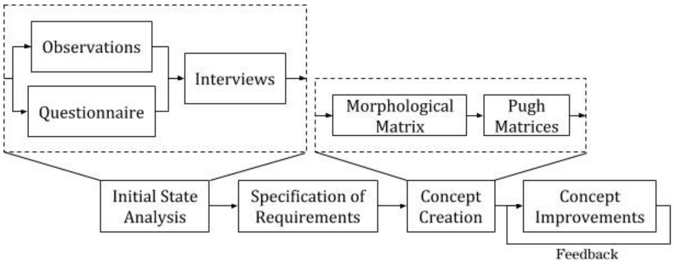

Fig. 1. Sequence of applied methods.

3.1. Initial State Analysis

Observations [30, 31] were performed at two stations, with the aim to map existing work sequences and gather quantitative data for potential support areas for digital assembly instructions. In total 18 operators were observed, assembling 285 cars.

The questionnaire contained open and close-ended questions [32], aiming to understand the intended users and their needs for cognitive support. The questionnaire collected both quantitative and qualitative data. The results from the questionnaire showed a trend of operators not understanding and using the existing assembly instructions, see Fig. 2 and 3. In total 86 operators answered the questionnaire, evenly distributed between the day, evening, and night shifts. 70% of the operators had worked at the selected stations for more than one year and were therefore considered as experienced operators.

The interviews gathered qualitative data and were semi-structured [31, 33, 34]. In total 14 people, evenly distributed between the three shifts, were interviewed; three supervisors, eleven operators of which three were team leaders and two safety representatives. The purpose of the interviews were to understand how the existing cognitive support initially were designed, how the operators preferred it to be, and how to make the transition.

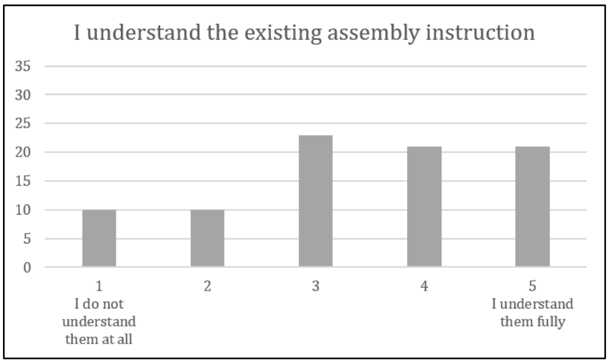

Fig. 2. Questionnaire results: Operators' understanding of existing instructions.

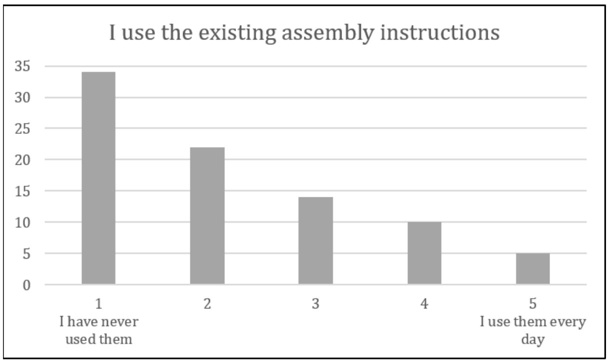

Fig. 3. Questionnaire results: Operators' usage of existing instructions.

The quantitative data from the initial state analysis was analysed with basic descriptive statistics [31] and the qualitative data by dividing it into subcategories [34]; initial state, recommendations for assembly instructions, working habits, and change management.

The initial state analysis concluded that operators preferred simplified instructions which were easy to comprehend and understand. Further, the assembly instructions were favoured to be in a digital format with updated, accurate and visual support. The instructions should avoid complicated or corporate language to increase the understanding and usage of the assembly instructions. The inclusion of operators in the development phase of the assembly instructions was also stated as a requirement to increase the relevance, usage, and acceptance for the developed assembly instructions.

3.2. *Specification of Requirement*

The triangulation [31] from the initial state analysis generated the input for the developed specification of requirements [35, 36], which resulted in the demands set on the digital assembly instructions.

3.3. *Concept Creation*

The morphological matrix [37] generated 2400 design concepts, and with its traceability, the concepts were assessed and organised down to 242 concepts based on the specification of requirements and existing technology restrictions. To limit the number of potential concepts, only subfunctions which had a direct effect on the assembly instructions were included.

These 242 design concepts were the input for the Pugh matrices, which were used as a risk management tool to determine which concepts to select for further improvement [37]. 17 criteria were used, regarding usefulness, flexibility, maintenance, safety and comprehensibility, of the assessment. In total, four iterations were conducted with different base lines, where approximately half of the concepts were removed in each iteration, resulting in seven concepts to further elaborate on.

