Expert-based Classification of Worker Assistance Systems in Manufacturing Considering the Human

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Keywords: Industry 5.0, Smart Manufacturing, Worker Assistance Systems, Operator 4.0, Sustainable Manufacturing.

Abstract: The transformation process of manufacturing industry into a more digitalized world is a key challenge of the fourth industrial revolution. Advantages of new technologies must be used effectively, and therefore employees need to be prepared to deal with these new technologies and the complexity and speed that today's production entails. Worker assistance systems offer the possibility to simplify the interaction between humans and complex machines and to reinforce physical and cognitive skills of employees. Although worker assistance systems are available on the market, methods focusing on the classification of appropriate worker assistance systems for specific work tasks and worker types are missing. This work presents an expert-based classification of worker assistance systems in manufacturing based on classification attributes and capabilities.

1 INTRODUCTION

In addition to the Digital Transformation in production, sustainability in manufacturing is playing an increasing role (Despeisse & Acerbi, 2022). This is also reflected in the relatively new term "Industry 5.0", which according to the definition of the European Commission aims to make production more sustainable, more resilient and more human-centered (EC, 2021; Anvari, 2021). Assistive technologies can play a major role in production, especially in the area of social sustainability (Zimmer et al., 2022). By means of assistance systems, work processes can not only be made more ergonomic and safer (Gualtieri et al., 2020), but at the same time human skills (Sony & Mekoth, 2022) and diversity in manufacturing can be increased. However, many companies are currently faced with the challenge of obtaining a comprehensive overview of existing worker assistance systems on the market and selecting the most suitable aid systems for internal work processes from the wide variety available. There are currently only isolated studies on the potential of individual worker assistance systems (Zigart & Schlund, 2020; Tropschuh et al., 2022), which often makes it difficult to compare the systems with one another. The problem tackled in this study is how to facilitate the selection and comparison of worker assistance systems based on their specific characteristics.

Thus, in this paper, an expert-based classification of worker assistance systems regarding classification attributes and capabilities is presented. Actually no similar concept for the classification of worker assistance systems in manufacturing can be found; therefore the results of this work represent an original and novel contribution to the scientific body of knowledge. The goal is to create an first concept of a reliable database, which makes it possible to compare and later also select worker assistance systems for certain purposes. Once such a concept to create a database is established, relevant or newly developed systems can be added and continuously further evaluated in the future to ensure topicality. For the evaluation purpose, a web platform was programmed/configured that makes a user-friendly evaluation possible.

The paper is structured as follows. First, in Section 2 a theoretical background is given with a

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Mark, B., De Marchi, M., Rauch, E. and Matt, D.
Expert-based Classification of Worker Assistance Systems in Manufacturing Considering the Human.
DOI: 10.5220/0011591200003329
In *Proceedings of the 3rd International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2022)*, pages 184-191
ISBN: 978-989-758-612-5; ISSN: 2184-9285

review and summary of available worker assistance systems. Afterwards classification attributes and capabilities are distinguished. In Section 3 the procedure for setting up an expert based database for worker assistance systems is discussed. Section 4 shows the results of a first pilot implementation of such an expert based database concept before ending with a short summary and conclusions in Section 5.

2 BACKGROUND

In the following, the worker assistance systems to be evaluated as well as the classification attributes and capabilities are presented.

2.1 Worker Assistance Systems

As for the systems to be evaluated, those were chosen from the identified systems in the systematic literature review (SLR) of Mark et al. (2021), that are either already established/industrialized and used in industry for some time (I) or not yet used (or since a shorter period), and therefore still under research (R). This leads to the resulting systems that are presented in Table 1.

Table 1: Evaluated worker assistance systems in the expert-based database.

