Acceptance Expectancy for Cognitive Assistance Systems Variants in Smart Factories

Bastian Pokorni and Christian Saba
Department of Connected Manufacturing Systems
Fraunhofer Institute for Industrial Engineering IAO
University of Stuttgart, Institute of Human Factors and Technology Management (IAT)
Stuttgart, Germany
bastian.pokorni@iao.fraunhofer.de, christian-oswaldo.saba-gayoso@iao.fraunhofer.de

Abstract

This study intended to gain initial insights into which technical design options of cognitive assistance systems for manual assembly are predicted to have a higher acceptance between future potential users. The methodology is based on combining previously obtained results, indicating which acceptance factors are the most important in this field, together with new generated data with the same participants on the appreciated relevance of relationships between these factors and today existing technical design options. Combining both results numerically enables a final qualitative statement about preference tendencies inside each of those technical assistance aspects of cognitive systems, identified by experts as the most relevant for potential future users. The results show a higher acceptance tendency for hand-carried/mobile, documentation-based, dialogical assistance systems with a high adjustment level for the assistance, a selective assistance frequency, an intervention module both while work process and by the result as well as a task-oriented assistance and the omission of at least personal-related data. Based on these results, planners should be able to find better orientation, when designing a cognitive assistance systems for manual assembly.

Keywords
Cognitive Assistance System, Technology Acceptance and Industry 4.0.

1. Introduction
Factories are changing. Increasingly volatile markets, shorter product life cycles and more individual products are creating a growing need for flexibility and adaptability in production (Haemmerle et al. 2017, Bauer et al. 2016). As a result, however, the processes in factories are becoming more and more complex. Tasks that are always the same or physically heavy are now often automated to relieve the physical burden on humans. However, complex and frequently changing processes cannot be fully automated economically (Yoshimura et al. 2006). Compared to machines, humans have the advantage of being able to react flexibly to new tasks and unexpected situations and to find creative solutions to unknown problems. Therefore, even in the future, successful production will be based on qualified and motivated employees (Hunter 2022). The more complex and extensive the production processes are, the higher is not only the physical but also the mental strain on people. In production, cognitive assistance systems should help to reduce this stress and support people in the performance of their tasks (Romero et al. 2016). However, the design and configuration of these assistance systems poses major challenges for engineers. The systems must be specifically adapted to the respective context of use. In addition to the work tasks and the work environment of use, special attention must be paid to the future user. A system can bring proven benefits to the company according to technical and economic criteria and yet not be accepted by the user due to poor implementation and thus not be used (Mattsson et al. 2020). "In addition to the technological developments, it is necessary to develop guidelines to accompany the process of selecting and configuring assistance systems from a user perspective." (Hinrichsen et al. 2016). User-centered development and user participation in the design process is therefore essential in the development of assistance systems in production (Pokorni 2021, Pokorni et al. 2020). However, this is often neglected (Kleineberg et al. 2017). Various standards do provide structural approaches for integrating the user into the development of human-machine systems (DIN EN ISO 9241-210, 2011, DIN EN ISO 9241-11, 2017). However, fundamental findings on acceptance factors in relation to cognitive assistance systems in production are still lacking.

The addressed tendencies show the urgent need for posing and resolving the following research questions:

- Which technical configuration options for cognitive assistance systems in manual assembly fulfil best each of future users' related acceptance factors?
- Can technical configuration options for cognitive assistance systems in manual assembly be systematically prioritised to increase acceptance chances within potential future users?

1.1 Objectives

In the aim of resolving the posed questions above, previously not addressed targets need to be achieved such as:

- Translation of acceptance needs into specific design options for cognitive assistance systems in manual assembly processes
- Prioritisation of configuration options for cognitive assistance systems in manual assembly processes.

For this purpose, Chapter 2 should provide the relevant basics and the research gap, Chapter 3 the chosen research design, Chapter 4 the data collection in detail and Chapters 5 and 6 the discussion and conclusions for obtained results.

2. Literature Review

This chapter provides an overview of the state-of-research and gaps in industrial assistance-applications acceptance.

2.1 Cognitive Assistance Systems

Assistance systems are used in places where there is a discrepancy between the operational performance requirements of the work task and the performance capacity or skills of the employees (Yang and Plewe 2016, Li et al. 2018). The assistance provided by the technical system is generally performed by taking in the required information from the environment. This information is then processed by the system and passed on to the worker via a user interface. The person takes in the provided information via his or her senses, processes it cognitively in turn and gives feedback to the system via the corresponding input systems (Yang and Plewe 2016). Potentials and areas of application for assistance systems can be found in all areas of a company, e.g., in production, assembly, maintenance or logistics (Schumacher et al. 2020). The overall goal of these systems is to enhance the user to take quickly the right decisions in order to perform the work task more efficiently (Gorecky et al. 2014). In manual assembly, cognitive assistance systems are mainly used to provide work instructions, parts lists, drawings or special information. Furthermore, systems can also document work processes or monitor the accuracy of execution and notify the worker if necessary (Hinrichsen and Bornewasser 2019, Claeys et al. 2015, Burggräf et al. 2021).

