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Cognitive Assistance Systems for Manual Assembly throughout the German Manufacturing Industry

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Summary

Research questions:	Do the main German manufacturing industries use cognitive assistance systems in their manual assembly as described theoretically in literature?
Methods:	For collecting primary data, an online survey was conducted and data from 68 representatives within the main German manufacturing industries was used for measuring the targets for and effects of their usage of cognitive assistance systems in the context of social economics, learnings aspects, quality and productivity improvements.
Results:	The analysis shows that cognitive assistance systems are utilized in the main German manufacturing industries with a statistical probability for increasing the stability of processes within manual assembly. Moreover, cognitive assistance systems seem to be used for the alignment and documentation of finished assembly steps, such as screwing, helping workers avoid mistakes in the execution of tasks and slips of memory or faulty reasoning in recalling previous processes. Finally, this study detects an urgent need for improvements in the automotive industry, especially in manual assembly, for process descriptions.
Structure of the article:	Introduction; Literature Review; Research Questions & Methods; Empirical Results; Conclusions; About the Author; Bibliography

Introduction

Nowadays, firms and manufacturing companies in Germany face strong international competition on the markets due to mega trends such as globalization, new production technologies, dynamic product lifecycles, resource scarcity, knowledge society, instability, demographic change, climate change, mobility, and quality of living (Abele, 2011). Based on globalization and dynamic product lifecycles, future markets can be characterized as unpredictable and volatile due to an increasing number of individual products and declining quantities (Reinhart & Zülke, 2017). Furthermore, an increasing percentage of individual products of up to 600% between 1980 and 2002 was detected (Wildemann, 2009). With the customers' need for individual products, the product complexity and variances jumped upwards over all departments of a company (Reinhart, 2017).

Especially in manual assembly, rising product complexity and variances can lead to higher cognitive demand and therefore higher error rates and lower productivity (Merkel, Atug, Berger, Braunreuther, & Reinhart, 2018). Digital assistance systems are able to support assembly workers by matching their abilities and needs to their work requirements and providing individual information for their ongoing tasks (Apt, Bovenschulte, Priesack, Weiß, & Hartmann, 2018).

This study aims at recognizing and conveying the capabilities of cognitive assistance systems for the main German manufacturing industries, especially in assembly. Therefore, the current perception and usage of cognitive assistance systems in the German industry require investigation.

Literature Review

Cognitive Assistance Systems

In the context of the fourth industrial revolution and production environments, the term "assistance systems" is basically defined as a system that supports workers' actions. These assistance systems address the human information process based on the levels of perception, decision and execution, whereas those that support workers' perception and decisions are specifically called "cognitive assistance systems" (Reinhart, 2017).

These cognitive assistance systems transmit order-specific and real-time information to support the ongoing decision-making process based on the ability of the worker to react, think, remember, and make decisions (Apt et al., 2018).

A couple of cognitive assistance systems were developed and integrated, especially in manual assembly, for supporting workers' perception and decision-making processes. These cognitive assistance systems can generally be divided into stationary, mobile, and wearable systems (Merkel, Starz, Schultz, Braunreuther, & Reinhart, 2017).

Stationary cognitive assistance systems are integrated into workstations and are unmovable. Examples of stationary cognitive assistance systems are pick-by-light, pick-by-voice, and pick-by-vision systems, integrated screens, displays, tablets in a holder, and projectors (Richter, 2015).

Mobile cognitive assistance systems are handheld systems that are location-independent. Examples of mobile cognitive assistance systems are tablets, tablet computers (including a keyboard), smartphones, intelligent equipment (power screwdrivers), handset scanners, and intelligent gloves (Merkel et al., 2017).

Wearable cognitive assistance systems can be worn on the human body, leaving workers able to use both hands for manual tasks. Examples are augmented-reality and virtual-reality glasses, electronic shelf labels, smartwatches, headsets, and gesture control (Merkel et al., 2017).

Assistance systems that support workers physically at execution level by providing energy for strong physical tasks and compensating and avoiding human strain and fatigue are called physical assistance systems (Reinhart, 2017; Lewin, Wallenborn, Küstner, Erdelmeier, & Fay, 2017; Apt et al., 2018). Physical assistance systems will not be considered primarily in this study.

Targets and Effects of Cognitive Assistance Systems in the Context of Social Economics

Demographic change is one of the most challenging issues for manufacturing companies. The total population in Germany, assuming a constant immigration level, is set to increase from 81.9 million in 2015 to 83.9 million by the end of 2021 (Apt et al., 2017)

A further aspect is the growing age of the population, which will influence the labor force structure within Germany. The overall labor force share based on the population in Germany will decrease from 69.1 percent in 2015 to 63.4 percent by 2035 (Deschermaier, 2017). The decrease in the male labor force share is mainly responsible for the decreasing overall work force in Germany. Especially the male labor force age group between 45 and 60 years will have the most steeply decreasing number of employees by 2035 in comparison to 2015 (Deschermaier, 2017).

Additionally, the mental capability of a worker depends, among other reasons, on their age (Apt et al., 2018). In particular, the mental capacity of the human information process, which consists of reception, decision-making and execution processes, can decrease from the age of 45 (Tempel & Illmarinen, 2013).

A controversial issue raised by the Organization for Economic Co-operation and Development (OECD) is the likelihood that future working conditions will be more mentally demanding, diverse, and complex (OECD, 2016).

Therefore, such future conditions would require a higher mental capacity from workers, which cannot be provided at the age of 45 or older, unless the worker is supported by cognitive assistance systems.

