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Development of a Morphological Box to Describe Worker Assistance Systems in Production

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ABSTRACT

This study project focuses on the complex selection process of worker assistance systems. Due to rising complexity of products and processes in the manufacturing sector, together with changing work environments, the choice for suitable support systems becomes more difficult. An extensive literature review resulted in the derivation of a broad variety of influencing parameter which laid the foundation for a uniform developed morphological box. An exemplary implementation demonstrates and proves its advantage compared to other decision-making tools.

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Chapter 1

INTRODUCTION

1.1 Motivation

European jobs involving manual work represent the second most numerous category in the manufacturing sector. [1] Germany alone employs more than seven million people in this sector and has an export quota of around 45%, making it to a significant sector for its economic success. [2] Due to rising digitalization and Industry 4.0, human workers are facing higher demands because of more customized products. Hence, there is a growing trend towards more complexity with an increasing number of variants, smaller lot sizes and shorter product life cycles.

As a result, adequate training for manual work plays an important role to enable efficient production processes in the global market. [1] Human workers will continue to stay indispensable in value chains, which leads to a growing importance of Assistance Systems on the shop floor. Further challenges must be respected due to demographic change, such as longer working lives, skill shortage and the continuous demand for novel solutions to support the employee.

Besides supporting and unburden human workers in assembly processes, adaptive assistance systems are also used for teaching purposes and learning new skills, new assembly processes, and situation awareness training. Moreover, being aware of common mistakes, error rates and therefore the productivity is increased.

There are many more various approaches and technologies to support the manufacturing sector. However, their individual field of application and corresponding limits are mainly unexplored. [2]

Previous work has shown that there is a wide range of different design-approaches when it comes to the development of new assistance systems. Still, all these research and concepts are mainly based on single dimensions such as level of corresponding automation, cognitive or physical impact on employees, or complexity evaluations. With respect to the classification and characterization of existing assistance systems, there is only very little progress.

Due to the fact that the requirements for individual assembly systems and other operational fields in manufacturing differ, a universal decision-tool is necessary to determine the most suitable system for each use case.

1.2 Objective

Given the problem for missing classification tools when characterizing worker assistance systems, various parameter and dimensions will be derived and evaluated to cover all functionalities of known assistance systems. Since there are almost no existing approaches in this field, an extensive literature review will lead to the introduction and description of dimensioning parameter. A well-known creativity and decision-making tool will be used to represent the framework for this study-project. The result will be the development of a morphological box to describe worker assistance systems in production

Furthermore, the implementation of a database for existing assistance systems available on the market will be described. Based on this database, the solution from the morphological box will provide a suggestion for a possible assistance system referring to all influencing parameters.

Center of attention is the research question of how and with which parameter worker assistance systems in production can be labeled and classified in order to facilitate a structed selection process.

Chapter 2

STATE OF THE ART

2.1 Defining Worker Assistance Systems

The Oxford dictionary defines the term “assistance” as “the action of helping someone by sharing work” [3] Referring to this definition, basically any system can be seen as an assistance system. Extending this generic definition by another criteria, which states that they are also “interactive”, a more precise definition can be summarized: “An advanced assistance system is an interactive interface which encapsulates complexity, increases the acting capability of the user and therefore allows a better usage of the plant.” [4]
Since manufacturing companies are facing a trend towards smaller batch sizes, higher customized products and complexity, the demand for advanced assistance systems rises. This results in ever-changing production-lines, work-routines and assemblies. Thus, a growing physical and cognitive workload of human workers can be observed, which makes it essential to unburden employees and stay competitive simultaneously.
Towards the trend of Industry 4.0 a large variety of different assistance systems became available on the market. Depending on each individual field of application, a suitable system must be chosen that leads to new challenges in the area of human machine interaction. [5]

As for today, there are three generic fields in which advanced assistance systems for human worker can be divided in. Referring to the definition and focusing on the “increase in acting capability”, humans can be supported either sensorial, physical or cognitive. Table 1 represents a brief subset of assistance systems for each category and potential field of application.

Sensorial	Physical	Cognitive
Eye Tracking	Exoskeleton	Augmented reality (AR)
Motion sensing	Collaborative robot	Virtual reality (VR)
Safety glove	Back support	Head-mounted-display
…	…	…

Table 1 - Categorial representation of exemploratory assistance system

Since the implementation and correct use of these systems does not directly relate to higher productivity, the actual challenge is the satisfaction from the economic perspective and all beneficiaries. [6] Because each specific field of application faces individual restrictions, constrains and digital limitations, the demand for a supportive decision-method becomes evident. As there are many influencing factors when optimizing specific processes, further classification criteria are necessary

2.2 Design Oriented Classification of Worker Assistance Systems

In order to develop a framework model that leads to a qualitative decision-tool, multiple participating dimensions must be considered. By referring to the originally design process of assistance systems in general, some basic approaches can be observed.

There are four interdependent criteria that should be distinguished when designing an assistance system. [2] Figure 1 visualizes the interdependence and some guiding questions.

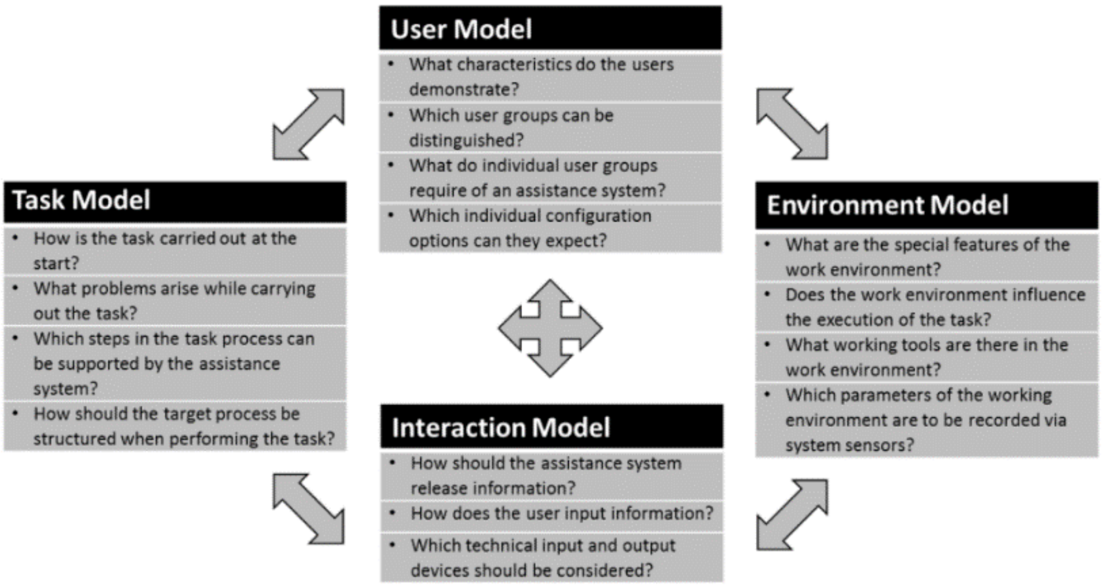

Figure 1- Interdependence model supporting design process of an assistance system [2]

Starting at the top of the scheme, it is obvious that the human worker (User Model) plays an important role in the design process. Also, the operational area (Task- & Environmental Model) as well as the level of automation / support (Interaction Model) are respected. The interdependence of these models makes it a vital tool for the development of a large set of characterizing parameters.

2.2.1 Profile-Data-Model

Since human workers are crucial in the selection process of suitable assistance systems, describing parameters of the operator are inevitable. These parameters need to consider personal characteristics, physical limitations, and qualifications. [7] The idea originates from including human workers in cyber physical production systems (CPPS) via individualized profile-data models. Because of the ever-changing working environment in today's production systems, some challenges for different human factors can arouse. The profile data model enables the possibility to allocate worker in an optimized way. By selecting suitable parameters that aim to create authentication-, competence, and ergonomic profiles of each worker, the variety of possible assistance systems can be reduced. [7]
Figure 2 visualizes a basic structure of the model in which the worker is the core element with some exemplary parameter.