Worker Assistance System	Explanation	Readiness
Telemanipulator/ Balancer/ Lifting Aid	System that is used to transport workpieces between workplaces.	I
Eye Tracking	Technology for measuring the point of eye gaze or the motion of an eye relative to the head.	R
Portable Computer	Technical system that technically supports worker in manufacturing.	I
Wearable Sensor	Devices that can measure health related metrics and other personal data.	R
Ergonomic Manual Workplace	The Ergonomic Manual Workplace can be seen as an aggregation of different technologies to increase ergonomics, e.g., by a height-adjustable tabletop, bright light, and enough space to be adaptable to the employee.	I
AI Based Intelligent Personal Assistant	Artificial intelligence or software agent that helps the operator while interacting with computers or machines.	R
Computer Assisted Instructions	Computing device combined with a monitor to show e.g., instruction manuals.	I
Physiological Sensor – Galvanic Skin Response (GSR)	Measures a change in the electrical resistance of the skin which is caused by emotional stress.	R
Intelligent Hand Tracking	System that uses two depth cameras to track the hand movements of the worker on the workspace.	R
Smart Phone	Device that can be used during industrial manufacturing to see instruction manuals and receive notifications.	I
Voice Control	A voice control that can be individually adapted to the user and the industrial working environment.	R
Tablet	Digital device that can be used for showing instruction manuals during industrial manufacturing.	I
RGB Camera	Camera equipped with standard CMOS sensor through which colored images are acquired.	I
Augmented Reality (AR)	Technical system that superimposes a computer generated picture on the user's current view of the real world.	R
Passive Exoskeleton	Different supporting structures/mechanisms for supporting the musculature of the arm.	I
Collaborative Robot	System that is also known as "Cobot" which is capable of learning diverse tasks to assist human.	I
Physiological Sensor – Heart Rate (HR)	Measures the speed of the heartbeat by the number of beats per minute.	R
Active Exoskeleton	Active support for the human body.	R
Smart Scan Glove	System that combines a gloves, smartphone, and Bluetooth to support workers during their work.	R
Object Positioning Tracking System	System that detects the position of items (e.g., a drill) which are equipped with the tracking system.	R
Projection-Based Assistance System	Technical system that projects e.g., instruction manuals on the workplace.	I
Mobile Robotic Assistant	Mobile platform/robot with high accuracy and flexibility.	I
Smart Watch	Industrial smart watch that can be used for diverse kind of applications, e.g., assembly or maintenance.	R
Infrared Camera	System that is used to recognize the operator and their intention by e.g., hand gestures.	I
Virtual Reality (VR)	Technical system that simulates experiences that can be similar or also different from real life.	R

2.2 Classification Attributes and Capabilities

When it comes to worker assistance systems, a first step is to classify each system. The classification approach is divided into two different branches. The first branch focuses on attribute categories to describe the characteristics and interaction of the worker assistance systems. According to previous research published in Mark et al. (2021) they consist of 50 attributes with 147 values grouped into five categories, namely (i) human worker, (ii) work environment, (iii) workplace, (iv) task/process, and (v) performance. Examples for classification attributes can be e.g., gender, scope of application, humidity, light condition, type of information transfer, type of task.

The second branch presented in Mark et al. (2021) focuses on 23 capability parameters which are also divided into five categories, namely (i) skills, (ii) relevant senses, (iii) cognitive abilities, (iv) physical abilities, and (v) personal attributes. These categories are later used to assess each worker assistance system.

3 PROCEDURE AND STRUCTURE OF THE EXPERT-BASED DATABASE

In this section, the procedure and structure applied for the classification of the attributes and capabilities via a developed prototype web platform are explained. The selection of an expert-based approach is explained and the web platform itself is shown together with the used traffic light colour coding for classification as well as the Likert scale for the capability rating.

3.1 Expert-based Approach

In order to collect necessary data for the establishment of a database, two different approaches resulted to be possible. One is to collect the data through experiments with all identified assistance systems and the other is to let the assistance systems be evaluated by experts. The SLR of Mark et al. (2021) showed that experiments were conducted with some worker assistance systems in the existing literature, but only a few systems were considered in experiments and additionally only specific aspects could be investigated (such as the preferred user acceptance for two different systems). Further, the setup and conduction of extensive empirical testing and comparison of each of the worker assistance systems in Table 1 resulted to be unrealistic in sense of effort, cost and time required. For this reason, it seemed to be most reasonable to have the individual systems be evaluated by experts in the field.

Therefore, experts were contacted who are currently working or have been working in the past with the respective systems either in research or industry.