To face the above challenges, cognitive assistance systems supporting the human information process can be used for reducing the need for mental capacity from workers (Reinhart, 2017; Bischof et al., 2015; Merkel et al., 2015, & Apt et al., 2018). Furthermore, cognitive assistance systems are used for visualizing process- and product-related safety instructions, therefore increasing occupational safety within manufacturing companies (Bischof et al., 2015).

Targets and Effects of Cognitive Assistance Systems in the Context of Learning Aspects

In the context of learning aspects, cognitive assistance systems are used for workers with less professional experience in manual assembly (Lewin, Wallenborn, Küstner, Erdelmeier, & Fay, 2017). Moreover, the theoretical training period for a worker in a new task can be divided into assistance, learning, and learning-transfer periods based on the worker's expertise and training time. In addition to that, the assistance period can be placed at the beginning of the worker's training time because the worker's expertise is at the minimum then. Assistance systems, such as step-by-step working process descriptions, can be used during the assistance period to increase the expertise level, reduce the training time for this period, and thus also reduce the error rates. During the learning period, the level of assistance can be reduced by an increasing and consistent level of worker expertise. In this period, the level of assistance systems crosses the expertise of the worker. During the learning-transfer period, the worker is able to use assistance systems on demand or for quality checks and documentation. Furthermore, the worker is not obliged to assistance system in this period and is able to decide on their own on the need and level of support. Furthermore, the expertise can increase during the learning-transfer period up to a maximum of scale (Lewin et al., 2017).

Cognitive assistance systems in the form of digital process descriptions are used for reducing the learning period of the worker, as they can provide less complex and standardized information at this stage. These two parameters can have an influence on reducing the overall training time required for a worker and increasing innovation capacity (Bischoff et al., 2015).

Furthermore, cognitive assistance systems support the worker in mastering tasks with growing complexity based on high product-related variance. These systems are able to collect the precise demands of the worker, process, and environment and provide worker-specific information, based on their expertise and qualification level, for executing the task in hand. Additionally, cognitive assistance systems are used for providing the possibility of transmitting learning technologies, such as frequently e-learning technologies, at manual working stations (Merkel et al., 2015).

Targets and Effects of Cognitive Assistance Systems in the Context of Quality Aspects

The main usage of cognitive assistance systems is for reducing and preventing human errors in manual assembly (Wiesbeck, 2014). Human errors can be divided into the categories execution errors, memory errors, and fallacy (Reason, 1994).

Human error rates can increase in manual assembly due to worker overload, lack of concentration, or neglect. Neglect can stem from mental underload, and execution errors are often assembly tasks skipped by the worker. Fallacy can occur in high cognitive-demand tasks, where specific and individual skills are required or new issues and challenges have to be faced by the worker (Wiesbeck, 2014).

Cognitive assistance systems, especially for quality issues, have the potential to reduce error rates in manufacturing processes by providing and transmitting order- and worker-specific process instructions. This information must be clear and avoid misinterpretation by the worker (Bischoff et al., 2015).

Product-related information can be displayed on mobile devices to reduce the main error rates and increase the quality of both individual products and the manufacturing process in general (Lewin et al., 2017).

In practice, this means cognitive assistance systems are able to provide additional and quality-specific product-related information by recognizing and identifying the product, the ongoing process, and the worker. One example is an intelligent power torque, which can identify the specific product and adjust the product-related torque for the worker. Therefore, the worker cannot choose the wrong torque for the assembly of the components (Bischoff et al., 2015).

Targets and Effects of Cognitive Assistance Systems in the Context of Productivity Aspects

Cognitive assistance systems can increase overall productivity by using mobile assistance systems and digital process descriptions (Bischoff et al., 2015; Merkel et al., 2015).

In general, process descriptions can be divided into paper-based and digital process descriptions in manual assembly. Paper-based process descriptions, as the name implies, are printed on a piece of paper and hung up at the manual assembly workstation for the worker. Digital process descriptions comprise different components and use specific technologies to enhance workers' capabilities in manual assembly. Digital process descriptions can be further divided, depending on their components and technologies, into static and dynamic process descriptions. Digital static process descriptions have the ability to display PDF- or Word-documents for workers to read. Digital dynamic process descriptions, on the other hand, enable the visualization of video-files showing the manual assembly process and interactive 3D-models of the components that have to be assembled by the worker (Merkel et al., 2015).

Digital process descriptions, as such, can provide real-time and continuous information transfer for workers at their manual assembly workstations. This information transfer via digital process descriptions and mobile assistance systems, e.g. the use of tablets, can eliminate the time otherwise spent searching for product-related information, especially after a set-up for a variance or a new product (Bischoff et al., 2015; Merkel et al., 2015).

Digital process descriptions can minimize the proportion of non-value-added tasks and maximize the value-added tasks and therefore a worker's productivity by providing assembly process descriptions and process knowledge (Wiesbeck, 2014).

With the help of cognitive assistance systems, the error rates within manual assembly can be reduced and, in comparison with paper-based process descriptions, new and updated digital process descriptions with a new revision status can be provided more up to date and locally, and transmitted via a wireless local area network (Merkel et al., 2015)

Research Questions & Methods

The target and motivation of this study is to investigate whether the theoretically described cognitive assistance systems are used in manual assembly in the main German manufacturing industries. As described in the theoretical reflection, the literature elaborates the aims and effects of using cognitive assistance systems in manual assembly for addressing key topics, such as social, economic, and learning aspects, as well as preventing quality issues and increasing the overall productivity. The task of the empirical part is to evaluate the mentioned aims and effects of using cognitive assistance systems for manual assembly in German manufacturing with the help of an online survey. In order to achieve these objectives, five hypotheses were developed for this study.