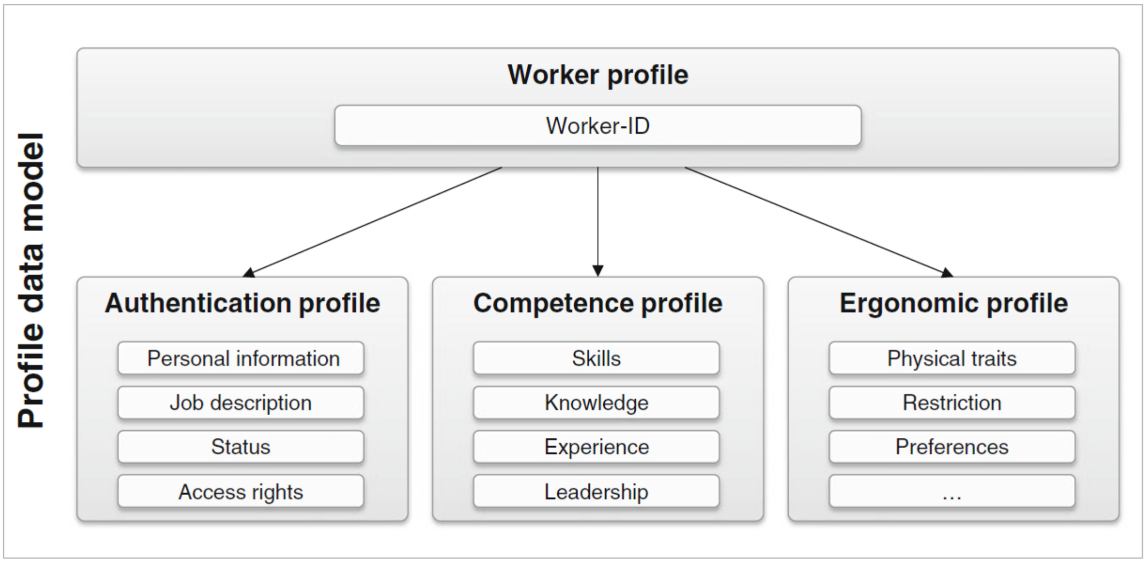

Figure 2 - Scheme profile-data-model [8]

The authentication profile comprises mostly organizational information for management purposes. This data is mainly used for scheduling or allocation tasks. However, it can also include information concerning access rights and resulting adaptivity for assistance systems.

The competence- and ergonomic profile include more individual data. Competences like production skills, work experience, as well as strength and weaknesses, are more meaningful when searching for suitable assistance systems. [7] Furthermore, general knowledge factors must be included. These involve for example language skills and capability of handling new technology.

The ergonomic profile on the other hand provides significant information concerning the usability of an assistance system. [8] Workers that are physical limited due to injuries or handicaps may not be qualified for specific user profiles. Even the presence of pacemakers could be a limiting factor for the usability of certain systems.

2.2.2 Environmental Influence

A further influencing dimension that can be crucial for the selection process is the working environment. Specifically, all influencing parameter on the task that could interfere with the performance of an assistance system. Referring again to the basic concept when designing assistance systems (figure. 1), a small but explicit set of parameters can be derived.
As it can be seen in figure 4, only influencing factors from the environment are considered. Specifically, surrounding noise, vibration, humidity, or temperature.

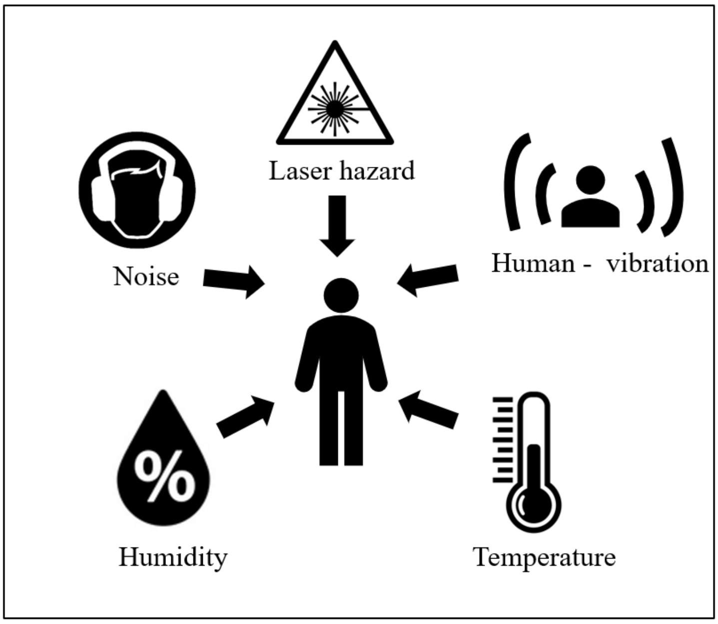

Figure 3 - Environmental influencing parameter on worker and assistance systems

As it can be difficult to quantity noise for example, this parameter must be ranked in meaningful intervals in decibel (dB). Considering that some assistance systems like motion detectors or other visual-based systems may struggle in environments with high vibration, it is inevitable to also include this main category in the selection process. All these parameters can be measured and controlled with appropriate sensors.

2.2.3 Workspace Influence

One of the main ideas of manufacturing with industry 4.0 is giving operators the right information at the right place at the right time. [9] With respect to the main field of application, the workspace in which assistance systems will be utilized has to be taken into consideration. Because each workspace/workstation differs to one another, a general characterization is necessary to determine which improvements are feasible and logical. Besides knowing the height in which a task is being performed, further information like reaching area of hands, and availability of lighting and required tools are affecting the decision process. All these prior analytical observations are crucial for a suitable choice. [10]

Since the previous introduced design scheme (figure 1) does not specifically include the workspace, a further approach is illustrated in figure 5. Given the fact that any workspace has major influence on keeping the present efficiency, more dimensions for consideration can be derived.

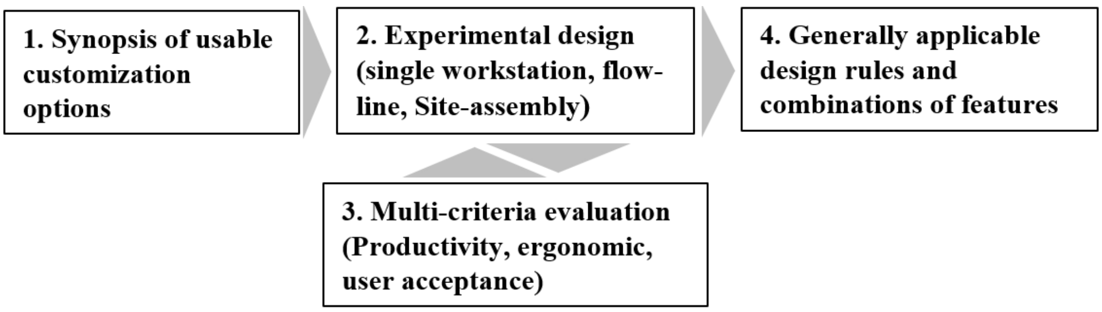

Figure 4 - Approach for the systematic development of individualizable assembly workstations [10]

Referring to the depicted procedure in figure 5, specifically to step 2 and 3, first the place of installation is defined which usually leads to fundamental differences in potential influencing parameter. Next, a set of evaluation criteria are reviewed to determine the effectiveness of the developed workstation

To make the transient more adoptable for employees, different experimental design approaches should be evaluated. A second more detailed approach can be seen in figure 6. Instead of experimentally evaluating a chosen or developed design, some predefined requirements and prototypical implementations lead to more qualitative solutions.

