How to Configure Assembly Assistance Systems – Results of a Laboratory Study

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Abstract. Manual assembly is shaped by increasing product complexity with higher scope of work and fluctuating demands. To cope with these changes, employees need to collect and process more information. Companies, therefore, face a wide range of challenges, particularly in terms of information supply. Informational assistance systems provide employees with cognitive support, helping to manage complexity. To evaluate the potentials of such systems a laboratory study is accomplished at the Laboratory for Industrial Engineering of the Ostwestfalen-Lippe University of Applied Sciences and Arts. In this paper, selected results of the laboratory study are presented and recommendations for a configuration of assembly assistance systems are derived from the results.

Keywords: Informational assistance systems · Manual assembly · Human-machine interaction · Laboratory studies

1 Introduction

Assistance systems are used in various ways in industrial production to support employees. For instance, screwdrivers may be set automatically, or cameras may be used to check components and ensure they were assembled correctly. Particularly in light of the persistent trend towards more complex products with a large number of different configurations [1], the potential for using assistance systems in manual assembly is growing [2, 3]. Employees have to receive and process varying specifications or information to properly execute a broad range of given tasks in a short time. In the long-term, these changes result in uncertainties during the assembly process leading to increased cognitive strain for employees [4]. As a consequence, they may fail to meet both quantitative and qualitative production targets [5]. Combined with the imminent shortage of skilled workers and an aging workforce in western industrialized nations, companies are facing a large number of challenges [6]. One central challenge is optimizing informational workflow. Assistance systems can offer employees support by providing them the right information at the right time and in the right form [7–9].

Several empirical studies [10–12] confirmed the potential of informational assistance systems. However, those studies primarily involved assembling Lego models with a fairly low level of complexity, resulting in lower transferability and validity for real world industrial assembly processes. Furthermore, the training times and variant changes were only insufficiently recorded in those studies. In this context, a laboratory

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study is conducted at the Ostwestfalen-Lippe University of Applied Sciences and Arts, which considers the identified deficits focusing on five hypotheses to verify the human-oriented and economic potentials of different informational assistance systems in comparison to a paper-based information provision [13]. In this paper selected results of the laboratory study are presented. The results relate to the following three hypotheses [13]:

1. The use of an informational assistance system results in shorter training times in comparison to using paper-based instructions.
2. The use of an informational assistance system results in shorter execution times for the first assembly of a new product in comparison to using paper-based instructions.
3. The use of an informational assistance system results in a smaller number of picking and assembly errors in comparison to using of paper-based instructions.

Based on the presented results of the laboratory study, recommendations for the configuration or design of informational assembly assistance systems are derived.

2 Research Design

A 4 $\times$ 3 factorial research design with measurement repetition on the second factor is chosen to investigate the hypotheses, as already described in the publication Bendzioch et al. [13]. The first factor includes the assembly supporting mediums used to carry out the assembly task. The paper-based provision of information (I) is used as the control medium. This is compared with a smart glasses-based assistance system (II), a projection-based assistance system (III) and a tablet-based assistance system (IV). Participant receive the necessary information stepwise through one of the four supporting mediums to complete the assembly task. That information includes bill of materials, information of tools to be used, assembly hints and step-by-step instructions [13]. Only the bill of materials differs in how they are prepared. These were adapted to each specific support medium, so that the particular characteristics of each individual assistance system could be taken into account. In this way, the container positions are displayed for all assistance systems (II, III, IV). The products which need to be assembled are pneumatic assemblies from a mechanical manufacturer, each involving 21 to 48 individual parts. These products are divided into three degrees of complexity – easy (A), medium (B) and difficult (C) – based on the entropy measure (second factor). This measure is used in the context of complexity description or determination [14]. Each of the individual products are assembled four times in series (measurement repetition) in ascending complexity with the aid of one of the four supporting mediums. Completing the assembly task four times is sufficient to detect any training effects [15]. Participants are assigned to the four groups randomly.

Assembly time, assembly errors and picking errors are used as dependent variables to test hypotheses 1 to 3. The assembly time is defined as the total time to complete a product. Assembly and picking errors are recorded using a standardized error list [13]. Assembly errors include the following aspects: necessary tool not used, mounted in incorrect position, component in incorrect orientation, component not installed and other assembly errors. The following error categories are distinguished for picking errors: incorrect tool picked, incorrect part picked and too many/too few parts picked.

In order to assess the suitability of each participant for the study, an eye test and a motor skills test is conducted [13]. The smallest font and greatest viewing distance are used as reference variables for the eye test. The motor skills test is conducted using a Lego bricks car model and a paper-based assembly instruction similar in format and scope to those used in the main test.