Social Economic Aspects

The literature review shows that the individual performance of a worker depends on their abilities and competences. The mental capacity of a worker can decrease from the age of 45, primarily affecting the human information process, which consists of the reception, decision-making and execution process. Cognitive assistance systems are used to support workers by means of an adaptive, individual assistance system for their manual assembly work. The author expected manufacturing companies in Germany to use cognitive assistance systems in manual assembly for addressing demographic change, supporting under-performing staff, allowing age-appropriate integration in the workforce, aligning finished assembly steps, increasing occupational safety, and enabling jobs to be performed by low-skilled workforces. Therefore, the author hypothesizes the following:

Hypothesis 1:
The German automotive, mechanical, and electrical engineering industries use cognitive assistance systems in assembly to address socio-economic issues.

Learning Aspects

Based on the literature, cognitive assistance systems provide companies with a means of closing the expertise gap in order to complete specific and complex assembly tasks, address future challenges, and reduce the training time required by workers for new tasks. The author expected manufacturing companies in Germany to use cognitive assistance systems in manual assembly for training workers, accelerating the process of initial training, increasing the ability to innovate, considering employee-specific levels of qualification, supporting increase in knowledge, and for digital management of knowledge. Therefore, the author hypothesizes the following:

Hypothesis 2:
The German automotive, mechanical, and electrical engineering industries use cognitive assistance systems in assembly to train workers.

Quality Aspects

In the literature review, cognitive assistance systems are used for preventing and reducing human errors in manual assembly. Therefore, cognitive assistance systems are used to provide and transmit order- and worker-specific process instructions, which have to be clear and avoid potential misinterpretation by the worker. The author expected cognitive assistance systems to be used for reducing the complexity of tasks, helping workers avoid mistakes in the execution of tasks, lapses of memory or faulty reasoning, increasing the quality of work and data, reducing the error rate, and increasing the actuality of the job instructions. Therefore, the author hypothesizes the following:

Hypothesis 3:
The German automotive, mechanical, and electrical engineering industries use cognitive assistance systems in assembly to increase overall product quality.

Productivity Aspects

As mentioned in the literature analysis, cognitive assistance systems are used to increase productivity by decreasing the time required for work preparation and searching for product-related information, especially after a setting-up for a variance or a new product. The author expected manufacturing companies in Germany to use cognitive assistance systems in manual assembly to increase productivity and process stability, reduce workers' cognitive stress levels and the effort of documentation, allow for adaptive generation of assembly instructions, ascertain workers' working time and quality, achieve faster distribution of process descriptions, and assist workers with their decision-making process. Therefore, the author hypothesizes the following:

Hypothesis 4:
The German automotive, mechanical, and electrical engineering industries use cognitive assistance systems in the assembly to increase overall productivity.

Requirements for Digital Process Descriptions

The literature review shows that cognitive assistance systems, in this case digital process descriptions, are established in manual assembly for supporting workers' perception and decision-making processes at their manual assembly workstation. The author expected manufacturing companies in Germany to have a variety of requirements for digital process descriptions in manual assembly, such as identifying the component to be assembled with the help of the respective assembly instruction, recognizing progress with the component's assembly, capturing hand motion during assembly, identifying the assembly worker for the respective component, recognizing workers' assembly faults and mood. Further requirements for digital process descriptions are text addition, visual display of assembly steps, provision of feedback on individual performance and knowledge research at work, individual ability to configure digital process descriptions, adaptive creation of job instructions through system feedback, text-chat options, local data storage on assistance systems, and activation of assembly instructions through web applications.

Hypothesis 5:
The German automotive, mechanical, and electrical engineering industries have the same requirements for

cognitive assistance systems, especially for digital process descriptions, in manual assembly.

Methodology

For this study, the German manufacturing industry will be considered. The overall revenue of the German manufacturing industry was 2,054 billion euros in 2018 (Destatis, 2018). To get an indication of the main German manufacturing industries, the structure of their revenue has to be analyzed for 2018. The Federal Statistical Office of Germany defines economic sectors for clustering and comparing the variety of branches and companies based on their revenue. Accordingly, the automotive industry's revenue of 429 billion euros in 2018 makes it the most important sector within the German manufacturing industry (Destatis, 2018); followed by mechanical engineering, with a revenue of 261 billion euros in 2018, and electrical engineering, with a revenue of 184 billion euros in 2018 (Destatis, 2018).

In this paper, the author will focus on the German automotive, mechanical, and electrical engineering industries. These sectors are representative for complex products, are manufacturing-cost driven, and require strict obedience in terms of quality and processes. Additionally, these three sectors were responsible for generating up to 42.5% of German manufacturing revenue in 2018 and are crucial to the German economy as a whole.

As mentioned before, cognitive assistance systems can minimize the complexity of manual assembly processes, decrease workers' learning time, and increase overall product quality and the productivity of manual assembly. Therefore, cognitive assistance systems can fit perfectly for these three branches of the main German industry.

First and foremost, the automotive industry numbered 1,345 manufacturing companies and employed 850,708 workers, with an overall revenue of 429 billion euros in 2018. These automotive companies are original equipment manufacturers (OEM) and component suppliers. Second in terms of revenue, the mechanical engineering industry numbered 6,276 manufacturing companies and employed 1,083,064 workers, generating an overall revenue of 261 billion euros in 2018 (Destatis, 2018). Third in terms of revenue, the electrical engineering industry, including electronic components, numbered 4,139 manufacturing companies and employed 746,896 workers, with an overall revenue of 184 billion euros in 2018 (Destatis, 2018). In summary, the population drawn from the automotive industry, mechanical an electrical engineering industry is representative for 11,760 companies (Destatis, 2018).

This study focuses on the decision-makers employed in the automotive, mechanical, and electrical engineering industries who are responsible for introducing and using cognitive assistance systems in manufacturing, especially for manual assembly. The decision-makers in these three sectors are chief executive officers, chief digital officers, production managers, quality managers, production planning engineers, and can also be sales managers. This target group often has a background and experience in production, is involved in the strategic planning of an enterprise, has financial power, and is in contact with customers with regard to fulfilling their requirements.