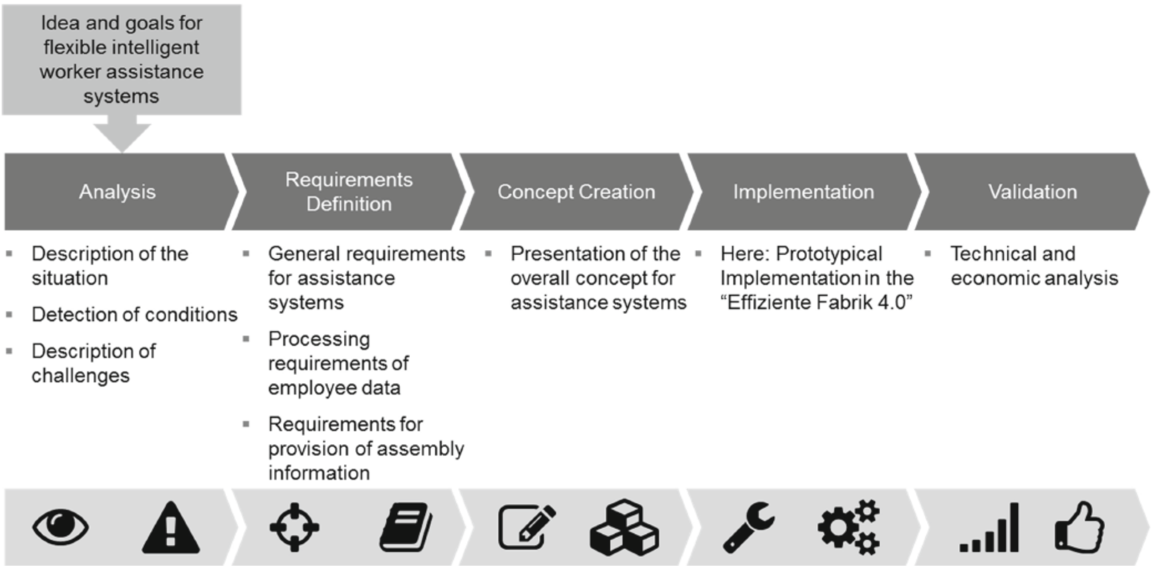

Figure 5 - Methodology for the implementation of worker assistance systems [11]

As it can be seen in the 2nd process step "Requirements Definition", the concept of defining profile data model is already applied. Consequently, by expanding available employee data with information concerning individual teaching preferences, the frequency of interaction or availability of information, both the efficiency and acceptance of prospective users increases drastically. Due to sudden and significant increase in available information to the user, it may interfere with known work sequences, resulting in reduced acceptance and productivity. [4]

The majority of company’s state, that they operate mainly on manual work (43%) or use hybrid systems (34%). [12] These hybrid systems are characterized by Human Hybrid Robots (HHR). “The idea is based on person- and process-adapted coupling of human, technical system, tool and other functionalities in a passive and/or active hybrid system.” [13] Figure 7 illustrated the approach of HHR in an exemplary use case.

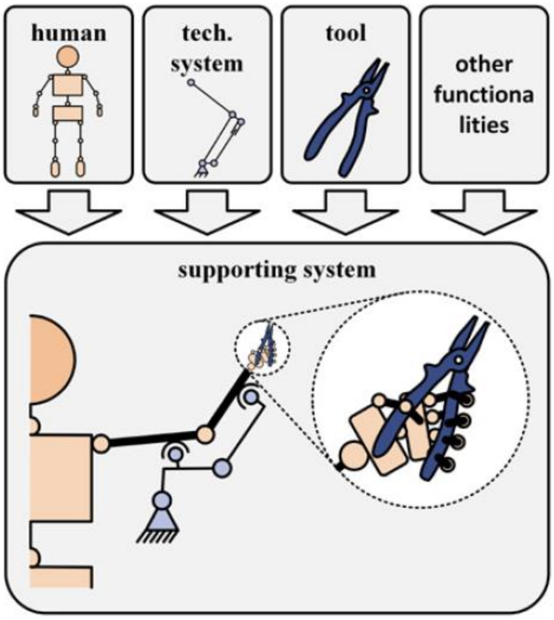

Figure 6 - Approach of the Human Hybrid Robot [14]

Referring to figure 7, the depicted hybrid-system focuses on the entire arm of an employee. Since not all arm-supportive structures have unlimited degrees of freedom or can be used in a mobile way, the workstation must fulfill certain criteria. Enough reaching area of hands and a solid basis for mounting need to be known at prior to meet full potential. HHR-systems can be viewed as a less invasive approach in supporting instead of redesigning work-processes and workstations. Still, sufficient information regarding the workplace needs to be known at prior when implementing such systems.

Taking a step back and reviewing the impact of workstations on the selection process, several influencing dimensions can be observed. Both approaches introduced in figure 6 and 7 also emphasize the human role and therefore the interdependence of worker and workspace-parameter when developing assistance systems

A set of different assistance systems with respected user preferences and environmental influences is illustrated in figure 7. As it can be seen, the worker is given the possibility to work standing and sitting due to the height adjustable table (1). Furthermore, he is partly isolated from environmental influences like noise and laser hazards.

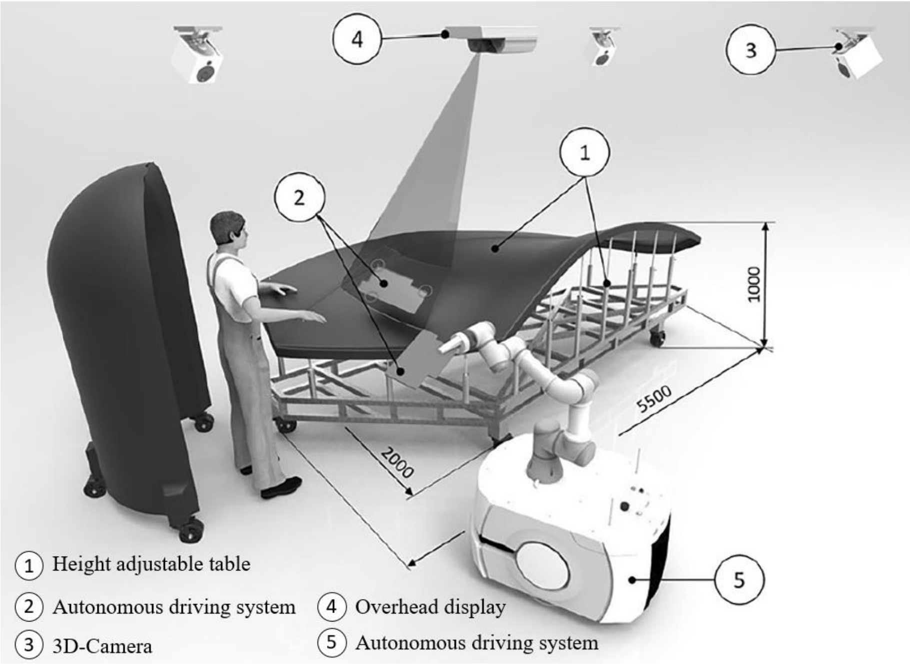

Figure 7 - Application of dimensions for individualized assistance system and workstation [10]

Additionally, overhead displays can be configured individually, depending on the level and degree of experience in order to make the transient towards more and supportive information less overwhelming.

Utilizing autonomous driving systems (5) prevents unnecessary and time-consuming motion of the human worker and allows centralized storage systems.

2.2.4 Task-Process Influence

The most essential part in finding the most fitting supporting system to unload employees, is the definition and characterization of the field of application. Therefore, it is important to understand the key differences between procedures, processes, and work instructions when designing a filtering tool for an arbitrary number of tasks.

Work instructions are describing, dictating, or stipulating a specific set of steps that need to be performed to reach an anticipated result. Other than work guides, instructions are mandatory and need to be carried out entirely to finish an activity, like an assembly step.

Consequently, a process is a set of work instructions, performed in a predefined order. Special attention must be paid when differentiating processes and procedures. [15]

Referring to the ISO9001:2015 Standard, a procedure "is a specified way to carry out a specific activity or process" [12] Procedures are consequently mandatory and need to be maintained to keep quality standards. While processes leave some degree of freedom in the performance, procedures must be carried out the same and are usually monitored in more detail.