2.2 Technology Acceptance

The respective technology acceptance of the employees has a particular influence on user satisfaction. This is the subject of many scientific studies such as Bandow and Holzmüller (2010). One of the best-known models for explaining technology acceptance is the Technology Acceptance Model (TAM) according to Davis (1989) and Davis et al. (1989). The acceptance model is a concept that explains what parts an acceptance construct consists of and what influences it (Bandow and Holzmüller 2010). According to Davis et al., there are "external variables" that influence "perceived usefulness" and "perceived ease of use". Perceived usefulness describes the subjective increase in performance perceived by the employee as a result of the technology (Davis 1986, Bandow and Holzmüller 2010). Perceived ease of use describes the degree to which the user perceives the system to be easy to use (Bandow and Holzmüller 2010). The higher the perceived ease of use is, the higher the user's perceived usefulness (Davis 1989). The described perceptual context gives rise to the user's attitude and intention to use the system and intention of the user, which ultimately influence the user behaviour. The TAM was supplemented in 2000 by Venkatesh and Davis with further influencing factors. The factors of experience and the voluntariness of the user were integrated, and the external variables were broken down (Venkatesh and Davis 2000). In 2008, Venkatesh and Bala published a series of additional external variables, which are now directly assigned to the two perceptions of usefulness and ease of use**.**

These external variables have an influence on the intention to use and the usage behaviour via the mechanisms described above. In order to optimise the subsequent usage behaviour of the employee when working with digital assistance systems, it is therefore necessary to link these external variables to the characteristics of the digital assistance system to be designed.

2.3 Research Gap

On the way to the 4th Industrial Revolution factories and the relationship between humans and machines will change. This will cause changes in the socio-technical work systems of factories. Employees will use cognitive assistance systems within their work tasks (Romero et al. 2016) The design and configuration of these complex socio-technical systems is becoming an increasing challenge for the responsible engineers. Cognitive assistance systems consist of various hard- and software components and by the end they will need to increase productivity and should be highly accepted by employees. This means that engineers need to know which technical designs and which overall behaviour of a cognitive assistance system will most generate acceptance. In the current state of knowledge, there are no findings, studies or observational investigations of which specific design options of cognitive assistance systems promote or inhibit acceptance and in which order.

3. Methods

To attempt closing the gap and fulfiling the objectives of this research, the approach consists of making use of previously collected results of Pokorni and Saba (2022), on numeric importance orders of through literature-(metanalysis) and empirical-based methods (survey) as relevant-founded acceptance factors of cognitive assistance system in manufacturing. Combining those results with new numeric estimations within the same sample (potential future users of the systems) of the fulfilment of the validated acceptance factors by different technical design options should lead to further conclusions. The procedure to obtain the new values goes through the next seven steps:

1. Literature review of state-of-art covered aspects and existing configuration options for assistance systems.
2. Prioritisation of seen relationships between found aspects in 1 and previously validated acceptance factors.
3. Development of a questionnaire to explore relationships between factors and specific design options.
4. Recruitment of same participants as in study of Pokorni and Saba (2022): Trainees for manufacturing jobs.
5. Data collection: monitored online survey.
6. Quantitative evaluation: numerical and graphical results.
7. Qualitative evaluation: discussion and conclusions.

First, a literature review was made to identify, which technical configuration options for assembly assistance systems were the most relevant. Taxonomies define different aspects as by Hinrichsen et al. (2016), Lusic et al. (2016), Kovacs et. al (2018) and Keller et al. (2019) were identified. The finally selected assistance aspects from this literature review as well as the contained technical configuration options are shown in Table 1.

Table 1. Relevant Technical Configurations Options and Assistance Aspects (derived from literature review)

Selected Technical Configuration	Corresponding Assistance Aspect
Stationary/fixed, Hand-carried/Mobile, Wearable	Execution type
Documentation, Advice, Instruction, Intervention	Information provision
Monological, Dialogical, with Externals	Interaction form
Language assistance, Speed adjustment, Lighting adjustment, Modular adjustability, Degree of Assistance	Adjustment options
One-time assistance, Continuous assistance, Selective assistance, Periodical assistance	Assistance frequency
Assistance while work process, Assistance by result, Assistance both while process and by result	Intervention degree
Assistance before work task, Assistance while work task, Assistance after work task	Assistance time
Documentation of performance-related data, Documentation of person-related data	Documentation contents

In the second step, an expert group consisting of people experienced in science and industry with a deep knowledge of cognitive assistance systems were asked to decide which of the general assistance aspects found in step 1 would

most likely be related to the validated acceptance factors in the previous study of Pokorni and Saba (2022). For this purpose, their expertise in the field as well as logical exclusion were used, so that each acceptance factor could be linked to different assistance aspects by different frequency. As an example, factor "Trust" would, according to the experts, not be dependent from the execution type, but instead of the *Documentation contents* and *Intervention degree*. The resulting relationships from this analysis are listed in Table 2.

Table 2. Related Acceptance Factors and Assistance Aspects (derived from experts-allocation)

Assistance Aspect	**Sensibly Related Acceptance Factors (previously validated)**
Execution type	Facilitating conditions, Design/Interface, Perceived Enjoyment, Reliability, Perceived Playfulness, System Quality, Perceived Ease of Use
Information provision	Design/Interface, Logical Comprehensibility, Reliability, Facilitating Conditions, Information Quality, System Intelligence, Psychological Risk, Perceived Usefulness
Interaction form	Design/Interface, Facilitating conditions, Perceived Ease of Use
Adjustment options	Design/Interface, Facilitating Conditions, System Intelligence, Perceived Usefulness, Self-learning ability
Assistance frequency	Assistance Facilitating conditions, Perceived Enjoyment, Perceived Playfulness, System Intelligence, Perceived Usefulness
Intervention degree	Perceived Control, Trust, System Quality, Privacy Risk, Perceived Usefulness, Psychological Risk, Perceived Control
Assistance time	Perceived Enjoyment, Perceived Playfulness, Perceived Usefulness
Documentation contents	Privacy Risk, Trust, Psychological Risk

To explore the relationships between the specific technical design options contained in each identified acceptance aspect and the related acceptance factors in step 2 a survey was chosen as the measurement instrument for quantitative evaluation. Questions were sorted in different blocks, covering each assistance aspect. To obtain numeric answers in the preference measurements a single choice (SC) and multiple choice (MC)-based questionnaire was used, as according to Stockemer (2019) these techniques represent valid quantitative methods for the social sciences. Multiple choice questions were chosen for cases, where combinations of different configuration options inside an aspect were technically possible as in the case of the options contained in aspects (1), (2), (4), (7), (8) of Table 1.