3 Results

In the first data collection stage, 32 participants (eight per support medium) took part in the empirical study. Of these persons, 5 are female and 27 are male, with ages ranging from 21 to 37 (M = 25.31; SD = 3.76). The majority of participants (93.75%) are students. Statistical analysis is conducted using SPSS 26. An ANOVA with measurement repetition is used to test hypothesis 1. The analysis shows that there is a significant main effect between repeating the assembly task and assembly times for each product ($F_A(1.62, 45.35) = 91.90$, $p < .001$; $F_B(1.77, 49.51) = 124.65$, $p < .001$; $F_C(1.69, 47.36) = 202.38$, $p < .001$). This effect can also be identified descriptively from the mean values of the assembly times shown in Fig. 1. Assembly times decrease down to a certain level of performance as the number of repetitions increases. Therefore, the results suggest a training effect resp. a reduction of the assembly times through the repeated assembly of the products.

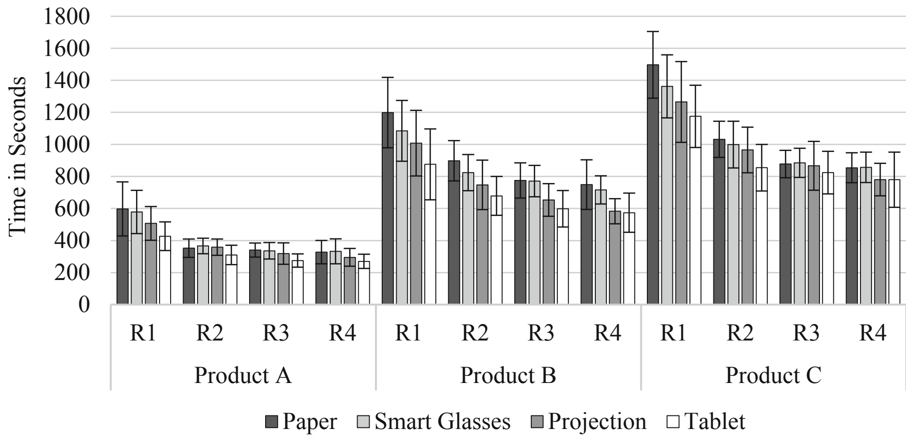

Fig. 1. Assembly times (mean values and standard deviations) for the products and repetitions, depending on the assistance systems used (I–IV).

Furthermore, Fig. 1 shows that assembly and training times vary depending on the complexity of the product and the used assistance system. This effect can be proven for product B through a significant main effect, which the used support medium has on assembly times ($F_B(3, 28) = 4.33$, $p = .013$). Regarding product B, pairwise comparisons in consideration to the Bonferroni correction showed a significant difference between providing information on paper and a tablet-based assistance system ($p = .017$). However, no significant difference is noted between the other support mediums or products. Therefore, hypothesis 1 must be rejected.

Referring to the second hypothesis, the initial assembly time (R1) for each product and support medium is considered. The values can be seen in Fig. 1. In average, all informational assistance systems are faster in completing the task for the first time than the control medium. However, a single factor variance analysis only shows a significant main effect for product B between the assembly time and the support medium used ($F_A(3, 28) = 2.56$, $p = .075$; $F_B(3, 28) = 2.94$, $p = .050$; $F_C(3, 28) = 2.90$, $p = .053$). Furthermore, the post-hoc test (Bonferroni correction) for product B shows that the use of a tablet-based assistance system results in shorter assembly times for initial assembly, in comparison to the control medium ($p = .044$). Since no support medium indicates significant differences across all products, the second hypothesis must be rejected.

To evaluate hypothesis 3, the picking and assembly errors, summed up over all products and repetitions, are investigated separately for all support mediums (Fig. 2). It should be noted that all errors are recorded, including those which were corrected during the assembly process. Both types of error do not have a normal distribution, therefore the Kruskal Wallis test is used for independent samples. The statistical analysis shows that the used support medium does have a significant influence on picking errors ($H(3) = 14.47$, $p = .002$). However, this influence cannot be confirmed for the assembly errors ($H(3) = 1.96$, $p = .582$). Post-hoc tests completed afterwards (Bonferroni correction) show that fewer picking errors occur with a projection-based assistance system in comparison to a paper-based provision of information ($z = 3.77$, $p = .001$). Therefore, the third hypothesis cannot be confirmed completely, and must be rejected.