Empirical Results

Data Sample

One hundred and twenty-three employees participated in the online survey and ninety participants completed the whole survey. Questionnaires completed by members of other sectors, i.e. outside the automotive, mechanical, and electrical engineering industries, were disregarded, as were participants with no production plant in Germany. Therefore, the final sample consists of 68 participants (N = 68), of whom twenty are members of the automotive industry, thirty-one of the mechanical engineering industry, and seventeen of the electrical engineering industry.

The business roles of the participants can be divided into business executive (n = 7), plant manager (n = 3), production manager (n = 16), industrial engineer (n = 11), assembly worker (n = 5), research and development (n = 16), sales (n = 5), information technology (n = 3), and others (n = 2). Most of the participants use batch production with a lot size of between 11 and 9,999 parts (n = 38), followed by small-batch production of between one and ten products (n = 32), mass production with a lot size of more than 100,000 parts (n = 24), and finally large-batch production with a lot size of between 10,000 and 100,000 parts (n = 23).

Data collection

For the online survey, the platform www.soscisurvey.de was used. The survey is based on a 5-point Liker-type scale. The Kolmogorov-Smirnov test (K-S test) was run to test the normal distribution of the variables. The calculated statistically significant level is below the α-error of .05. The result is that all variables are statistically significantly different. In practice, this means that all variables of the automotive, mechanical, and electrical engineering industries do not follow a normal distribution. In order to use the one-sample t-test for testing the means, the data of the variables must be normally distributed. To address this challenge, Eckstein (2016) pointed out that a one-sample t-test can also be used for a sample size above 50 participants if the data of the variables is not normally distributed. Therefore, the automotive, mechanical, and electrical engineering industries (N = 68) have to be considered as one sample size for the following statistical analysis.

Utilization of Cognitive Assistance Systems in Assembly

Before reporting the empirical data, the utilization of cognitive assistance systems in terms of the total number of participants (*N* = 68) will be presented in Table 1. The aim is to get a first indication of the utilization of cognitive assistance systems according to industry: automotive (*n* = 20), mechanical engineering (*n* = 31), and electrical engineering (*n* = 17). In assembly, screens are the most utilized cognitive assistance system component for participants in the automotive industry (*n* = 16, 80.0%), as well as in the mechanical (*n* = 22, 71.0%) and electrical engineering industries (*n* = 11, 64.7%); followed by "pick-by-light" cognitive assistance systems in the automotive industry (*n* = 10, 50%), components of touchscreen displays in the mechanical engineering industry (*n* = 9, 29%), and "worker information" cognitive assistance systems in the electrical engineering industry (*n* = 8, 47.1%). Furthermore, the automotive industry leads the field in utilization of the sixteen cognitive assistance systems and components (*n* = 89, 27.8%).

Table 1:
Cognitive Assistance Systems Utilized in Assembly, N = 68

	Automotive Industry		Mechanical Engineering Industry		Electrical Engineering Industry	
	n = 20	%	n = 31	%	n = 17	%
Pick-by-light system	10	50.0	5	16.1	2	11.8
Worker Information System	9	45.0	7	22.6	8	47.1
Tablet	4	20.0	6	19.4	4	23.5
Tablet computer	7	35.0	3	9.7	2	11.8
Screen	16	80.0	22	71.0	11	64.7
Touchscreen display	6	30.0	9	29.0	5	29.4
Smartphone	9	45.0	6	19.4	4	23.5
Projector	4	20.0	-	-	1	5.9
AR glasses	2	10.0	-	-	1	5.9
VR glasses	2	10.0	-	-	1	5.9
Electronic shelf label	1	5.0	1	3.2	2	11.8
Smartwatch	1	5.0	1	3.2	1	5.9
Headset	7	35.0	1	3.2	3	17.6
Gesture control	1	5.0	1	3.2	1	5.9
Intelligent tools	8	40.0	5	16.1	5	29.4
Intelligent gloves	2	10.0	-	-	-	-
Total	89	43.0	67	32.4	51	24.6

Hypothesis 1: Socio-economic Aspects

Hypothesis one contended that manufacturing companies in Germany, such as the automotive, mechanical, and electrical engineering industries (*N* =

68), would use cognitive assistance systems in assembly to address demographic change. Hypothesis one is linked with the fourth section of the online survey and can be divided into five sub-items concerning socio-economic aspects. The participants could rank their agreement using a 5-point Liker-type scale (Scale values: 1 = fully agree, 2 = rather agree, 3 = neither nor, 4 = rather disagree, 5 = fully disagree). In order to test hypothesis one, a one sample t-test is used to compare the mean value of the sample for determining whether the mean value of the population is statistically significantly different from the given test value of 2.0.

Table 2:
One-Sample T-Test of Socio-economic Aims and Effects with a Test Value of 2.0

Cognitive Assistance Systems: Social Economic Aspects	N	M	SD	t	df	Sig.
Support Under-performing Worker	66	2.58	1.15	4.06	65	.000*
Support Elder Worker	66	2.67	1.00	5.43	65	.000*
Record & Compare Assembly Steps	65	1.82	0.85	-1.76	64	.083
Increase Work Safety	66	1.94	0.80	-0.61	65	.541
Enable Low-Skilled Workforces	65	2.09	0.96	0.77	64	.443

Note. Scale values: 1 (fully agree) – 5 (fully disagree). *p < .05.