The first version of the questionnaire was pre-tested, refined and modified until obtaining a final version that contained 41 items. Table 3 shows the finally chosen measurement statements for the relationship of the assistance aspects and the associated acceptance factors.

Table 3. Selected Questions after pre-evaluation

Contained Assistance Aspect	**Measure items for relationship testing to acceptance factors**
Execution type (MC)	Next execution type configuration**(-s)** would for me increase the presence of following **(acceptance factors)** the most:
Information provision (MC)	Next information provision configuration**(-s)** would for me increase the presence of following **(acceptance factors)** the most:
Interaction form (SC)	Next interaction form configuration would for me increase the presence of following **(acceptance factors)** the most:
Adjustment options (MC)	Next adjustment configuration option**(-s)** would for me increase the presence of following **(acceptance factors)** the most:
Assistance frequency (SC)	Next assistance frequency configuration would for me increase the presence of following **(acceptance factors)** the most:
Intervention degree (SC)	Next intervention degree level configuration would for me increase the presence of following **(acceptance factors)** the most:

Assistance time (MC)	Next assistance time configuration option**(-s)** would for me increase the presence of following **(acceptance factors)** the most:
Documentation contents (MC)	Next documentation content configuration**(-s)** would for me increase the presence of following **(acceptance factors)** the most:

4. Data Collection

This study had as participants the same ones as in the previous study of Pokorni and Saba (2022). These had been specifically selected with the purpose of representing potential users of cognitive assistance systems in manual assembly/production environments: trainees in German Vocational Training (2-3,5 years in so-called dual system) for a manufacturing profession. In total, the same 50 male and 6 female participants from the previous study completed the questionnaire.

The participants were invited to a 1-hour virtual meeting. In the first half, all participants were given a remote 20-minute pitch of the actual research at the Future Work Lab in Stuttgart (Hämmerle et al. 2017), they already knew before from the previous study. So, they could refresh their theoretical knowledge about the different types of cognitive assistance systems. After the theory-centered pitch participants were sent the link to the online questionnaire and could start directly to complete it, while they stayed in the same online-meeting room for eventual understanding questions.

5. Results and Discussion

After the data collection a quantitative evaluation was possible. For this purpose, all numerical results were summarised and then again graphically visualized for interpretation.

5.1 Numerical Results

The preferences made by the participants were directly counted from the single/multiple choices and thematically sorted for evaluation. Columns 2 to 5 in Tables 4-15 show each of the counted values, when asking the sample to choose across the different design options the one(-s) to cover best each of the related acceptance factors, whereas in Table 16 a final calculation for the overall preferences within each assistance aspect can be derived from merging all preference results with the importance ratings for each factor (calculated previously in Pokorni and Saba (2022) and displayed in the upper left side in bold and brackets, column 1, in Tables 4-15).

Table 4. Preferred design options with respect to the factor “Facilitation conditions”

Facilitating conditions (8,5)	Related Technical Configuration Options (N=56)				
Execution types	*Stationary/Fixed 19*	***Mobile 44***	*Wearable 16*	-	-
Information provision	*Documentation 32*	*Advice 31*	***Instruction 38***	*Intervention 24*	-
Interaction form	*Monological 20*	***Dialogical 24***	*With externals 12*	-	-
Adjustment options	***Language 37***	*Speed 32*	*Lighting 23*	*Modularity 27*	*Degree 35*
Assistance frequency	*One-time 3*	*Continuous 20*	***Selective 25***	*Periodical 8*	-

Table 5. Preferred design options with respect to the factor “Perceived Usefulness”

Perceived Usefulness (9,25)	Related Technical Configuration Options (N=56)				
Information provision	***Documentation 41***	*Advice 34*	*Instruction 32*	*Intervention 28*	-
Adjustment options	*Language 38*	*Speed 37*	*Lighting 26*	*Modularity 31*	***Degree 40***
Assistance frequency	*One-time 3*	*Continuous 18*	***Selective 27***	*Periodical 8*	-

Intervention degree	*By Work process 4*	*By Result 20*	***By both 32***	-	-
Assistance time	*Before work task 22*	***While work task 40***	*After work task 12*	-	-

Table 6. Preferred design options with respect to the factor "Design/Interface"

Design/ Interface (9,07)	Related Technical Configuration Options (N=56)				
Execution types	*Stationary/fixed 12*	***Mobile 42***	*Wearable 26*	-	-
Information provision	***Documentation 38***	*Advice 34*	*Instruction 37*	*Intervention 33*	-
Interaction form	*Monological 15*	***Dialogical 35***	*With externals 6*	-	-
Adjustment options	***Language 47***	*Speed 38*	*Lighting 33*	*Modularity 46*	*Degree 33*