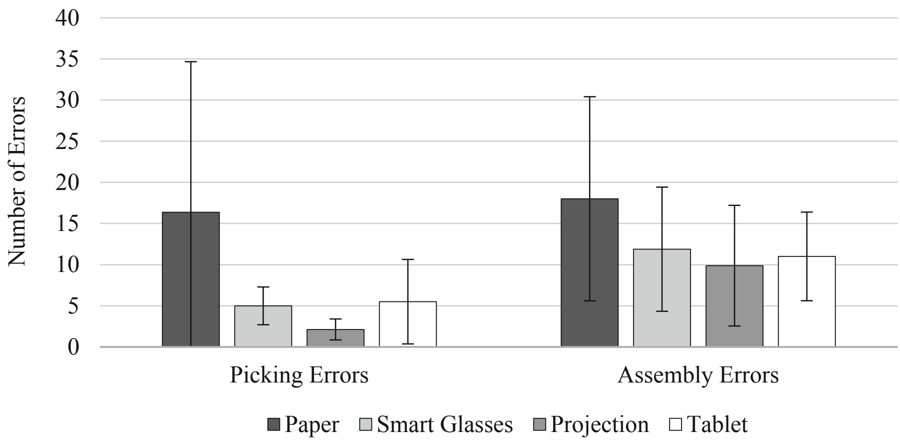

Fig. 2. Picking and assembly errors across all products and repetitions (mean values) depending on the assistance systems used (I–IV).

4 Conclusion

The results presented above show that hypotheses 1, 2 and 3 must be rejected, based on the available data. There are significant differences between individual assistance systems, but these do not persist across all products and all types of errors. This may be due to the sample size, but may also be due to the high deviation among assembly times and errors. However, a descriptive consideration of the results indicates that assembly assistance systems can help shortening assembly times and reducing errors. Furthermore, configuration and usage recommendations for informational assistance systems could be derived based on the results.

The usage of an informational assistance system does have the potential to reduce training times in a reasonable manner (hypothesis 1). Comparing the paper-based provision of information with the tablet-based assistance system, reveals a chance to reduce training times by about one-fifth. The average reduction in assembly time – across all repetitions – for product A is 20.77%, for product B 24.70%, and for product C 14.72%. The potentials of the tablet-based assistance system are also reflected in the initial assembly times for each product (hypothesis 2). Compared to the control medium the initial assembly times could be reduced by 28.52%, 26.95% and 21.48% for products A, B and C respectively. In addition, the results regarding the second hypothesis show that using a projection-based assistance system is one possible alternative to the tablet-based system (product A 15.13%, product B 15.93% and product C 15.46%). Furthermore, picking errors can be reduced most by using a projection-based assistance system, in comparison to the control medium (87%). Additionally, the other two assistance systems also help considerably to reduce picking errors (greater than 60%). These results are likely due to the fact that the container position was not represented visually in the control medium. There are no major differences between the individual assistance systems in terms of assembly errors. However, working with any of the assistance systems leads to an average decrease of 40% in assembly errors in comparison to the control medium. Based on the percentages for total savings, the application potentials shown in Table 1 can be derived for the three informational assistance systems. These relate to the main areas of investigation of hypotheses 1 and 3. In this way, Table 1 supports an application-specific selection of an assistance system based on the study results, such as using a projection-based assistance system to reduce picking errors.

Table 1. Application potentials of the informational assistance systems in light of the potential for reducing picking errors, assembly errors and training times.

Assistance systems	Application potentials		
	Reduction of picking errors	Reduction of assembly errors	Reduction of training times
Smart Glasses	Helpful	Helpful	Slightly helpful
Projection	Highly helpful	Helpful	Helpful
Tablet	Helpful	Helpful	Highly helpful

Furthermore, even in preparing the study, important findings on the best way to deliver assembly information could made. Initial pretest showed that information in the form of text should be reduced to a minimum, because texts were mostly not used by the participants. Using pictures, figures or symbols led to better results. The laboratory study also showed that providing information centrally, as is the case with the tablet-based assistance system, makes completing the assembly work subjectively simpler. There is no need for workers to search for information, since it is all displayed on the output medium. In contrast, with projection-based assistance systems workers must first locate information in the working system. So Information should be prepared in such a way that employees can view it in a set location and with a single glance. However, this recommendation for providing information centrally only applies to classic single workstations with a limited width. Otherwise, providing information centrally would require a significant amount of walking. In addition, the study shows that the tablet probably achieved such good results (for instance in terms of training times), because test persons were already familiar with the medium and how it works (in contrast to smart glasses) before starting the test.

The presented results of the study indicate that informational assistance systems can help to prepare information in line with employee needs and to increase productivity. In order to assess the potential of informational assistance systems more precisely, the study should be extended to a larger number of participants in the next project phase.

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