Table 2 illustrates the results of the one-sample t-test. As a result, the mean of *Record & Compare Assembly Steps* (*M* = 1.82, *SD* = 0.85) and *Increase Work Safety* (*M* = 1.94, *SD* = 0.80) are lower than the test value of 2.0. Whereas the significant level of *Record & Compare Assembly Steps* with a value of *p* > .05 (.083) is close to being statistically significantly different from the test value of two. This means that the main German manufacturing industries could use cognitive assistance systems for *Record & Compare Assembly Steps*.

The mean scores of *Supporting Under-performing Worker* (*M* = 2.58, *SD* = 1.15) and of *Supporting Elder Worker* (*M* = 2.67, *SD* = 1.00) are higher than the ‘normal’ score of 2.0. Additionally, the *Supporting Under-performing Worker* score *t*(65) = 4.06, *p* < .001 and *Supporting Elder Worker* score *t*(65) = 5.43, *p* < .001 are statistically significantly different from the given test value of 2.0. This leads to the assumption that the main German manufacturing industries do not use cognitive assistance systems for supporting under-performing or elder workers.

Hypothesis 2: Learning Aspects

Hypothesis two assumed that manufacturing companies in Germany (*N* = 65) use cognitive assistance systems for learning activities in assembly. Hypothesis two is linked with the fourth section of the online survey and can be divided into six sub-questions, as shown in Table 3, concerning the use of cognitive assistance systems for training workers. The participants could use the same procedure as described for hypothesis one. Also, for testing hypothesis two, a one sample t-test is used to compare the mean value of the sample to determine whether the mean value of the population is statistically significantly different from the given test value of 2.0.

Table 3:
One-Sample T-Test of Learning Aims and Effects with a Test Value of 2.0

Cognitive Assistance Systems: Learning Aspects	N	M	SD	t	df	Sig.
Used for Training the Worker	64	2.33	1.11	2.36	63	.022*
Reduce the Training Period	65	2.05	1.01	0.37	64	.713

Increase the Ability to Innovate	64	2.80	0.96	6.62	63	.000*
Consider Levels of Qualification	65	2.52	0.73	5.77	64	.000*
Support the Increase of Knowledge	65	2.78	0.94	6.70	64	.000*
Used for Digital Knowledge Management	65	2.35	0.98	2.93	64	.005*

Note. Scale values: 1 (fully agree) – 5 (fully disagree). *p < .05.

The one-sample statistics in Table 3 show that all sample mean values are greater than the 'normal' score of 2.0. Analyzing the significance level with a value of $p < .05$, statistically significant differences can be identified for the five items of using cognitive assistance systems for *Training the Worker*, $t(63) = 2.36$, $p = .022$, *Increasing the Ability to Innovative* $t(63) = 6.62$, $p < .001$, *Considering the Level of Qualification* of the worker, $t(64) = 5.77$, $p < .001$, *Supporting the Increase of Knowledge*, $t(64) = 6.70$, $p < .001$, and finally for *Digital Knowledge Management*, $t(64) = 2.93$, $p = .005$. Thus, it can be concluded that the main German manufacturing industries do not use cognitive assistance systems for these five items. The analysis of the item *Reducing the Training Period* ($M = 2.05$, $SD = 1.01$) is, considering the mean value, close to the test value of 2.0 but shows a non-statistically significant difference $p > .05$ (.713). Therefore, this item cannot be characterized further.

Hypothesis 3: Quality Aspects

Cognitive assistance systems are used in the main German manufacturing industries to reduce and prevent human errors in assembly. Hypothesis three is linked with the fourth section of the online survey and can be divided into seven sub-questions, as shown in Table 4. The participants could use the same procedure as described for hypothesis one. Also, the test procedures are the same as for hypothesis one.

Table 4:
One-Sample T-Test of Quality Aims and Effects with a Test Value of 2.0

Cognitive Assistance Systems: Quality Aspects	N	M	SD	t	df	Sig.
Reducing Task Complexity	64	2.23	0.97	1.93	63	.058
Avoiding Mistakes in Execution	64	1.83	0.73	-1.90	63	.062
Reducing Mental Errors	64	1.84	0.72	-1.74	63	.086
Increasing Quality of the Work	63	1.95	0.87	-0.44	62	.665
Increasing Quality of the Data	64	1.98	0.88	-0.14	63	.888
Reducing Error Rate	64	1.86	0.85	-1.32	63	.191
Increasing Actuality of Job Instructions	64	2.00	0.87	.000	63	1.00

Note. Scale values: 1 (fully agree) – 5 (fully disagree). *p < .05.

Table 4 shows the results of the one-sample t-test for analyzing hypothesis three. The means of six items are exactly or lower than the test value of 2.0. The significant levels of *Avoiding Mistakes in Execution* $p > .05$ (.062) and *Reducing Mental Errors* $p > .05$ (.086) are close to being statistically significantly different, meaning that the main German manufacturing industries could use cognitive assistance systems for *Avoiding Mistakes in Execution* and *Reducing Mental Errors*. The other four items, namely *Increasing Quality of Work* $p > .05$ (.665) and *Data* $p > .05$ (.888) and *Reducing Error Rate* $p > .05$ (.191) and finally *Increasing Actuality of Job Instructions* $p > .05$ (1.00), are not statistically significantly different.

As a result, the mean of the item *Reducing Task Complexity* ($M = 2.23$, $SD = 0.97$) is higher than the test value of 2.0. Furthermore, the significance level of this item with a value of $p > .05$ (.058) is close to being statistically significantly different. Therefore, the main German manufacturing industries could not use cognitive assistance systems for *Reducing Task Complexity*.