Again, design schemes when configuration processes in collaboration with human is used to derive dimensions of interest for further characterization. Figure 8 illustrates the connection of humans and the process to be performed according to some exploratory parameter.

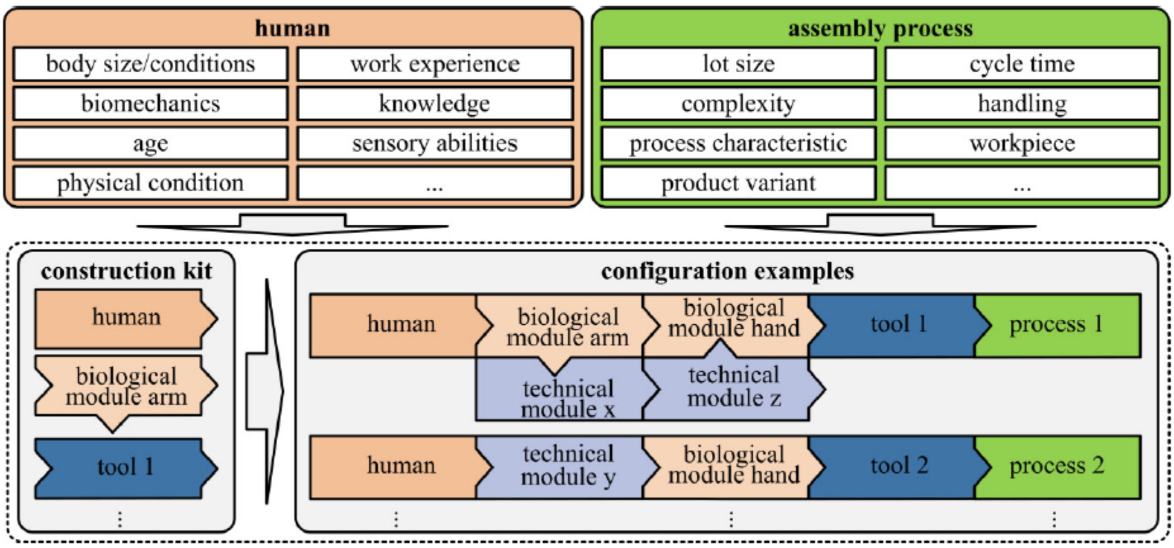

Figure 8 - Person and process customized configuration [13]

Assuming that within an assembly process there is also an interconnectivity of parts, a procedure of how they must be assembled can be present. This may lead to the necessity not just for handling different parts, but also monitoring assistance systems to meet quality standards.

The result for successful executed processes is predetermined by a worker experience and capability as well as supporting technology. Hence, an elaborated description of the process or work task reveals a broad number of dimensions to be respected. Knowing the precise amount and kind r of required parts in an assembly process, leads to less motion and waiting times. In addition to classical lean management-techniques like the introduction of Kanban, further informational assistance systems for monitoring purposes lead to even higher efficiency.

By evaluating each workstation individually, also the level of customization can be considered. Thus, not entire assembly lines need to be digitally enhanced but only those of special interest. Referring again to figure 8 and examining the characterizing parameter for assembly processes, also the complexity, frequency of changing product variants and the handling of parts are considered. Since these parameters are mainly influenced by the experience of each worker, the adaptivity of supporting systems must be respected.

Assuming an employee with little experience is facing frequently changing assembly processes, the amount of necessary information is high at the beginning of the learning process. In this regard, figure 9 represents the “Moments of Need model” [16], that can be transferred to assistance systems on the shop floor. Arguing that adaptivity is needed, the number of necessary instructions decrease with rising skill levels.

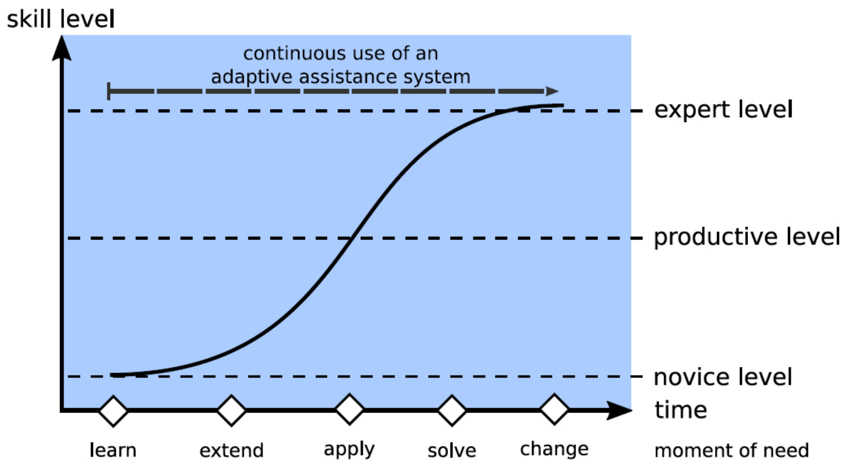

Figure 9 - Mapping of the Moments of Need model to a skill development curve of a shop floor worker [16]

After reaching a productive level within the assembly process, the learning process finalizes. Consequently, additional work experience will result in the ability to solve problems and change work cycles individually. [17] Depending on the learning process, an adaptive assistance system allows users to adjust available and visible information themselves.

2.2.5 Performance Influence

As fourth and last main category, some parameter concerning the desired and anticipated configuration and performance of potential systems must be included. Considering all previously described influencing parameter on employees, work environment and the process itself, the way how additional information and support will be provided to the employee can be differentiated.

Assistance systems are described to be context-adaptive when the system detects changes in the working environment, in performance of the task or in the person carrying out the work and reacts to such changes in real time. [18] In association with the scope of an employee's learning process and need for training, context sensitivity means that the system can rely on historical data and supports only in specific situations. [18]

Leading example in this case is the mode of information output. Depending on the situation in each individual case, a visual representation could be the optimal way, but environmental influences such as vibration make it the most inefficient. As a result, a combination of different systems lead can also lead to the best result.

Secondly, the information input to the system can be a crucial and vital parameter. As mentioned above, historical data is collected along the use of the system to anticipate, predict, and adapt to situations. Assuming assistance systems are used in the field of quality management, the need for documentation becomes of higher importance. Lead-Management must therefore decide how frequent and in which extent documentation must be carried out.

Furthermore, the level of adaptability must be defined. The reduced predictability of the behavior of the assistance and the transfer of control to a system can result in reduced acceptance. [4] Hence, an increase in stress and pressure to the employee. Figure 10 introduces 4 level of adaptability which can be used to define the level and extend of adaptability. The chosen level contributes among other dimensions to the amount of user interaction.

Class	Description
fixed assistance	An assistance system of this class works for all situations and all users in the same way.
adapted assistance	An assistance system which is optimized for the usage by a certain user group in a certain context for a specific task. The assistance system is optimized during the design phase.
adaptable assistance	An assistance system of this class can be adapted by the user according to the task, the situation and the preferences.
adaptive assistance	An assistance system of this class adapts itself according to the user, the task and the situation.

Figure 10 - Different classes of adaptability for assistance systems [19]

2.3 Decision Loop Oriented Classification of Worker Assistance Systems

Chapter 2.2 and all corresponding subchapters focused on design-approaches for deriving characterizing dimensions and parameter to classy assistance systems. This chapter on the other hand focuses on decision-making-tools.

The OODA–Loop can be described as an information strategy concept which was originally developed for the military. Today it is also used in fields with competitive environment, specifically in the economy. [20] The loop consists of four stages, illustrated in figure 10.