3.2 Web Platform for Evaluation

In order to ensure a structured evaluation of the worker assistance systems, a prototypal web platform was developed. This was selected since it has several advantages compared to an evaluation with other formats, e.g., Excel datasheets or phone calls. On the one hand, the well-structured web platform represents a user-friendly way and makes it possible to guide the evaluator through the evaluation process by first explaining the aim of the evaluation, how to do it, and the final evaluation itself. On the other hand, having a web platform makes it possible to organize the huge amount of data in a structured way for further processing. In addition, the evaluation can be done from everywhere, which was important especially in times of Covid-19 pandemic restrictions.

On the landing page of the web platform, without registering and creating an account, first information are given on the home page of the web platform.

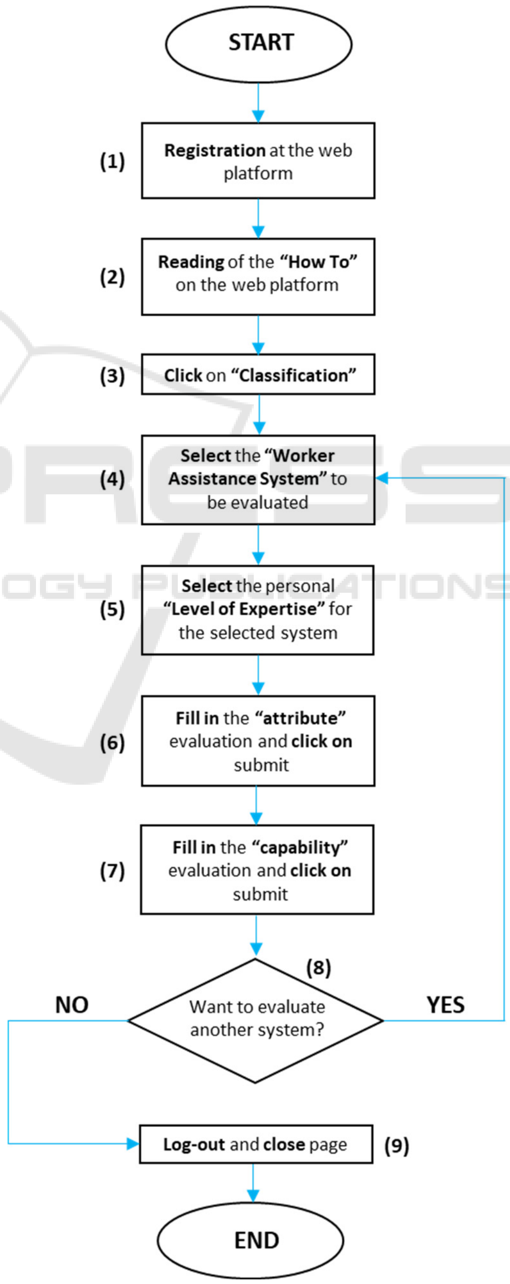

Figure 1: Process flow diagram for system evaluation.

By clicking on the button “Why” the user gets further clarification concerning the developed concept and the purpose of the evaluation (“About”). By clicking on the button “How”, the user is sent to the “How to” page which provides the user with necessary information on how to do the attribute classification and capability evaluation as an expert. The process flow diagram in Figure 1 shows the process the evaluator needed to go through in order to evaluate a system. First, by clicking on “Register”, the user creates an account on the web platform (1). After the “How to” has been read (2), the user may click on “Classification” (3), which occurs in the main bar after the user logged in. Now, the user is able to choose the worker assistance system to be evaluated (4). Afterwards, the level of expertise of the evaluator regarding the previously selected system needs to be inserted (5). What follows is the evaluation of the classification attributes (6) and capability parameters (7) which can both be confirmed by clicking on the submit button. After one system has been evaluated, there is the possibility to continue with further systems the user is familiar with (8) or log-out and close the session (9).

3.3 Evaluation Step 1: Morphological Box Approach and Traffic Light Colour Coding for Attribute Classification

In step 6 of Figure 1 a morphological box approach and traffic light colour coding is used. The morphological box approach is a creativity technique that was first introduced by Fritz Zwicky in 1976 (Erdenberger, 2008; Post, 2021). It can be used to present different attributes regarding a problem, method, or product and makes it possible to evaluate non-related attributes in a structured way. Figure 2 shows an excerpt of the web platform in which the morphological box approach was applied. On the left side the attributes are listed (e.g., average temperature), and the characteristics, in form of different values (e.g., <0 [32°F]), are shown on the right.