Table 7. Preferred design options with respect to the factor "Perceived Enjoyment"

Perceived Enjoyment (7,55)	Related Technical Configuration Options (N=56)				
Execution types	*Stationary/fixed 1*	*Mobile 27*	***Wearable 30***	-	-
Assistance frequency	*One-time 8*	*Continuous 17*	***Selective 27***	*Periodical 4*	-
Assistance time	*Before work task 25*	***While work task 35***	*After work task 21*	-	-

Table 8. Preferred design options with respect to the factor "Perceived Playfulness"

Perceived Playfulness (5,21)	Related Technical Configuration Options (N=56)				
Execution types	*Stationary/fixed 3*	***Mobile 32***	*Wearable 27*	-	-
Assistance frequency	*One-time 13*	*Continuous 5*	***Selective 27***	*Periodical 11*	-
Assistance time	*Before work task 20*	***While work task 25***	*After work task 23*	-	-

Table 9. Preferred design options with respect to the factor "Perceived Ease of Use"

Perceived Ease of Use (9,13)	Related Technical Configuration Options (N=56)				
Execution types	*Stationary/fixed 45*	***Mobile 48***	*Wearable 4*	-	-
Interaction form	***Monological 31***	*Dialogical 21*	*With externals 4*	-	-

Table 10. Preferred design options with respect to the factor "System Quality"

System Quality (8,88)	Related Technical Configuration Options (N=56)				
Execution types	***Stationary/fixed***	*Mobile*	*Wearable*	-	-

	37	*30*	*1*		
Intervention degree	*By Work process 8*	*By Result 11*	***By both 37***	-	-

Table 11. Preferred design options with respect to the factor "System Intelligence"

System Intelligence (7,04)	Related Technical Configuration Options (N=56)				
Information provision	*Documentation 31*	***Advice 35***	*Instruction 27*	*Intervention 29*	-
Adjustment options	*Language 28*	*Speed 36*	*Lighting 17*	*Modularity 21*	***Degree 46***
Assistance frequency	*One-time 4*	*Continuous 18*	***Selective 29***	*Periodical 5*	-

Table 12. Preferred design options with respect to the factor "Psychological Risk"

Psychological Risk (-8,75)	Related Technical Configuration Options (N=56)				
Information provision	***Documentation 12***	*Advice 16*	*Instruction 19*	*Intervention 33*	-
Intervention degree	*By Work process 27*	***By Result 11***	*By both 18*	-	-
Documentation contents	***Personal related 32***	*Performance related 40*	-	-	-

Table 13. Preferred design options with respect to the factor "Reliability"

Reliability (9,66)	Related Technical Configuration Options (N=56)				
Execution types	***Stationary/fixed 40***	*Mobile 23*	*Wearable 0*	-	-
Information provision	***Documentation 32***	*Advice 27*	*Instruction 22*	*Intervention 29*	-

Table 14. Preferred design options with respect to the factor "Trust"

Trust (9,63)	Related Technical Configuration Options (N=56)				
Intervention degree	*By Work process 6*	*By Result 18*	***By both 32***	-	-
Documentation contents (reverse)	*Personal related 35*	***Performance related 34***	-	-	-

Table 15. Preferred design options with respect to the factor "Privacy Risk"

Privacy Risk (-7,16)	Related Technical Configuration Options (N=56)				
Intervention degree	*By Work process 19*	***By Result 13***	*By both 24*	-	-
Documentation contents	*Personal related 45*	***Performance related 27***	-	-	-

Factors "**Information Quality (9,43)**", "**Self-learning ability (9,66)**", "**Logical Comprehensibility (9,09)**" and "**Perceived Control (8,2)**" had each been previously linked to just one assistance aspect and were founded to be most related to *Documentation-based information provision* (N=41), *Assistance Degree adjustment* (N=42), *Instruction-based information provision* (N=39) and *System Intervention by result* (N=24) respectively.

Table 16. Preferred configuration options across all acceptance factors and within each aspect (weighted sum)

(Total weighted sums)/100	Related Technical Configuration Options (N=56)				
Execution type	*Stationary/fixed 14,19*	***Mobile 20,52***	*Wearable 7,84*	-	-
Information provision	***Documentation 18,23***	*Advice 16,3*	*Instruction 15,59*	*Intervention 10,74*	-
Interaction form	*Monological 7,12*	***Dialogical 10,06***	*With externals 2,97*	-	-
Adjustment options	*Language 14,98*	*Speed 14,7*	*Lighting 9,55*	*Modularity 12,67*	***Degree 15,91***
Assistance frequency	*One-time 2,1*	*Continuous 6,18*	***Selective 10,11***	*Periodical 2,65*	-
Intervention degree	*By Work process -0,83*	*By Result 4,63*	***By both 7,43***	-	-
Assistance time	*Before work task 4,96*	***While work task 7,65***	*After work task 3,16*	-	-
Documentation contents	***Performance related -8,7***	*Personal related -9,39*	-	-	-

Results in Tables 4 to 15 allow this way to answer the first posed question in this study about what configuration options of cognitive assistance system fulfil best each of the related acceptance factors. The options with the highest preference rates are displayed in bold. The importance ratings of each acceptance factors are relevant for the calculations in Table 16 that should give answer to the second question posed in this study. The acceptance factors rated as the least important in the previous study of Pokorni and Saba (2022) had been "Perceived Playfulness" with 5,21 and the most important had been "Reliability" with 9,66, by a Likert-Scala from 1 to 10. Acceptance factors considered to inhibit acceptance such as "Perceived Risks" become a negative importance rating for a correct interpretation. Besides, in case of multiple-choice designed questions the amount of preference entries across each aspect subgroup results in numbers over N=56 (number of participants of the study).