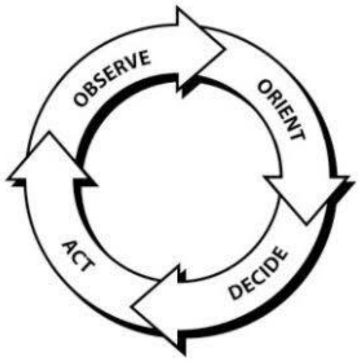

Figure 11 - OODE-Loop [20]

The loop starts with collection of information (observe) which will be interpreted (orient). Based on the previous steps, a decision is made (decide) which leads to an action (act). Generally, any kind of work can be categorized in either one of these four stages depending on the level of responsibility, allocated position in an assembly process, management, etc.

As a result, all available and considered assistance systems can be categorized according to their supporting type.

2.4 Morphological Box Approach

The morphological box is a creativity technique that was first introduced by Fritz Zwicky in 1976. [21] It can be used to visualize a set of different parameters relating to a coherent product, problem, method or similar. Belonging to the group of discursive creativity methods like the Cause-Effect-Analysis, it allows to evaluate multiple non-related parameters in a well-structured way. Based on the principle of morphological methods, the phenomenon of interest must be looked at in its entirety.

Building a morphological box starts by selecting suitable parameters that characterize the chosen phenomenon. It is important that these parameters are chosen uniformly, explicit and do not have any interference or affect one another. Each one is written down vertically in the first column, thus every parameter represents one row in the corresponding table. Next, appropriate values are assigned to each parameter, specifically all influencing values and circumstances.

Special attention needs to be paid on selecting these values since they represent the basis for new ideas and innovative approaches. All chosen values correspond to additional columns in each row. Consequently, a table with a specific number of rows (parameter) in the first column and varying number of columns (values) is created. Figure 1 represents an exemplary scheme of a morphological box.

<table>
<tr><th>Parameter</th><th colspan="8">Characteristic</th></tr>
<tr><th>1. Parameter</th><td colspan="2">Value</td><td colspan="2">Value</td><td colspan="2">Value</td><td colspan="2">Value</td></tr>
<tr><th>2. Parameter</th><td colspan="4">Value</td><td colspan="4">Value</td></tr>
<tr><th>3. Parameter</th><td colspan="2">Value</td><td colspan="2">Value</td><td colspan="2">Value</td><td colspan="2">Value</td></tr>
<tr><th>4. Parameter</th><td>Value</td><td>Value</td><td>Value</td><td>Value</td><td>Value</td><td>Value</td><td>Value</td><td>Value</td></tr>
</table>

Figure 12 - Representation of a morphological box

The mixture of analysis and synthesis leads eventually to the creation of multiple solutions. [22] To generate a meaningful outcome, the user must be unbiased and well informed of the given problem statement. Going through the set of all parameters one by one and selecting the most striking value, the result will be a combination of a large set of non-related parameters.

2.5 Assistance Systems on the market

2.5.1 List of Already Known Systems on the Market

This chapter will introduce two recently developed assistance systems to extend the present collection, represented by figure 13.

Sensorial (extend sensing capabilities)	Physical (extend physical capabilities)	Cognitive (extend cognitive capabilities)
Eye Tracking	Exoskeleton	Augmented Reality
Galvanic Skin Response	Arm Support	Virtual Reality
Heart Rate	Leg Support	Mixed Reality
Intelligent Hand Tracking	Back Support	Tablet
RGB Camera	Flexible Assembly Assist Robot	Visual Computing System
Motion Tracking & Gesture Recognition Device	Robots/Automats	Projection-Based Assistance Sys.
Smart Watch	Telemanipulator/Balancer/Lifting Aid	Head Mounted Display
Wearable Tracker	Wearable Lifting/Holding Aid	Smart Scan Glove
Haptic Glove	Ergonomic Manual Workplaces	Smart Phone
Infrared Camera	Robot Assistance System with ToF Camera	In-situ Projection
Portable Vibration Device	Collaborative Robot	Laser Projection System
Position Tracking System		Portable computer
		Computer Assisted Instructions
		Projector
		Monitor
		Pictorial Instruction
		Voice Control
		AI Based Intelligent Pers. Assistant

Figure 13 - List of known assistance systems at prior of study project [23]

Previous work has shown that there is already a broad variety of worker assistance systems that can be classified according to the three main categories first introduced in table 1.

2.5.2 Paper-Lamella-Jacket

The paper-lamella-jacked is a novel concept for a modular and wearable technical support system for reducing physical stress on the employee. The system focuses on modularity and the usage of soft elements for kinematic elements and interfaces to gain higher flexibility. [24] Basic principle of this new technology is the use of soft chamber elements with different geometries in a structured or non-structured way. A remote controllable vacuum inside the soft chambers and between the lamella-elements, results in higher pressure between the lamella-elements, thus strengthening the entire structure. Along figure 13 the functionality of the jacket can be further explained.

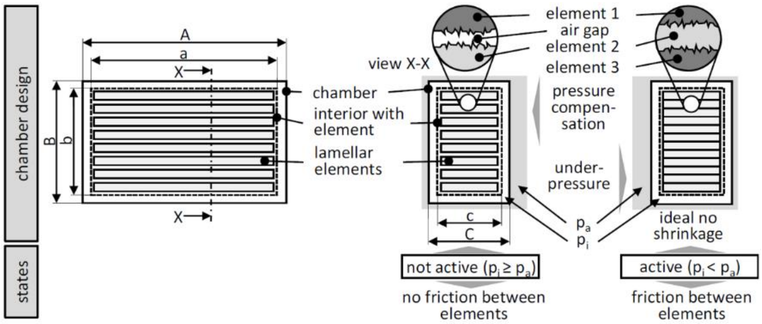

Figure 14 - Structure of a chamber as well as states for exemplary lamella elements [24]

The system can appear in two main system states: active and not active. “Once the pressure inside the chamber p_i is less than the pressure outside the chamber p_a, they are active otherwise not active” [24] Both these stages are illustrated on the right-hand side in figure 13. When “activating” the vacuum inside the chamber, the airgap becomes smaller and a “stiff” structure is present. If the system is activated, forces and torques can be transmitted along the lamella elements.

As the vacuum is the key parameter for regulating the system, also the overall pressure difference, arrangement of elements, kind of material and number of layers contribute to the stiffness and corresponding strength.

The new technology was implemented in a prototype-vest, as it can be seen in figure 14.

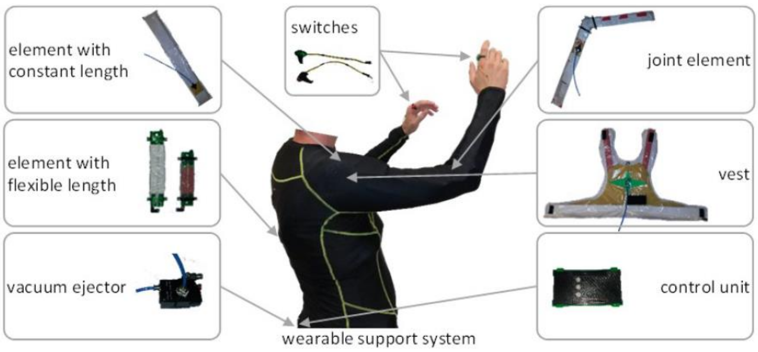

Figure 15 - System design of the functional prototype [24]

Since the functionality is based on the changing presence of a vacuum, a vacuum ejector in combination with a regulating control unit are present. The unit is controlled by the user through switches. To ensure human safety and sufficient motion when using the system, different variants of soft chambers were used. As it can be seen, there are two connected chambers in the area of the elbow joint.

Main field of application for this particular system is the support of the upper body when performing tasks overhead. [25] The described technology can also be used to unload different areas of the body. Nevertheless, there is still potential for optimization.

2.5.3 Muscle Glove

The second novel approach for wearable assistance system is the “soft muscle glove”. It aims to support in situations when performing hand-intensive activities by reducing muscle contraction force and time in a defined work-rest cycle. [26] Based on a biomimetic design, the focus lies on the salient features and functionalities of the human hand. Figure 15 represents a photograph of the first prototypical design.