Hypothesis 4: Productivity Aspects

Hypothesis four proposed that the defined population uses cognitive assistance systems for improving productivity in their assembly. Hypothesis four is linked with the fourth section of the online survey and can be divided into eight sub-questions, as shown in Table 5. The participants could use the same procedure as described for hypothesis one. Furthermore, for testing hypothesis four, the one sample-test is used for comparing the mean value of the sample in order to determine whether the mean value of the population is statistically significantly different from the given test value of 2.0.

Table 5:
One-Sample T-Test of Productivity Aims and Effects with a Test Value of 2.0

Cognitive Assistance Systems: Productivity Aspects	N	M	SD	t	df	Sig.
Increasing Productivity	64	2.14	0.73	1.54	63	.129
Increasing Process Stability	64	1.78	0.75	-2.35	63	.022*
Reducing Cognitive Stress Level	64	2.33	0.91	2.89	63	.005*
Reducing Paperwork	63	1.97	0.80	-0.31	62	.755
Allowing Adaptive Generation of Instruc.	64	2.23	0.89	2.12	63	.038*
Recording Working Time and Quality	64	2.63	1.12	4.47	63	.000*
Faster Distribution of Job Instructions	64	2.11	0.88	1.00	63	.321
Supporting the Decision-Making Process	64	2.22	0.81	2.17	63	.034*

Note. Scale values: 1 (fully agree) – 5 (fully disagree). *p < .05.

The results of the one-sample t-test for analyzing hypothesis four are presented in Table 5. As a highlight, the mean of *Increasing Process Stability* with the help of cognitive assistance systems (M = 1.78, SD = 0.75) is lower than the 'normal' score of 2.0 and has a statistically significant mean difference of 0.22, $t(63) = -2.35$, $p = .022$. This leads to the assumption that this item is statistically significantly different. Therefore, the main German manufacturing industries use cognitive assistance systems for *Increasing Process Stability*.

The means of the items *Increasing Productivity* (M = 2.14, SD = 0.73), *Reducing Cognitive Stress Level* of a worker (M = 2.33, SD = 0.91), *Allowing Adaptive Generation of Process Instructions* (M = 2.23, SD = 0.89), *Recording Working Time and Quality* (M = 2.63, SD = 1.12), providing *Faster Distribution of Job Instructions* (M = 2.11, SD = 0.88), and finally *Supporting the Decision-Making Process* (M = 2.22, SD = 0.81) are higher than the 'normal' score of 2.0.

Furthermore, a statistically significant difference can be detected for the items *Reducing Cognitive Stress Level* of a worker, $t(63) = 2.89$, $p = .005$, *Allowing Adaptive Generation of Process Instructions*, $t(63) = 2.12$, $p = .038$, *Recording Working Time and Quality* of a worker score, $t(63) = 4.47$, $p < .001$, and finally *Supporting the Decision-Making Process* score, $t(63) = 2.17$, $p = .034$. This leads to the assumption that these four items are statistically significantly different and that the main German manufacturing industries do not use cognitive assistance systems for these four items. The item *Reducing Paperwork* (M = 1.97, SD = 0.80) has a lower value than the test value of 2.0. But on the other hand, considering the significance level of this item of a value of $p > .05$ (.755) reveals no statistically significant difference. This item cannot be characterized in detail further.

Hypothesis 5: Digital Process Descriptions

Before reporting the empirical data for hypothesis five, the variety of process description in manual assembly is presented in Table 6, followed by the participants' overall satisfaction with their utilized process description and their overall importance in Table 7. The target is to get a first indication of the variety of process descriptions used and then the overall satisfaction with and importance of those process descriptions utilized in manual assembly in the automotive (n = 20), mechanical engineering (n = 31), and electrical engineering industries (n = 17).

Table 6:
Utilization of Process Descriptions in Manual Assembly, N = 68

	Automotive Industry		Mechanical Engineering Industry		Electrical Engineering Industry	
Process Descriptions	n = 20	%	n = 31	%	n = 17	%
Missing	-	-	-	-	1	5.9
Paper-Based	17	85.0	23	74.2	12	70.6
Digital-Static	16	80.0	18	58.1	13	76.5
Digital-Dynamic	6	30.0	6	19.1	1	5.9

Table 6 shows that participants in the automotive industry (*n* = 20) prefer paper-based process descriptions (*n* = 17, 85%) followed by digital-static process descriptions (*n* = 16, 80%). The mechanical engineering industry uses mainly paper-based process descriptions (*n* = 23, 74.2%) in its manual assembly. The electrical engineering industry utilizes digital-static process descriptions (*n* = 13, 76.5%) in its manual assembly.

The next table (Table 7) shows the results of the adequacy-importance model detailing the satisfaction with and importance of the process descriptions utilized in manual assembly for participants in the automotive (*n* = 20), mechanical (*n* = 31), and electrical engineering industries (*n* = 17). High levels of satisfaction and importance for the participant signify "continuation of performance" and signal no need for action seeking improvements. Low satisfaction but high importance for the participant signifies "urgent need for improvement". Therefore, for the automotive industry, demonstrating dissatisfaction with its utilized process descriptions (*M* = 2.40, *SD* = 0.68) and high importance (*M* = 4.55, *SD* = 0.61), the author detects an urgent need for improvements based on these two facts.