By multiplying the counted choices by the importance ratings and adding them across all configuration options within each assistance aspect (1-8) the total weighted sums for each subgroup of the acceptance aspects can now be gained as Table 16 shows (here divided by 100 for a better overview). The options that obtained the highest weighted sum in each row are highlighted in bold.

$$Total\ Weighted\ Sum\ per\ option = \sum (Assigned\ factor\ importance * Number\ of\ Preference\ Entries)$$

5.2 Graphical Results

In this chapter most relevant graphical results should be displayed for improving interpretation quality of all results. Figures 1 to 3 show the most relevant graphical results for Tables 4-15, from where some conclusions can be directly taken.

Fig. 1 shows the summarized results for the preferences between the design options inside the aspect *Execution type* respective to seven acceptance factors, selected in step 2 by the experts to be likely to have a relationship with. Here it can be appreciated that the *hand-carried/mobile option* was more frequently seen by the participants as fulfiling user experience-oriented acceptance factors such as "Design/Interface", "Playfulness", "Enjoyment", "Facilitating Conditions" and "Ease of Use" whereas *stationary assistance systems* are considered to fulfil best performance-oriented acceptance factors such as "System-quality" and "Reliability". Interesting was also that with regards to the

factors “Enjoyment” and “Playfulness” the *stationary/fixed option* had by far the lowest selection rate, whereas concerning the factors “System Quality”, “Reliability” and “Perceived Ease of Use” the *wearable option* had similarly an extreme low preference rate.

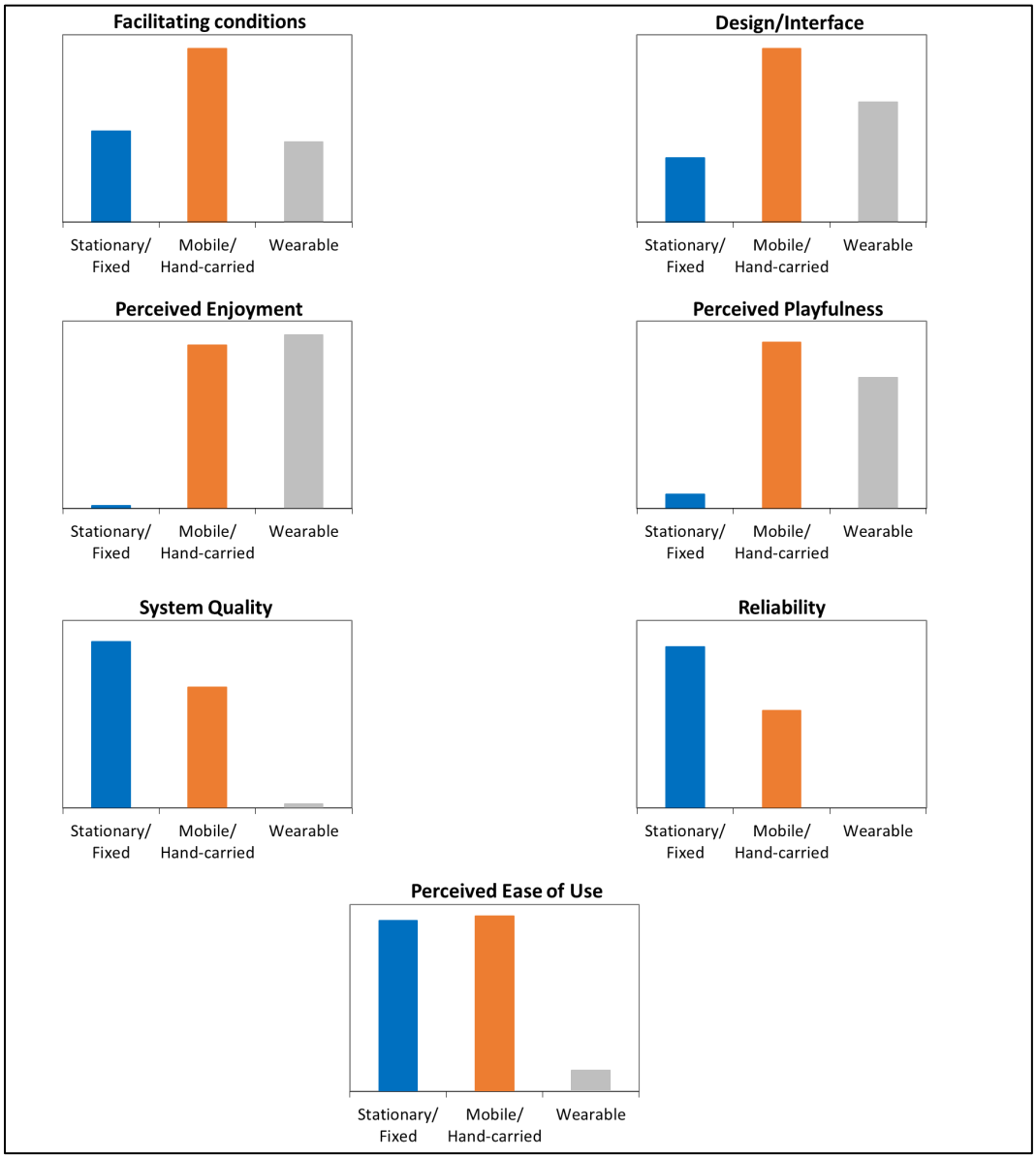

Figure 1. Column Chart: *Execution types* and related acceptance factors (MC-questions)

Other assistance aspects with relevant results represented the information provision types, as some tendencies can be also observed in Fig. 2. In this case, the *classical documentation* as *information provision option* seemed for the participants to fulfil best task-oriented acceptance factors such as “Information Quality”, “Reliability” and “Usefulness”. On the other hand, with regards to the user experience-oriented factors one statement can be clearly implied: an *intervening system for information provision* evokes for the majority the sensation of a “Psychological Risk” in form of stress. Other user-related factors cannot be clearly associated with just on information provision type.