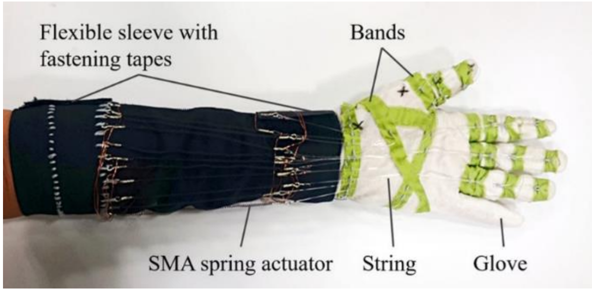

Figure 16 - Prototype of the muscle glove with flexible sleeve [25]

With respect to previous research by the developer of this assistance system, it is evident that the human-hand is a high complex system itself. Simulating the autonomic features requires a broad understanding in skeleton, tendons and muscles and pulleys in each finger. [27]
Most important features in this innovative technology are the use of shape memorizing alloy (SMA) springs in combination with controllable actuators. A detailed overview of the working principle of the “gripping aid” can be seen in figure 16.

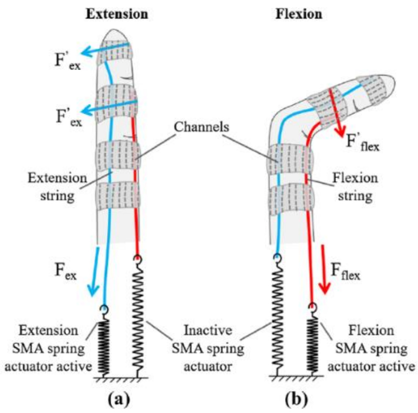

Figure 17 - Flexion and extension mechanism of the muscle glove [27]

Based on a set of 2 SMD-springs for each finger, the gripping aid can be controlled according to three stages: on, hold and off. [27] The blue and red strings in figure 16 are representing the artificial tendon, pulley, and muscles in combination with the SMD-springs. The first prototype of the glove only weights 85g, inclusive the actuators and microcontroller, which makes it a promising wearable assistance system in the future. [27]

Chapter 3 DEVELOPMENT OF A MORPHOLOGICAL BOX TO DESCRIBE WORKER ASSISTANCE SYSTEMS IN PRODUCTION

In this chapter, a uniform developed morphological box is described and explained in detail. The extensive literature review in chapter 2 provides the basis for the development of this framework. Since previously described approaches are only argued theoretically by providing design rules for development processes, this chapter shows the actual implementation and application of all these derived parameter and dimensions.

With respect to the interdependence of multiple influencing parameters on working tasks and the usability of assistance systems, a more detailed model can be created. As it can be seen in figure 17, a total of five main categories will be considered.

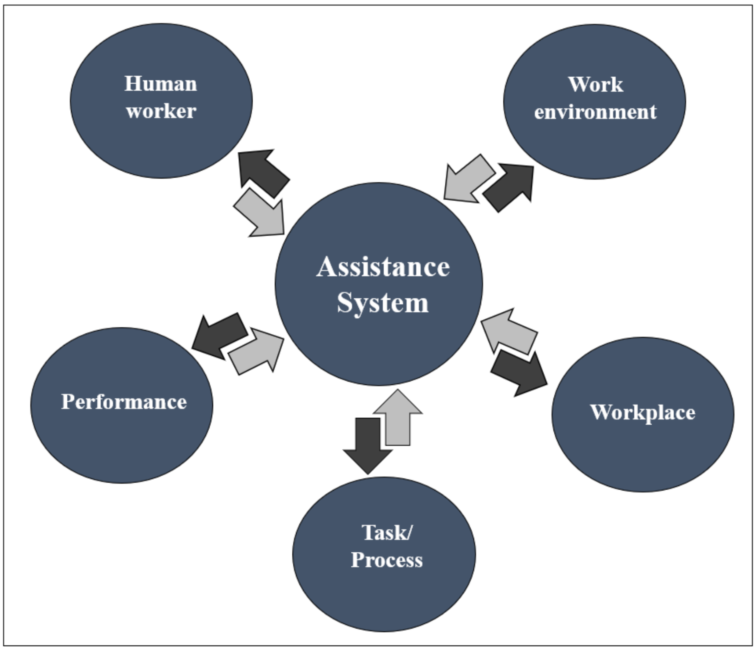

Figure 18 - Classification and selection model

As an extension to already existing interaction schemes (fig. 1), a larger set of categories such as workplace and desired performance-based parameter will be covered.

Basis for a qualitative decision-tool is the detailed classification of existing data. Specifically, all known existing assistance systems must be classified according to the main categories. Symbolized by arrows going into two directions, the selection process must be seen as a two-way street. At first, all assistance systems according to predetermined values need to be classified to set up a database. Next, the individual selection of the most fitting values provide a suggestion for the most convenient assistance systems.

Due to the user’s individual use-case, all limiting parameter and constraints of the company will be respected. Finally, the morphological box can be used both for classification and selection.

The first main category of the box includes all “Employee-based”-parameter. As it has been pointed out, the derivation of these parameter is based on the creation of an individual profile-data-model to characterize and describe employees

Table 3-1 is the first section of the morphological box, providing all derived parameter and corresponding values. By classifying a worker based on his anthropomorphic, a lot of wearable assistance systems might unsuitable. Also, a collective choice is in the realm of the possible.

Respecting the amount of people working preferably with their right hand and having a body height of 181-185cm, wearable systems for a department can save the evaluation and selection process, therefore keeping the efficiency.

Parameter	***Value***				
Gender	Male		Female		Transgender
Age	18-15	26-30	31-40	51-60	61-X
Height [cm]	150-170	171-180	181-185	186-190	191-x
Handeness	Right		Left		Both
Glasses	Yes			No	
Debility of sight	Long-sighted		Short-sighted		None
Phys. limitations	Pacemaker		Wheelchair		Prothesis
Language skills	German	Englisch	Italian	Spanish	Other
Work experience [Years]	0 -1		1-2		2 - X

Table 2 - Category 1 – Employee Influence

By classifying a worker based on his anthropomorphic, a lot of wearable assistance systems might unsuitable. Also, a collective choice is in the realm of the possible.

Respecting the amount of people working preferably with their right hand and having a body height of 181-185cm, wearable systems for a department can save time for the evaluation and selection process. The employee data model also includes parameter like physical limitation and debility of sight. These values prohibit the suggestion of wearable physical aid for employees in wheelchairs or electromagnet-working technologies for people with pacemakers.

Next main category summarizes environmental-based-parameter. Due to some the sensitivity of some assistance systems to their environment, this category is included to characterize surrounding influences. Table 3-2 gives an overview of the chosen intervals for the corresponding values.

Parameter	***Value***		
Average Temperature [C°]	0-15	16-30	Varying
Noise [dB] [28]	< 80 dB	80 - 85 dB	> 85 dB
Vibration – Hand / Arm [$\frac{m}{s^2}$] [28]	$< 2.5 \frac{\mathrm{m}}{\mathrm{s}^2}$	$> 2.5 \frac{\mathrm{m}}{\mathrm{s}^2}$	
Vibration – Body [$\frac{m}{s^2}$] [28]	$< 5 \frac{\mathrm{m}}{\mathrm{s}^2}$	$> 5 \frac{\mathrm{m}}{\mathrm{s}^2}$	
Humidity / Moisture [$\frac{g}{m^3}$]	Yes	No	
Light	100 - 400 lm	400 - 900 lm	900 – 1300 lm
Laser Hazard	Yes	No	

Table 3 - Category 2 – Environmental Influence

As it might be difficult to quantify some of these parameters, the used of intervals seemed to be the best solutions in this case. Basic sensors can determine varying temperatures, or the exposure to vibration. Facing a steady exposure to vibration, may can lead to health issues of the employee. Ambient noise on the other hand can influence the quality of precision mechanics and other tasks that require a high level of concentration. Also, noise can limit the communication possibility to transfer information. Depending on which specific interval a user selects according to the situation in his shopfloor, either a visual representing information systems or wearable communication systems might be a possible solution. Certainly, these parameters influence the selection process but do not solely decide about the outcome.