Table 7:
Adequacy-Importance Model concerning Process Descriptions in Manual Assembly, N = 68

	Automotive Industry			Mechanical Engineering Industry			Electrical Engineering Industry		
	n = 20	M	SD	n = 31	M	SD	n = 17	M	SD
Satisfaction	20	2.40	0.68	31	3.10	0.91	17	3.12	0.78
Importance	20	4.55	0.61	31	4.45	0.57	17	4.59	0.51

Note. Scale values for satisfaction: 1 (very unsatisfied) – 5 (very satisfied). Scale values for importance: 1 (completely unimportant) – 5 (very important)

Hypothesis five relates to the assessment that the main German manufacturing industries have the same requirements as the literature concerning cognitive assistance systems, especially for digital process descriptions, for manual assembly. Hypothesis five is linked with the fifth section of the online survey and can be divided into 15 questions, as shown in Table 8. These 15 questions were divided into six questions concerning environmental recognition, followed by nine questions concerning the visual illustration of digital process descriptions for manual workers at manual assembly stations. The participants could rank their agreement by a using a 5-point scale (1 = very important, 2 = important, 3 = neither nor, 4 = unimportant, 5 = completely unimportant). In order to test hypothesis five, a one-sample test is used to compare the mean value of the sample so as to determine whether the mean value of the population is statistically significantly different from the given test value of 2.0.

Table 8:
One-Sample T-Test of Requirements for Digital Process Descriptions with a Test Value of 2.0

Cognitive Assistance Systems: Digital Process Descriptions	N	M	SD	t	df	Sig.
Environment Recognition						
Identification of the Component	62	1.77	0.69	-2.59	61	.012*

Recognizing the Process of the Assembly	62	1.92	0.66	-0.96	61	.340
Motion Capture of Hands During Task	62	2.81	1.01	6.31	61	.000*
Identification of the Assembly Worker	62	2.58	0.88	5.20	61	.000*
Recognition of Assembly Faults	62	1.56	0.72	-4.79	61	.000*
Mood Recognition of the Worker	61	2.89	1.07	6.48	60	.000*
Visual Illustration						
Text adding	56	2.46	0.85	4.08	55	.000*
Visual Display of Assembly Steps	61	1.80	0.79	-1.94	60	.057
Provision of Feedback	62	2.37	0.83	3.50	61	.001*
Provision of Knowledge Research	62	2.27	0.89	2.43	61	.018*
Individual Ability to Configure	62	2.48	0.92	4.15	61	.000*
Adaptive Creation of Job Instructions	62	1.90	0.74	-1.03	61	.307
Text-chat Options	61	2.98	1.03	7.50	60	.000*
Local Data Storage on Assistance System	62	2.94	1.05	6.99	61	.000*
Ready for Web Application	61	2.48	1.13	3.27	60	.002*

Note. Scale values: 1 (very important) – 5 (completely unimportant). $^*p < .05$.

The requirements analysis for digital process descriptions based on a one-sample t-test can be seen in Table 8. With regard to the first topic, environmental recognition, the mean of *Identification of the Component* (M = 1.77, SD = 0.69) and *Recognition of Assembly Faults* during assembly (M = 1.56, SD = 0.72) are lower than the 'normal' score of 2.0. Furthermore, a statistically significant mean difference of 0.23, $t(61) = -2.59$, $p = .012$ for *Identification of the Component* and for *Recognition of Assembly Faults* of 0.44, $t(61) = -4.79$, $p < .001$ can be characterized. This leads to the assumption that these two items are statistically significantly different. Therefore, the main German manufacturing industries require both *Identification of the Component* and *Recognition of Assembly Faults* from digital process descriptions during assembly.

On the other hand, the mean of the items *Motion Capture of Hands* during assembly tasks (M = 2.81, SD = 1.01), *Identification of Assembly Worker* (M = 2.58, SD = 0.88), and *Mood Recognition of the Worker* (M = 2.89, SD = 1.07) are higher than the 'normal' score of 2.0. Furthermore, for all three items there is a statistically significant difference between means ($p < .05$). Therefore, the main German manufacturing industries do not require features such as *Motion Capture*, *Identification of Assembly Worker*, or *Mood Recognition of the Worker* from digital process descriptions.

Analysis of the visual illustration of digital process descriptions reveals that the mean of *Visual Display of Assembly Steps* (M = 1.80, SD = 0.79) and the significance level with a value of $p > .05$ (.057) are close to being statistically significantly different. Therefore, the main German manufacturing industries could require *Visual Display of Assembly Steps* from digital process descriptions.

On the other hand, the means of *Text adding* (M = 2.46, SD = 0.85), *Provision of Feedback* (M = 2.37, SD = 0.83), *Knowledge Research* (M = 2.27, SD = 0.89), *Individual Ability to Configure* (M = 2.48, SD = 0.92), *Text-chat Options* (M = 2.98, SD = 1.03), *Local Data Storage on Assistance Systems* (M = 2.94, SD = 1.05), and finally *Ready for a Web Application* (M = 2.48, SD = 1.13) are higher than the test value of 2.0. Furthermore, for these seven items, there is a statistically significant difference between the means ($p < .05$). Therefore, the main German manufacturing industries do not require these seven features from digital process descriptions.

Conclusions

The target and motivation of this article are to investigate whether the theoretically described cognitive assistance systems are used in manual assembly in the main German manufacturing industries. According to the theoretical findings, these cognitive assistance systems can be divided into the categories socio-economic aspects, professional learning experience, quality issues, increasing the overall productivity, and requirements from digital process descriptions in manual assembly.

First, to prioritize cognitive assistance systems in manual assembly in the main German manufacturing industries, the number of utilized cognitive assistance systems were counted by means of an online survey. The author found that screens are the most utilized cognitive assistance systems as a component in the automotive industry as well as the mechanical and electrical engineering industries; followed by the pick-by-light system in the automotive industry, the components of touchscreen displays in the mechanical engineering industry, and a cognitive assistance system, the worker information system, in the electrical engineering industry. The automotive industry leads the field regarding utilization of the sixteen cognitive assistance systems and components.

Second, in the context of socio-economic aspects, the main German manufacturing industries could use cognitive assistance systems for recording and comparing assembly steps.