Finally, the preferences across all as single-choice formulated questions, represented as pie charts, produced similar results, showing that in case of the assistance aspects *Interaction Form*, *Assistance frequency*, *Intervention Degree* and *Assistance Time*, the preferences for the contained design options had the same tendency, regardless of the nature

(user-/task-oriented) of the examined acceptance factor relationship. An example of this fact can be seen in Figure 3, where the *Selective Assistance option* was the most preferred across all related acceptance factors.

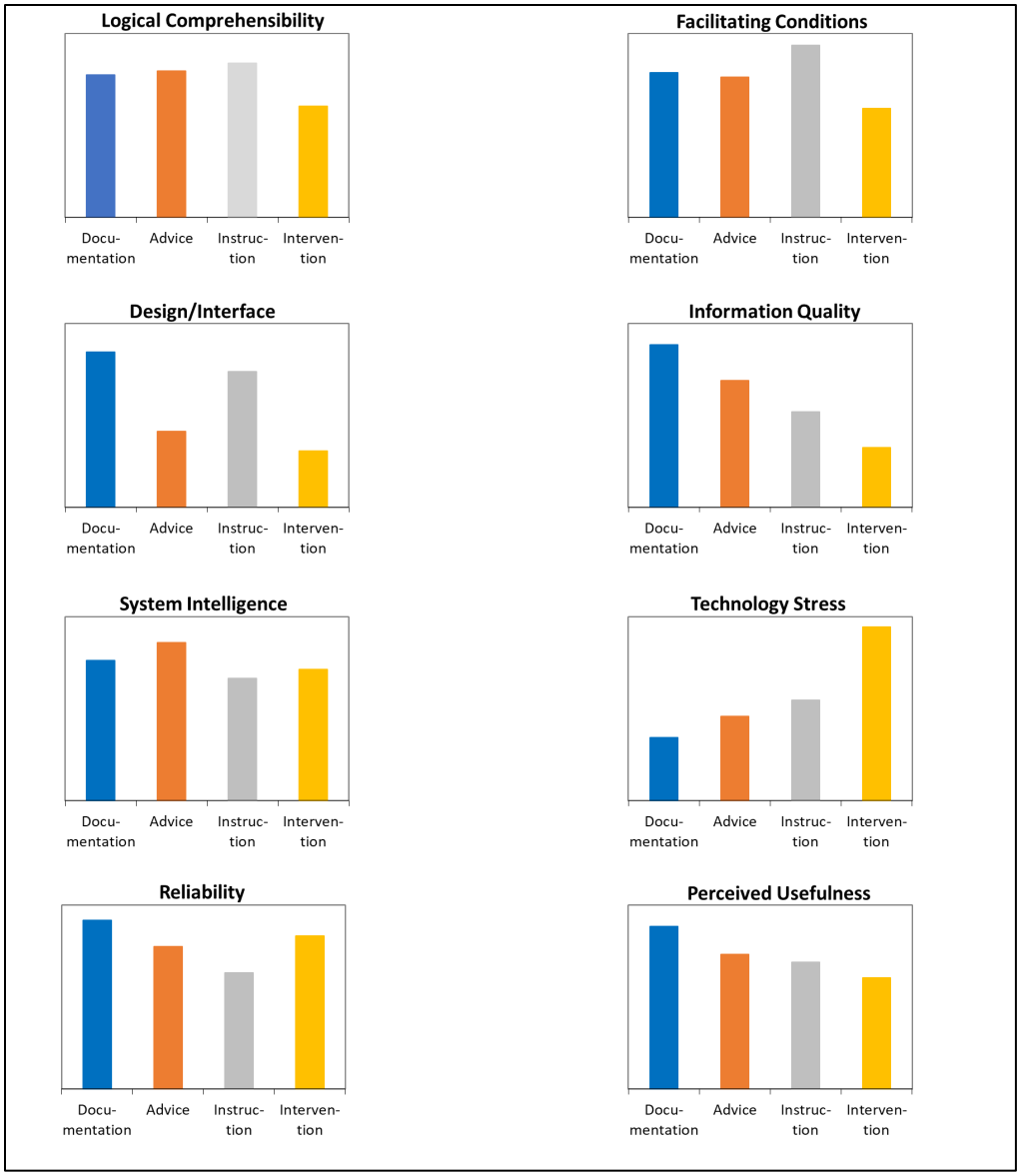

Figure 2. Column Chart: *Information provision* and related acceptance factors (MC-questions)

With respect to the overall results from Table 16, the total weighted sums for each technical configuration aspect-subgroup are graphically displayed in Fig. 4. Positive results are presented here pointing to the right, whereas negative results point to the left. Interpretation can be done so, that the further the beam points to the right (or less to the left by presence of just negative results in one sub-aspect), the more acceptance can be expected. So, for each studied acceptance aspect one technical design option can be seen as the one to have a higher acceptance level in case of similar study subjects (to the sample) and the objects (tested system) of this study. The summarized results in Figure 4 show a high acceptance tendency for *mobile*, *documentation-based*, *dialogical*, *assistance-flexible, time-selective*, *whole-process present* and *work process-oriented* assistance system with *few documentations of performance-related* data and even *less of personal-related data*. So, it can be assumed that a technical design containing these options will result in a high acceptance level of the users in near future.