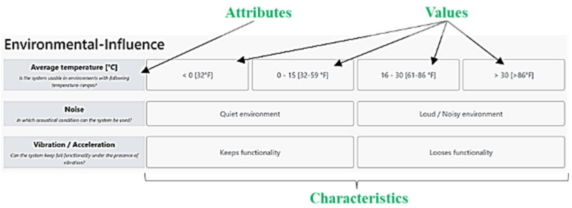

Figure 2: Excerpt of the morphological box approach used on the web platform.

For the evaluation of the classification attributes a traffic light colour coding was used. It is a system which can be utilized to indicate the status of variables by applying the colours green, orange and red, similar to traffic lights. This system is already used in product labelling (e.g., food and drink (Trudel et al., 2015) where it shows among others the amount of fat, sugar, and salt or in performance monitoring (e.g., project management). Table 2 explains the meaning of the colours in the scope of this work and the translation of each colour into a number which will be of importance in the following chapters. Within the web platform, the colour (i) green can be applied by clicking once, (ii) orange by clicking twice, and (iii) red by clicking thrice.

Table 2: Traffic light colour coding and the meaning of the colours.

Colour	Meaning	Value
Green	Yes (if the answer is “true”)	1
Orange	Possibly (if the “possibility” can be seen for implementation under certain circumstances)	0.5
Red	No (if the answer is “false” and the system is not applicable for the underlying value)	0

Figure 3 shows an excerpt of the morphological box by having applied the traffic light colour coding for showing the status of each value.

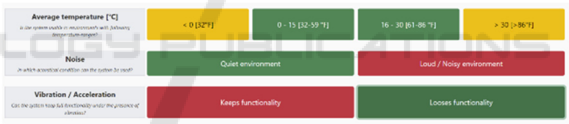

Figure 3: Excerpt of the morphological box approach with traffic light colour coding.

3.4 Evaluation Step 2: Likert-Scale for Capability Rating

After having filled in the classification evaluation in step 6 (in Figure 1), step 7 follows with the capability evaluation. For this purpose, a Likert scale is used. It is a psychometric scale, named after the psychologist Rensis Likert and is commonly used for questionnaires in research (Kriksciuniene et al., 2019). Speaking about survey research, it is the most widely used method for scaling responses. In this second step of the evaluation, it is necessary to rate the enhancement of the respective worker assistance systems regarding the predefined capability parameters. Therefore, a Likert scale from 0 (no enhancement at all) to 3 (maximum enhancement) was used. An excerpt of the evaluation page provided on the web platform can be seen in Figure 4. The respective rate can be selected by clicking on the dedicated white circles.

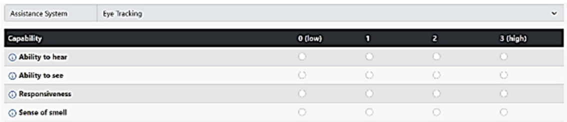

Figure 4: Excerpt of the Likert-scale used for the parameter evaluation.

4 REALIZATION

In this Section, the realization of the expert-based evaluation database is presented. Therefore, more information about the expert evaluation itself is given, the examination of both the attribute data as well as the capability data are shown and finally discussed in an encompassed manner.

4.1 Expert Evaluations

The method developed here represents a novel way of looking at worker assistance systems in a unified way. This uniformity allows for subsequent selection based on various relevant parameters. The purpose of the methodology is to ensure that the evaluations of systems continue to evolve over the coming years and that new systems are included in the methodology. This allows the values to be based on an increasingly well-founded and large data set. The purpose of the expert evaluation carried out here is to build up an holistic database with trustworthy data. By the time a sufficient number of votes for the worker assistance systems had been reached (79 system ratings), 41 experts from research and industry, and different countries had participated.

Figure 5: Origin of the experts.

Figure 5 shows the origin of the experts, whereas Figure 6 presents the belonging of the experts either to research or industry. The experts could be identified through the systematic literature review as well as through case study reports and the personal network.