Third, for analyzing and interpreting the utilization of cognitive assistance systems for training assembly workers, five out of six items have a mean value higher than the test value of 2.0 and a statistically significant difference. These five items are listed in Table 9. Based on the higher test value than 2.0 and the statistically significant differences, these five elements are statistically valid. Therefore, the main German manufacturing industries do not use cognitive assistance systems for these five items

Fourth, the analysis of cognitive assistance systems for improving quality in assembly reveals that all seven items, as shown in Table 10, are not statistically significantly different from the given test value of 2.0 in both directions. For all of these items, a statistically restricted interpretation is possible. The main German manufacturing industries could use cognitive assistance systems for avoiding mistakes in execution and for reducing mental errors.

Fifth, the main German manufacturing industries could use cognitive assistance systems for improving their productivity. As a highlight, the mean of increasing the stability of a process with the help of cognitive assistance systems is lower than the ‘normal’ score of 2.0 and has a statistically significant mean difference. This fact leads to the assumption that the main German manufacturing industries use cognitive assistance systems for increasing process stability.

Sixth, the final findings of the empirical part indicate that the automotive, mechanical, and electrical engineering industries have the following requirements from cognitive assistance systems, especially concerning digital process descriptions. The automotive industry primarily uses paper-based process descriptions followed by digital-static process descriptions. The mechanical engineering industry also prefers paper-based process descriptions, and the electrical engineering industry utilizes mainly digital-static process descriptions. By considering the adequacy-importance model, the author detected an urgent need for improvements concerning process descriptions in manual assembly. These findings are not tested in this article concerning their statistically significant difference and are therefore only allow limited interpretation. This article provides statistical-significance-tested possible solutions to an urgent need for improvements in digital process descriptions such as automatic identification of components and recognition of assembly faults during assembly.

By analyzing the advantages and flaws of the data sample and instruments of this work, at the beginning, the participants were categorized into the representatives of a company in either the automotive, mechanical, or electrical engineering industry. However, each participant has their own perspective, mind-set and information concerning the aims and effects of cognitive assistance systems for their company. Personal views can differ from the overall vision, mission, and strategy of an enterprise or company, which are normally defined by the share- and stakeholders. In total, 38 percent of the participants are business executives, plant, or production managers. A higher respondent rate of shareholders and stakeholders would potentially have led to a more representative empirical result of this article.

A further limitation relates to the sample size of 68 participants. In relation to the total number of 11,760 German manufacturing companies based in the automotive, mechanical, and electrical engineering industries (Destatis, 2018) and corresponding number of representatives, a higher respondent rate could lead to more representative results. Furthermore, the unequal sample size and the number of 50 participants required in literature mean that the sample from across the automotive (n = 20), mechanical engineering (n = 31), and electrical engineering industries (n = 17) cannot be divided. Therefore, the sample size of 68 participants had to be applied by the author to gain the results for the aims and effects concerning usage and the requirements from cognitive-assistance systems.

Furthermore, by applying an online survey, which consisted of six sections and 54 questions, it is possible that these questions could have been interpreted and understood in different ways by the participants.

As described in the theoretical reflection, the literature regarding the aims and effects of using cognitive assistance systems for manual assembly seeks to provide solutions for the main topics, such as socio-economic aspects, professional experience and required learning times, quality issues, and increasing overall productivity. These aims and effects can be relevant for all companies throughout the world, all companies in Germany, and all departments of producing companies. Therefore, future research activities should contain further or other sectors of German industry. Furthermore, global research activities, especially in China as a growing market, concerning the aims and effects of using cognitive assistance systems could be very interesting for detecting the status quo. After that, recommendations for actions to expand the use of cognitive assistance systems in different companies, sectors, or departments, or further requirements regarding the development of cognitive assistance systems can be derived from future research activities.

To use the outcomes to provide inspiration, it would be valuable to use the data to develop new and customer-oriented cognitive assistance systems for the main German manufacturing industries. The results of the empirical part of study show that cognitive assistance systems are utilized in the automotive, mechanical, and electrical engineering industries mainly for increasing the stability of manual assembly processes. Furthermore, based on this study, cognitive assistance systems, which increase the quality within manual assembly, seem to have potential for further development. These targets and effects can be classified with the aid of an ability model for cognitive assistance systems, based on Merkel et al. (2017), for derived required abilities, technologies, and components. Following that, new and customer-oriented cognitive assistance systems can be developed.

Furthermore, in considering the participants' satisfaction and evaluation of importance, based on the adequacy-importance model, the author detected an urgent need for improvements to the process descriptions currently utilized in manual assembly in the automotive industry. In order to ascertain an urgent need for improvements, the author collected the requirements for developing new and customer-oriented digital process descriptions. Moreover, the usability of cognitive assistance systems can be a research area in the future. With regard to the generation of digital process descriptions, the state of the art is that planning engineers use cameras to take pictures of real parts or components and write texts to provide process descriptions. A new research area could address automated generation of content for manual assembly based on the virtual 3D models and 3D components used in the design department. Assembly process descriptions and quality checklists can be derived from the design plan, and thus from the design department, and can be provided at an early stage, in an efficient and continuous way, to the worker in manual assembly. The participants ($N = 68$) identified and confirmed the importance ($M = 3.91$, $SD = 0.99$) based on a 5-point Liker-type scale (Scale values: 1 = completely unimportant, 2 = unimportant, 3 = neither nor, 4 = important, 5 = very important) of automatically generated content for manual assembly.

About the Author

Klaus Fink studied mechanical engineering, specializing in automotive engineering and lightweight construction, at Kempten University of Applied Sciences. After graduating, he worked as a project manager in the automotive industry in product and process development and studied part-time on the MBA program at Kempten Professional School of Business and Technology. He currently works as a scientific assistant at the Fraunhofer Research Institute for Casting, Composite and Processing Technology IGCV in Augsburg.

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