The visualization of all numerical and graphical data enables also to answer both research questions posed to this study, firstly regarding the possibility of associating each acceptance factor to a technical configuration option and secondly prioritising systematically between technical configuration options according to the preferences of the users.

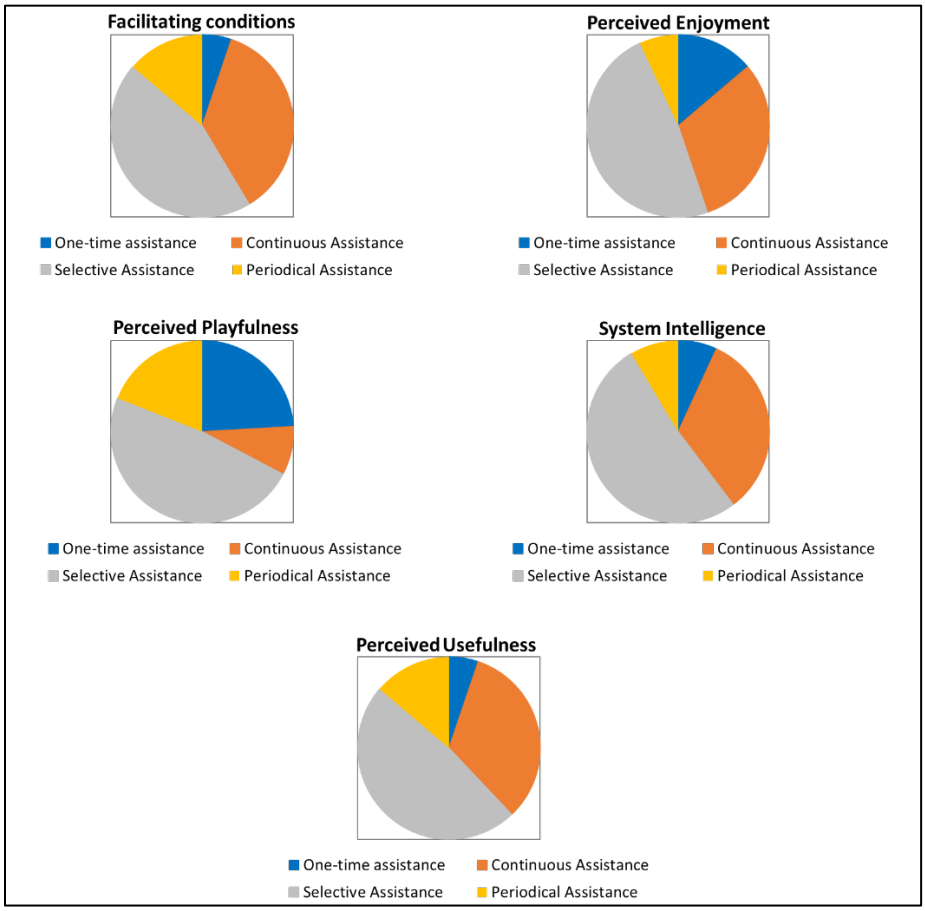

Figure 3. Pie Chart: *Assistance frequency* and related acceptance factors (SC-questions)