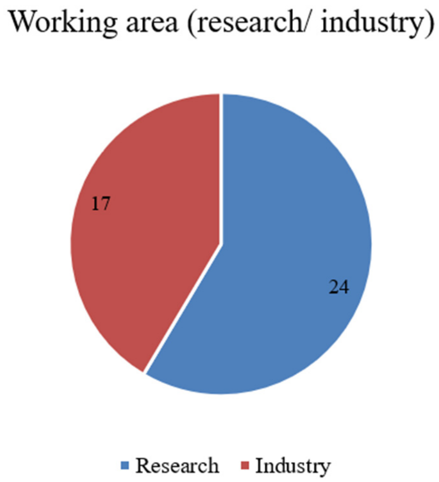

Figure 6: Working area (research/ industry).

4.2 Examination of Attribute Data and Discussion

Microsoft Excel was used to examine the huge amount of data. An algorithm was developed to structure the around 14.000 lines of data and insert it into a template form. Figure 7 shows an excerpt of the examination spreadsheet. With the collected data for each worker assistance system the arithmetic mean and standard deviation was built. In order to consider the level of expertise of each evaluator, the selected value was taken into account when building the arithmetic mean. The following Equation 1 explains the formula applied and Equation 2 shows how the first average value was calculated from Figure 7.

$$= ((x_1*y_1) + (x_2*y_2) + (x_3*y_3) + (x_4*y_4))/z$$

$$x = \text{Level of expertise}$$

$$y = \text{Rating of expert} \qquad (1)$$

$$z = \text{Sum of all levels of expertise } (x)$$

$$= ((2*1) + (2*1) + (3*1) + (2*1))/9 \qquad (2)$$

By examining the data collected through the expert evaluations together with the comments that were given by the experts, the 50 attributes could be assessed and relations to individual worker assistance systems could be drawn.

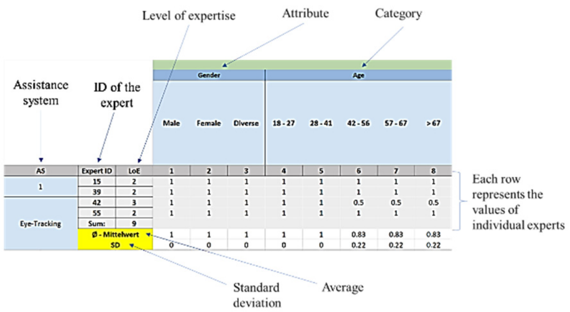

Figure 7: Simplified excerpt of the examination Excel (attributes data).

Figure 8 shows the average standard deviations of each of the individual categories. It can be seen that all standard deviations are rather low, but a trend can be noticed. It confirms the higher variance of task and performance related categories compared to others. The values of the category attributes “employee-influence” (12 attributes) and “workplace” (7 attributes) are lower compared to the values of the attributes “environmental-influence (8 attributes), “task/ process” (12 attributes) and performance (11 attributes). An explanation could be the following: Worker assistance systems that until some time ago might have been seen as individual assistance systems got further developed in different directions. The resulting systems can no longer be seen as sub-categories of the original systems but more as newly resulting and further developed systems. As example can be mentioned the collaborative robot, which now has many different versions that differ especially in terms of task/ process and performance rather than workplace, environment, or employee. The attributes of the categories workplace, environment, and employee are more constant when advancing a system.

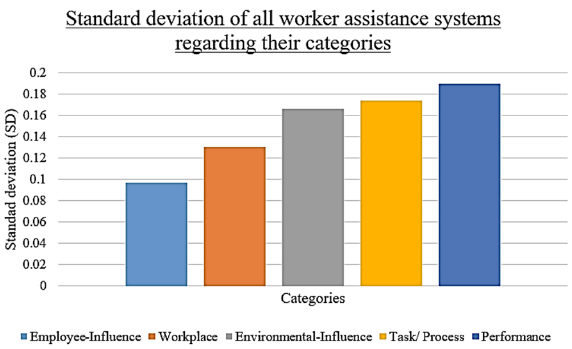

Figure 8: Standard deviations of all worker assistance systems regarding their categories.