3.4. *Concept Improvements*

The seven design concepts were improved in an iterative evaluation process in collaboration with operators. Based on information quality attributes [24], factors affecting design and presentation of assembly instructions [23], as well as operators' preferences from the initial state analysis, nine statements were derived. These nine statements guided the evaluation to assess that the work instructions:

- display information clearly.
- contain relevant content.
- does not contain any difficult terms.
- are easy to understand.
- can be interpreted fast.
- support the understanding of work tasks.
- support daily work.
- support standardised work.
- show ergonomic guidelines.

This approach resulted in the two final concepts for the assembly instructions; educational instructions and simplified instructions.

4. Results

The initial state analysis showed that operators assembling in shorter takt times encounter two different situations were cognitive support through assembly instructions are suitable. First, when the operator is either new to the job or the standardised way of working has been changed. The operators then need educational assembly instructions with the main purpose of supporting the operators' learning. Second, when the operators are experienced and only need to be reminded of variations deviating from the common assembly order. The operators then need simplified assembly instructions, which function as reminders to avoid missing a known but not common assembly.

The concept improvements concluded that the instruction types need to be presented in a digital format that enhances the likelihood of the assembly instructions being used. This format enables a presentation of the assembly instructions in real-time, with easy-to-update and more accurate information.

4.1. Educational Instructions

During the concept improvement, different digital formats were evaluated, and the video format was strongly favoured by the operators. Therefore, this format was selected for the educational instructions. The videos should contain shorter work sequences, making it easier to explain the standardised work methods. The educational instructions should be supported with explaining subtitles, detailed pictures, and clarifying symbols, see Fig. 4.

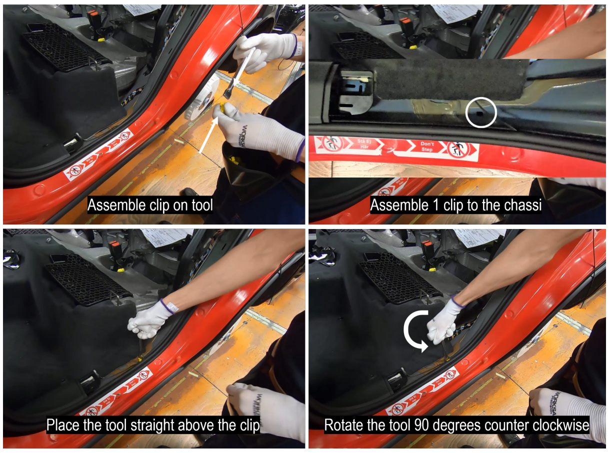

Fig. 4. Screenshots from video sequences, used in educational instructions.

The educational instructions should be sorted based on product models for an easier understanding, see Fig. 5. The assembly order should be easily visualised containing both the right sequence and deviating variants within the models.

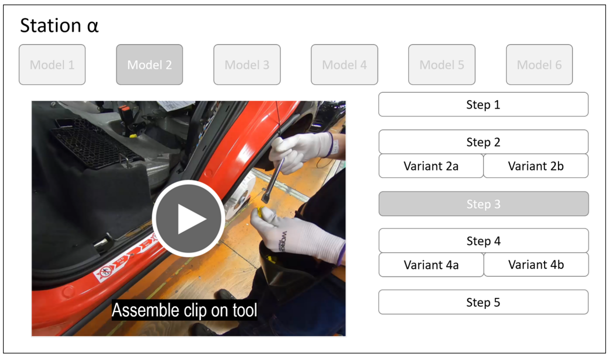

Fig. 5. Screenshot of the concept for presenting digital educational instructions.

Further, the educational instructions should be used in an environment where it is possible to pause and replay the videos, and thereby enhance the operators' knowledge. The education is favoured to be done together with a tutor, where the educational instructions work as a complementing learning tool.

4.2. Simplified Instructions

During the concept improvements, text format and symbols were evaluated for the simplified instructions. The symbols approach were favoured by the operators and thereby selected as the format for the simplified instructions. In this concept, a symbol indicates a variant or a deviation from the common assembly. Due to its purpose to highlight assembly variations, these symbols are henceforth called variation symbols, see Fig. 6. The variation symbols need to be distinct, interpreted fast, and overcome language barriers. The operators should be involved in the development of the variation symbols as it increases the likelihood of them being interpreted correctly and thereby also used.

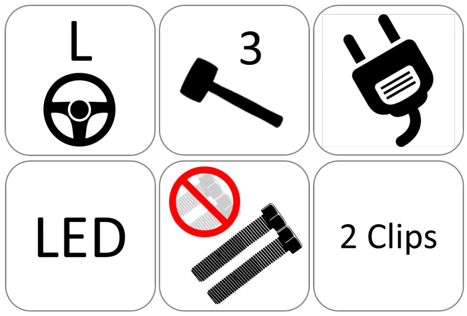

Fig. 6. Examples of six different variation symbols, used in the simplified instructions.