The third main category encompasses workplace-based-parameter. Meaningful dimensions that describe the workplace are collected in table 3-3. Defining the type of manufacturing and the location in which the work is being performed, leads to the elimination of some systems which can only be used stationary

<table>
<tr><th>Parameter</th><th colspan="5">Value</th></tr>
<tr><td>Support Type</td><td colspan="2">Sensorial extend</td><td>Physical support</td><td colspan="2">Cognitive</td></tr>
<tr><td>Manufacturing type</td><td colspan="2">Flow line</td><td>Field assembly</td><td colspan="2">Individual working area</td></tr>
<tr><td>Location</td><td>Stationary</td><td>Mobile</td><td>Commissioning</td><td>Hand</td><td>Wearable</td></tr>
<tr><td>Electricity at workplace</td><td colspan="3">Yes</td><td colspan="2">No</td></tr>
<tr><td>Reaching area for hands</td><td colspan="2">0-45</td><td>0-180</td><td colspan="2">360</td></tr>
<tr><td>Tooling availability</td><td colspan="2">At Workplace</td><td>Shared</td><td colspan="2">Centralized</td></tr>
<tr><td>Exposure of Light</td><td colspan="2">Low</td><td>Middle</td><td colspan="2">High</td></tr>
<tr><td>Data transfer</td><td colspan="2">Linked by cable</td><td>Wireless</td><td colspan="2">Static (paper-based)</td></tr>
<tr><td>Compatibility / Installation effort for different assembly</td><td colspan="2">Entire workplace must be newly configured</td><td>Basic adjustments made to the workplace</td><td colspan="2">Minor adjustments made to the workplace</td></tr>
<tr><td>Network Status</td><td colspan="2">Workplace connected to network</td><td>Central Terminal connected to Network</td><td colspan="2">Minor adjustments made to the workplace</td></tr>
</table>

Table 4 - Category 3- Workplace Influence

Furthermore, a great amount of assistance systems requires the presence of a constant energy source. Correspondingly, a changing work-environment is unfavorable for devices that have a high energy consumption, while fixed workstations have a greater variety of choices with different limitations. A mobile work environment for example has basically an unlimited reaching area of hands since there are no obstacles present, but a fixed environment may be limited by portioned walls or rigid machinery. Also, the state of the digital progress is respected. Here, the access to the company network is specified and how data is transferred along the manufacturing process. Some limitations might encounter when it becomes necessary to do adjustments to the workplace. Without defining essential information like these in advance might complicate the selection process.

The fourth category addresses working-task- and process-based-parameter. All characterizing parameter and values are enumerated in table 3-4. These focus on dimensions like the type of work that is performed and how frequent tasks are being executed.

Parameter	Value					
Type of Manufacturing	Assembly	Dismantling	Information Management	Training	Inspection	
Type of Work /	Joining	Handling	Adjusting	Controlling	Managing	Set up
Range of Support	Total process	Partial process				
Working Environment	Sitting	Standing				
Influence of Vibration	None	Hand / Arm	Body			
# Assembly Steps	01 - 05	06 - 20	21 - X	None		
# of Parts	1 – 10	11 -20	21 – 30	31 - X		
Interaction / of assembled parts	Yes	No				
Individualization by employee	High	Medium	Low			
Lot size	Product-based	Batch-based	Lot-based			
Level of customization (Assembly)	0%	Low (25%)	Medium (50%)	High (>50%)		
Change frequency –	Permanent	Temporary	Rotaionally	None		
Motor skills – Joining accuracy	None-fine motoric skills	Fine-motoric skills				
Focus on .	Efficiency	Effectiveness	Flexibility			
Necessary # Hands	Single-handed	Both-handed				

Table 5 - Category 4 – Task-/Process Influence

By defining the number of assembly steps, necessary parts and providing little information about their interaction to one another, basically the level of complexity is described. Complex structures require experience and know-how to ensure functionality and keep quality standards. With regard to category 1, in which the employee is described, the interconnection within the model becomes evident. Since worker with little experience will not be able to perform complex tasks, or at least, might take a long time, either a better allocation or the choice for a high informational system would be the best choice.

Further, Job-change needs to be considered. As is has been pointed out in the 2nd chapter, smaller lot sizes and higher amounts of customized product can have great impact on employee's cognitive stress and force them to make decisions more frequently when problems arise. Again, by knowing change-frequencies of products and processes in advance, employees can be provided with enough cognitive and physical supporting systems.

As fifth and last main category, performance-based-parameter are considered. Again, all corresponding parameters are summarized in table 3-5. After the definition of all influencing dimensions on the employee, environment, workspace and working tasks, this category focuses on the working principle. Although these values determine the desired performance of systems, this category can also be seen as “Lead-Management-parameter”.

Parameter	***Value***			
Human-Machine Interface	Unimodal		Multimodal	
Information Input	Manual	Automatic	None	
Type of Input	Typing	Verbal	Gesturing	None
Initiative (Amount of support)	Active		Passive	
Information Output	Manual	Automatic	Threshold	None
Type of Output	Visual (optical)	Auditory (acoustic)	Tactile-kinesthetic	None
Visual Output	On-Screen	Highlighting in working areas	Superimposed on assembly object	None
Degree of visual representation	Selective presentation	Limited display (symbols, images)	Extensive display (Videos, Animations)	None
Class of Adaptability	Fixed assistance	Adapted assistance	Adaptable assistance	Adaptive assistance
User recognition	None	Upoloading of user profiles	Automatic uploading of user profiles	
Documentation	Sample-Based	Order-Based	Product-Based	

Table 6 – Performance Influence

Due to the broad variety of interaction modalities with all assistance systems, first the level human-machine interface needs to be defined. The resulting possibilities determine the main working principle and type of information input and output. Lastly, the magnitude of information output and adaptability must be defined to state the configuration of each individual employee.

Within this chapter one example will be classified according to the methodology previously described. The motion-sensing (Kinect) assistance system is defined as sensorial-support. “Kinect is a line of motion sensing devices produced by Microsoft that are often used for motion capturing and gesture recognition”

The designed classification methodology is based on a three-level color coding, making the approach more visible and tangible as it can be seen in table 4-2. First example is the motion sensing technology (Kinect) from Microsoft. Knowledge about the about the functionality and limitations must be known in advance to ensure a correct, meaningful, and qualitative classification.

● (green)	***Applicable***
● (orange)	***Partially applicable***
● (red)	***Not applicable***

Table 7 - Three level color classification for applicability

With this approach the system can be classified and ranked at the same time. A green color coding classifies a system to be fully applicable for a specific value within an analyzed parameter. Orange on the other hand may be applicable but also includes doubts and foresees possible constraints in some fields of operation. Assuming the user of a morphological box “chooses” either one of these values to be descriptive to his shopfloor, the system will be within the list of suggestions. Instead of determining a specific value to be applicable or not, the subset “partially applicable” allows the user of the morphological box to carefully review potential constraints that have been considered in the classification process.

A red color coding clearly denies the applicability of the system. As soon as a predetermined number of “Not applicable”-values are selected, the system will be erased from the list and not be considered. It becomes evident that extensive knowledge about the functioning of a system is required when performing the classification as a first instance.

Wrong assumptions and half-knowledge can become crucial and restricting in this important phase of implementation. A detailed example for the suggested classification-algorithm is depicted in the morphological box of table 4-3.