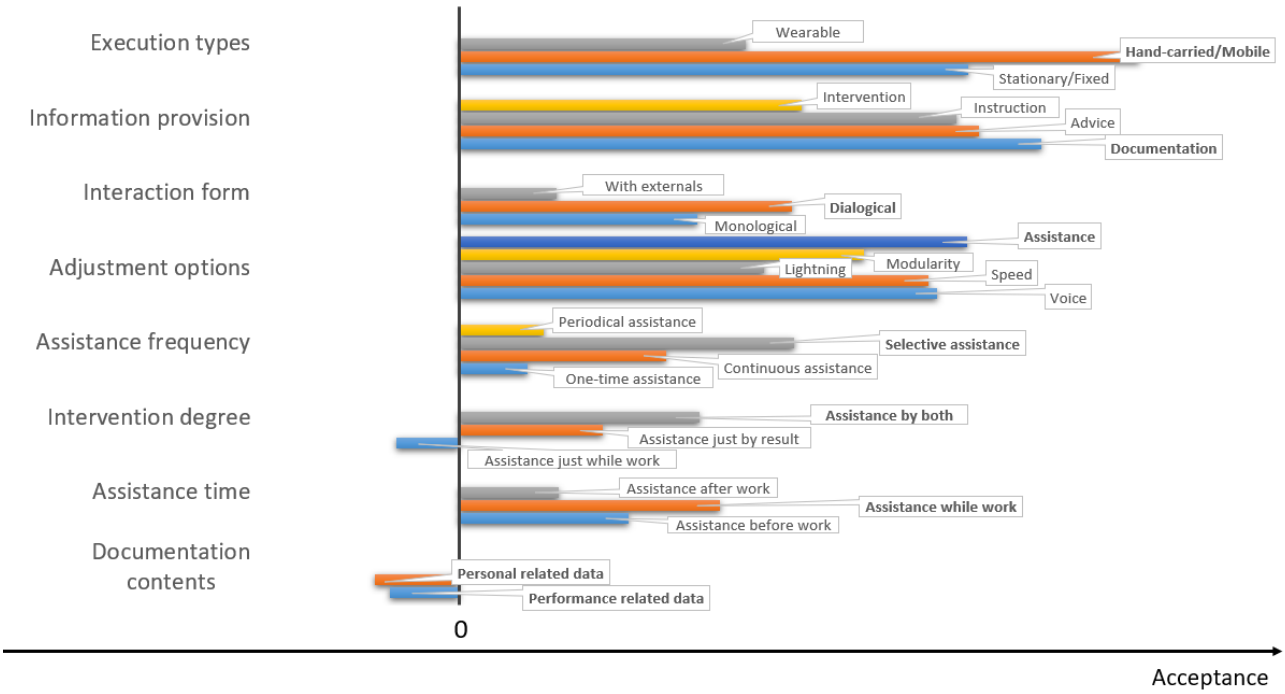

Figure 4. Horizontal column chart: Overall acceptance expectancy across all factors and within each aspect

In cases where the differences in the acceptance expectancy between the technical options are very large or short, the produced final chart in Figure 4 should help as a visual tool for agile decision about what technical design options to keep or to exclude by the design of assembly systems. Also, narrow preference differences within technical options could open the possibility of combining the assistance options, if technically possible. The total results obtained in this study can be finally interpretated as a statement, which technical configuration options are expected to generate most acceptance (or less rejection) in future potential users, as it considered a relevant exclusive sample of participants that have or will have to do with these systems in near future. The strength of this study lies therefore not only in the consideration of exclusively previously validated acceptance factors relevant for the subjects and objects studied, but also in the combination of previously gained numerical importance ratings with new calculated dependences (linkage) between these factors and the technical possibilities for cognitive assistance systems for assembly, with the same participants throughout all study stages, and allowing to define the best accepted design.

5.3 Proposed Improvements

The results are again, as in the previous study of Pokorni and Saba (2022), limited by the number of participants, conditioned by the attempt on focusing just on respondents, belonging to the research target group, and matching the results of the same participants in both studies. Thus, this represents a serious limitation for the study and reduces at the same time its significance. So, the sample size used in future studies to confirm results should be larger. Besides, it must be also mentioned that the first step of the methodology in this paper has a qualitative research character, so that it should be considered that one single literature review cannot help to identify all probably relevant acceptance factors needed for the approach of this study. Accordingly, further investigation on what are confirmed acceptance factors for assembly systems including exploration of new ones should be done.

Also, the linkage between the general assistance aspects and the acceptance factors done by the experts in step 2 of our methodology has a qualitative character and should be researched in the future in a more systematical way. A possibility would be here to calculate the relation degree on basis of correlation factors, gained via questionnaire as in the studies of Kesharwani (2020), He et al. (2020), Shin (2017), Gursoy (2019), Moriuchi (2019) and McLean (2019). So, dependencies between measures would be better validated than in this study and would even enable practicality of research-known methods such as “Quality Function Deployment”. Also, a new research about subgroups inside each technical configuration option should follow to define more detailed design wishes (Pick-by-Light, Pick-by-Voice, etc.) of users.

6. Conclusion

Anticipating to future challenges in work production is one of the most valuable contributions in Industry 4.0 research. Increasing complexity in manufacturing and the following cognitive load on employees need to be compensated through the introduction of cognitive assistance systems in production that support employees in their daily tasks. The multiple design options for such systems challenge engineers and so far, most previous research approaches have just focused on enabling the technical implementation of the systems, without considering the impact of specific design options on acceptance related factors at all.

Therefore, the objective of this study was the linkage evaluation between already validated acceptance factors and specific technical configuration options of cognitive assistance systems as well as their prioritisation across all acceptance factors in sum. The following objectives were defined:

- Translation of acceptance needs into design options for cognitive assistance systems in manual assembly processes
- Prioritisation of configuration options for cognitive assistance systems in manual assembly processes.

To accomplish both objectives, first in literature as-relevant coded assistance aspects, including specific technical design options, were selected and then sorted by a group of experts according to their suspected relationship with previously validated acceptance factors. Then, the specific user preferences were tested via survey. To obtain high-quality valid data, the survey just included potential future users of cognitive assistance systems as participants.

The results show different fulfilment grades of the acceptance factors by each technical configuration option. Besides, it could be concluded that there is a higher acceptance tendency for *hand-carried/mobile*, *documentation-based*, *dialogical assistance systems with a high adjustment level for the assistance*, a *selective assistance frequency*, an *intervention module both while work process and by the result* as well as a *task-oriented assistance* and the *omission of at least personal-related data*. Based on these results, planners should be able to find better orientation, when designing a cognitive assistance systems for manual assembly. Moreover, the proposed improvements in this paper should as well be taken into consideration in the future. Accurate statistical methods to calculate effectively precise correlations by simultaneous inclusion of larger numbers of participants and the iteration towards more specific design options (*Augmented Reality*, *Virtual Reality*, *Pick-by-Light*, etc.) of the assembly systems represent the next challenges.

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Biographies

Bastian Pokorni (*1985) is a researcher at Fraunhofer Institute for Industrial Engineering IAO in Stuttgart and head of department for Connected Manufacturing Systems.

Christian Saba (*1992) is a researcher at Fraunhofer Institute for Industrial Engineering IAO in Stuttgart and associate of department for Connected Manufacturing Systems.