4.3 Examination of Capability Data and Discussion

Similar to the attribute related data, Microsoft Excel was used to examine the huge amount of data regarding the capability evaluations and an algorithm helped to structure the data. Figure 9 shows an excerpt of the examination Excel.

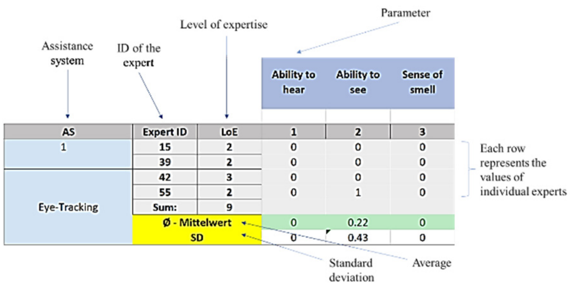

Figure 9: Simplified excerpt of the examination Excel (capability data).

4.4 Resulting Matrix and Prototype Implementation of an Expert-based Database for Existing Worker Assistance Systems

In this section, the resulting matrix of the (i) classification attributes and (ii) capability parameters is explained and shown with variables.

As for the evaluations of the (i) classification attributes, a matrix ATT (Equation 3) results, which consists in an evaluation regarding so called Use (U), that describe the applicability of the individual attributes regarding the assistance system. These U (in total 147 characteristic values to be evaluated) were evaluated for each assistance system from 0 over 0.5 to 1 (red, orange, green), whereas 0 stands for “No” (if the answer is “false” and the system is not applicable for the underlying value), 0.5 stands for “Possibly” (if the “possibility” can be seen for implementation under certain circumstances), and 1 stands for “Yes” (if the answer is “true”). Appendix 5 shows the values for one assistance system (dictionary form; key:value pair). It can also be written in form of the following matrix (Equation 3; with variables). The matrix ATT lists the applicability of the 147 characteristics in x direction (U1-U147). In y direction the different assistance systems (AS) evaluated by experts are shown (AS1-ASn). ASn stands for the possible position of the individual assistance systems (index).

$$ATT = \begin{bmatrix} AS1\_U1 & \cdots & AS1\_U147 \\ \vdots & \ddots & \vdots \\ ASn\_U1 & \cdots & ASn\_U147 \end{bmatrix} \quad (3)$$

Similar to the evaluation of classification attributes, the evaluation of (ii) capability parameters can be presented in a matrix form. The assessment of the identified assistance systems consists in an evaluation regarding so called Assistance (A), which describes the support/enhancement that the individual assistance systems can provide based on the capability parameters. These A were evaluated for each assistance system from 0 to 3, whereas 0 stands for "assistance system cannot give any support" and 3 for "maximum support". This results in a list with values for A for each of the evaluated assistance systems. It can also be written in form of the following matrix (with variables). The matrix CAP (Equation 4) lists the 23 parameters in x direction (A1-A23). In y direction the different assistance systems evaluated by experts are shown (AS1-ASn). ASn stands for the possible position of the individual assistance systems (index).

$$CAP = \begin{bmatrix} AS1\_A1 & \cdots & AS1\_A23 \\ \vdots & \ddots & \vdots \\ ASn\_A1 & \cdots & ASn\_A23 \end{bmatrix} \quad (4)$$

The data are saved to serve as a database in Microsoft Excel as well as in python dictionary format (key:value pair) for further processing. This database provides the basis that can be filled in with future assistance systems to be included in the selection and classification method.

5 CONCLUSIONS

The goal of this expert-based evaluation is to create a prototype of an expert based database which makes it possible to compare different worker assistance systems between each other and to select an appropriate aid systems for certain circumstances and situations. Based on a first set of data provided by 41 international experts in the field a prototype of such a database could be realized.

With the enabled database or using the approach for setting up the expert based database further research can be done to continuously add other assistance systems and to test its applicability in real industrial case studies where a selection of aid systems is needed. For the validation, a web platform was programmed/configured that makes a user-friendly expert evaluation possible. The results proved the possibility to evaluate different worker assistance systems in a holistic manner.

ACKNOWLEDGEMENTS

The research is a result of the project titled: Assist4Work: Social sustainability in production through age-appropriate and disability-friendly workplace design using assistance systems, grant number TN200J.

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