Employee-Influence							
Gender	Male	Female	Transgender				
Age	18-25	26-30	31-40	51-60	61-X		
Height [cm]	150-170	171-180	181-185	186-190	191-X		
Handeness	Right	Left	Both				
Glasses	Yes	No					
Debility of sight	Long-sighted	Short-sighted	None				
Ability to hear	Yes	No	Hearing-Aid				
Ability to smell	Yes	No					
Phys. Limitations	Pacemaker	Wheelchair	Prothesis				
Language skills	German	English	Italian	Spanish	Other		
Work experience [Years]	0-1	1-2	2-X				
Environmental							
Average Temperature [C°]	0-15	16-30	Varying				
Noise [dB]	… dB	… dB	… dB				
Vibration [Hz]	None … Hz	Low … Hz	Strong … Hz				
Humidity / Moisture [g/cm3]	Yes	No					
Light	100-400 lm	400-900 lm	900-1300 lm				
Laser Hazard	Yes	No					
Workplace							
Support Type	Sensorial extend	Physical support	Cognitive	Informational			
Manufacturing Type	Flow-line	Field-assembly	Individual-working area				
Location	Stationary	Mobile	Commissioning	Wearable			
Electricity at workplace	Yes	No					
Reaching area for hands	0-45°	0-180°	360°				
Tooling availability	At Workplace	Shared	Centralized	No tools required			
Parts for assembly	At workplace	Shared	Centralized	No Parts required			
Exposure of light	Low	Middle	High				
Data transfer	Linked by cable	Wireless	Static (paper-based)				
Compatibility / Installation effort for different assembly	Entire workplace must be newly configured	Basic adjustments made to the workplace	Minor adjustments made to the workplace	No adjustments made to the workplace			
Network status	Workplace connected to network	Central terminal connected to network	No Network connection				
Task - / Process							
Type of Manufacturing	Assembly	Dismantling	Information Management	Training	Inspection		
Type of Work	Joining	Handling	Adjusting	Controlling	Managing	Training	Set up
Decision making	Observation	Orient	Decide	Act			
Range of support	Total process	Partial process					
Working environment	Sitting	Standing					
# assembly steps	01-05	06-20	21-X				
# of steps	1-10	11-20	21-30	31-x			
Interaction of assembled parts	Yes	No					
Lot size	Product-based	Batch-based	Lot-based				
Level of customization (assembly]	0%	Low (25%)	Medium (50%	High (>50%)			
Change frequency	Permanent	Temporary	Rotationally	None			
Motor skills – Joining accuracy	None-fine motoric skills	Fine-motoric skills					
Focus on …	Efficiency	Effectiveness	Flexibility				
Necessary # of hands	Single-handed	Both-handed					
Need of Retentiveness	Low	Medium	High				
Performance							
Human-Machine interface	Unimodal	Multimodal					
Information input	Manual	Automatic	None				
Type of input	Typing	Verbal	Gesturing	None			
Initiative (Amount of support)	Active	Passive					
Information Output	Manual	Automatic	Threshold	None			
Type of Output	Visual (optical)	Auditory (acoustic)	Tactile-kinesthetic	None			
Visual output	On-screen	Highlighting in working areas	Superimposed on assembly object	None			
Degree of visual representation	Selective presentation	Limited displace (symbol, images)	Extensive displace (Videos, Animations)	None			
Level of Configuration	Set configuration of information input and output	Individual configuration of information output	Individual configuration of information input and output				
Class of adaptability	Fixed assistance	Adapted assistance	Adaptable assistance	Adaptive assistance			
User Recognition	None	Uploading of user profiles	Automatic uploading of user profiles				
Documentation	Sample-Based	Order-Based	Product-Based				

Table 8 - Exemplary classification of the system "Motion Sensing (Kinect)

Reviewing the solution in this particular case highlights some interesting facts. While the first category (employee) almost does not show any constrains and limitations, some not applicable values become visible in other areas.

Three environmental influencing parameters may constrain a proper implementation of the motion-sensing technology, first a relative low temperature and a high magnitude of vibration. Concerning the low temperature, it was assumed, that due to varying temperature a fogged lens might result in a low performance of the system. More tangible is the effect of a vibrating environment. Since it clearly prohibits the system of measuring an employee's movement properly, strong vibration was seen to be not acceptable while low vibration may be solved by small adjustments to the workplace or similar.

A few more restrictions for the motion sensing technology arouse when it comes to the location and manufacturing type. Since motion sensing requires a consistent work environment to generate meaningful and qualitative results, it cannot be used in field assembly and may be difficult to implement for individual working areas. Setting up and calibrating these systems can be challenging. The installation effort in this case may be significantly higher than more basic systems smart watches or other wearables. Basis or minor adjustments to the workplace are therefore not sufficient to ensure good functioning. Furthermore, a well working network structure directly to the workplace is necessary to inform user about wrong positioning, ergonomics, or entering/reaching in restricted areas. As it has been declared as "no applicable" in table 9, central-based terminals for data transfer and wireless connections can also be constraining influences in this case.

Regarding the task and process influencing parameter, only a few selected parameters do not seem to be applicable. Because the motion sensing technology is mainly used to inform users and support them about predefined restrictions, their use for information management or inspection purposes is not suitable. These values depend on human's ability of recognizing correlations. In addition, frequently changing tasks and processes demand more data that allows these systems to recognize different employees, without the need of constant recalibration.

Classifying the performance of motion sensing systems presupposes a comprehensive know-how of existing variations and combinations. While some are only used for human-recognition purposes to optimize the assembly procedures, others are used for safety issues or similar.
Since the system is based on computer vision technology, no information input as well as written input was declared as no applicable. Moreover, requiring a system with manual output would miss the overall performance of motion sensing since it is an autonomous working principle.

Chapter 5 DISCUSSION

In this study project the focus laid on the identification of existing classification methods and approaches for adaptive worker assistance systems. Additionally, an extensive morphological box was successfully developed, that includes a large quantity of parameter in consideration of all influencing dimensions on assistance systems.
It became evident that there is a great number of different design and development approaches Still, only specific fields of application and areas of operation are respected in these studies. Furthermore, most of these approaches did not respect the interdependence of all contributing factors, only some of these were mentioned and considered.
By critically reviewing and combining basic principles, an independently developed model-scheme was created. In a first instance this scheme was used to point out the interdependence of all direct and indirect values for a successful categorization procedure. With respect to the design rules of a morphological box, the results provide users a unique decision-making tool that suggests the most suitable assistance system for their individual use-case scenario.

Along the development process it became evident that there may arouse some compatibility criteria, for example when characterizing worker assistance systems. Due to the broad variety of systems, it can be challenging to specifically predetermine performance parameter, specifically sensorial-based systems. New developed systems may have the potential to not only monitor and observe, but also to decide and act based on visual based recognition. As a result, more precise research for different variations is necessary to avoid a superficial classification. Moreover, the combination of multiple systems can result in implementation difficulties and incompatibilities. Still, by classifying all systems with a deeper knowledge will eventually prevent this error source.

By using and further elaborating the results of this study project, companies will be given a powerful tool to reduce the time and effort in finding suitable worker assistance systems for their individual operational use case scenario. Instead of resource demanding experimental implementation and validation processes, companies will have the possibility to evaluate their current shopfloor. Consequently, areas for redesign or optimization to implement worker assistance systems become evident which leads to a more productive, preventive, and efficient work environment.

Chapter 6 CONCLUSION AND OUTLOOK

Due to the fact of an increasing demand of unloading human worker in manufacturing and a growing offer of worker assistance systems, the demand for qualitative support in this area is of great interest and potential. Because up to now there are no similar approaches that encompasses any influencing dimension, this field of research shows a great amount of potential.

Since up to this point only a subjective view has been taken on the development of the parameter catalog, a further extension of values and a broader elaboration of influencing factors must be carried out. In cooperation with companies that are already utilizing worker assistance systems, the quality and completeness of this decision-making-tool can be verified and further extended. A multiple reevaluation of all defined values for all previously described influencing categories will provide more recommendations and customization options. Furthermore, the list of currently known worker assistance systems must be updated frequently to ensure a completeness and to avoid lack of information and corresponding options. Also, the research of experts for each individual worker assistance system could have a significant advantage for the classification phase. Since the database is the foundation for the selection process, a more detailed outline of a workplace or process can be ensured.

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