The simplified instructions should be used as a support during the operational phase and therefore they need to be product-specific, accurate and presented in real-time, see Fig 7. The instructions should be presented to the operators on a display placed at the assembly station, easy for the operators to see. Further, the variation symbols should be placed on the diagonal of the display to make the operators interpret the information faster and not increase the cognitive burden with too many symbols, hence maximum five variation symbols during any particular moment.

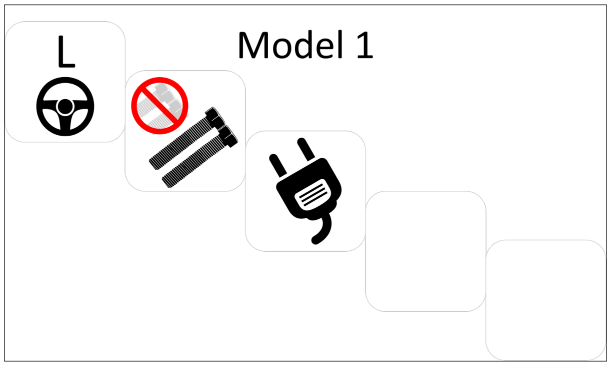

Fig. 7. Screenshot of the concept for presenting digital simplified instructions.

As the simplified instructions are placed close to the operators at the assembly line and easy to interpret from a distance, it makes it possible for the operators to prepare themselves for the upcoming assembly by checking the instructions while fetching material or walking down the station.

5. Discussion

The empirical results from the initial state analysis [38] and the subsequent specification of requirements entailed that it is difficult to encompass all six attributes concerning assembly instruction design [24, 26, 27] for operators working in final assembly with short takt times. This finding aligns with operators' varying cognitive needs during learning and operational phases [21]. Therefore, the creation of one concept for each of the phases, as proposed in this paper, is designed to support operators for the two different situations.

5.1. Educational Instructions during Learning Phase

During the learning phase, with educational instruction in a video format, the operators can learn new tasks and gain knowledge. The empirical results showed that operators wanted to find more in-depth information about their assembly tasks by using a digital tool, which contributes to the comprehensiveness of the available information [24, 26]. Another aspect to consider is the frequently updates needed for the videos and its information content to remain relevant and accurate [24, 26, 27]. However, for educational instructions, where operators are not limited by short takt times, circumstances are more similar to other work environments.

5.2. Simplified Instructions during Operational Phase

During the operational phase, simplified instructions should be used and the format should be variation symbols, which were also favoured by the operators. By using variation symbols the comprehensiveness of the information can be reduced [25], in favour of increasing the relevancy of the information which is important for shorter takt times [24, 26].

When the operators need cognitive support during a short period of time, symbols can be perceived quicker and with fewer mistakes compared to text instructions [23]. Intuition can be supported by the presented concept by showing standardised symbols and highlighting variations [23].

The simplified instructions are further presented in an effective and organised way by placing them on the display's diagonal to decrease the interpretation time [3]. To further decrease it, a maximum of five variation symbols should be used, based on the limits of the operators' short term memories [28]. Both those aspects are of importance to easier provide cognitive support for operators during shorter takt times.

5.3. Future Research

Empirical validation of the proposed concepts could be done to determine whether the concepts could contribute to improved cognitive support for operators working in real-time, during shorter takt times or not. By evaluating the two concepts in a larger scale, a better understanding of the benefits and drawbacks of the suggested concepts could be gained and how these concepts could be implemented at companies. Further validation of how the assembly instructions should be designed and used is valuable for preventing the operators to receive irrelevant information.

For Industry 4.0 moving forwards, Operator 4.0 remains an important topic for socially sustainable factories of the future [14]. In this context, future research needs to empirically ascertain the range of work tasks for Operator 4.0, and subsequently how assembly instructions should be presented to properly provide cognitive support in increasingly complex production systems. Consequently, the new technologies that enable Industry 4.0 and its cognitive support for Operator 4.0 will put higher demands on both the underlying IT systems and on organisational aspects to support new practices.

6. Conclusion

This paper proposes two concepts for digitalisation of assembly instructions for shorter takt times, supporting shop-floor operators in two different situations.

The first concept is educational instructions in a video format, used for training new operators or learning of new tasks by experienced operators. The videos target the learning phase and prepare the operators cognitively before they enter the operational phase. The concept includes well-developed videos, which are up-to-date, easy to access and simply sorted, from an operators point of view.

The second concept is simplified instructions which support the operators during the operational phase, by using an updated and accurate set of symbols that highlights variations in assembly tasks. This requires that the operators are experienced and can independently manage their assembly work. With the simplified instructions, the operators have the possibility to draw benefits of the simplified instructions due to them working as reminders and prepares the operators with relevant and accurate information just-in-time for the upcoming assembly.

By having two types of assembly instructions, the operators get suitable cognitive support when needed, which increases the likelihood of the assembly instructions being used. By involving the operators in the development of the various assembly instructions, it further increases the usage of them, which in turn may lead to an increased assembling quality.

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