Design of an Assembly Workplace for Aging Workforce and Worker with Disabilities

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Abstract. With the introduction of the Fourth Industrial Revolution (also known as Industry 4.0 or 14.0) the use of worker assistance systems gets more and more important. These assistance systems should support the worker to reduce both mental as well as physical stress and at the same time increase ergonomics. Besides the already mentioned positive aspects of assistance systems they can also support the inclusion of workers with limitations in the daily industrial production environment. In this paper, we apply Axiomatic design (AD) to systematically design a future operator’s workplace for older workers and workers with disabilities. Therefore, we conducted interviews with employers and physical and mental disabled people to identify the customer needs (CNs) and set constraints (Cs). In a next step, we defined the first level functional requirements (FRs) and the deduced corresponding design parameters (DPs). Following, the decomposition and mapping process and considering the independence and information axiom we designed a workplace equipped with worker assistance systems for better integrating elderly people and people with disabilities in manufacturing.

1. Introduction
The production environment has been changing fundamentally over the last years. This is mostly due to technologies and concepts based on “Industry 4.0”, which is also known as the fourth industrial revolution [1]. On the one hand, there is a high trend towards automatization and repeated activities and on the other hand the products are made in many variations, which leads to a smaller lot size [2]. This diversity, consequently, results in a growing total of product adjustments for the operator working in the production environment [3]. It can be said that the industry we are currently part of changes from “mass production” towards “mass customization” together with a lower product life cycle. In order to cope with the new challenges, the operator needs to be flexible and trained but first and foremost there must be enough workers available on the market.

Having this background in mind a worrying trend is noticeable. The population development in Europe varies from country to country. Overall, however, the continent’s share of the world’s population will continue to decline. The average age of people in Europe is the highest of all regions
of the world, and the trend is rising. In fact, this century Europe will be marked by enormous demographic changes [4]. It is not surprising that Europe is desperately looking for workers. Europe is heading towards the demographic trap. More and more people are leaving the labor market due to age, while the number of new entrants is not enough to close this gap [5]. In order to counteract this certainty, elderly people and people with disabilities could be involved in the labor market. Therefore, useful and appropriate worker assistance systems have to be found. Thus, these groups of people might turn out as a useful asset for the production industry and consequently get included into the daily life better.

Due to the lack of assistance systems especially for elderly people and people with disabilities and the high prices that had to be paid for such technology in the past there is a high potential for inventing a workplace equipped with aid systems. With this paper, we want to contribute to the research on worker assistance systems, as tools for a more inclusive manufacturing and to relax the extreme lack of workers due to the demographic change.

2. AD Based Design Approach
The aim of this research article is to develop a framework for the successful design of an assistant workplace for elderly people and people with disabilities to help the human in production 4.0.

This section presents a procedure to receive a framework and design concept for such an assistant workplace. The research team used AD as a research methodology to deduce a list of design solutions. In the following, this technique is shown in detail.

2.1. Axiomatic Design Methodology
Axiomatic Design has become one of the more commonly applied engineering theories regarding design in industrial practice and academic literature [6], since 1978 when it was first mentioned in a publication [7]. It was founded by Nam P. Suh in order to develop a generalized, systematic and scientific procedure for design. AD uses a concept of four different domains of the design world, which can be summarised as follows: 1) the customer domain with Customer Needs (CNs) where the customer wishes are shown, 2) the functional domain with Functional Requirements (FRs) where the translation of CNs into FRs takes place, 3) the physical domain with Design Parameters (DPs) where the design parameters are derived, and 4) the process domain with Physical Variables (PVs) where the DPs are translated into real PVs [8]. The two following axioms must be respected when performing AD [9]:

I. **Axiom 1**: The “Independence Axiom” to maintain the independence of the functional requirements (FRs),

II. **Axiom 2**: The “Information Axiom” to minimize the information content of the design.

Parallel physical and functional parts are constructed in order to apply these axioms. The physical hierarchy contains the final physical design solutions. Through AD the designer learns to keep an overview and how to construct and structure large design hierarchies quickly. Hence, there is more time for managing applications [10]. CNs were gathered and based on this, FRs and Cs could be defined, and design parameters were derived in an AD mapping process and top-down decomposition.

2.2. Collection of Customer Needs
Based on discussions and interviews with the different stakeholders specified in chapter three, nine customer needs (CN) could be collected. These are the following:

- **CN1**: Assistance system must be as flexible as possible.
- **CN2**: System must ensure the quality of the product.
- **CN3**: It must be possible to subdivide the working tasks in parts.
- **CN4**: Safety of the worker must be guaranteed during the tasks.
**CN5:** System must overcome the counting difficulties of the workers.

**CN6:** System must overcome the reading and understanding problems of the workers.

**CN7:** System must ensure/maintain the attention of the worker.

**CN8:** System should overcome the memorization problems of the worker.

**CN9:** There must be always a structure in what the workers need to do.

**CN10:** System should be able to support the operator with handling of heavy weight.

These mentioned customer needs as gathered from the interviews with caregiver of elderly people and people with disabilities, elderly people and people with disabilities themselves and companies give a starting point for the later discussed decomposition.

### 3. Decomposition and Mapping Process

#### 3.1. Definition of Top-Level Functional Requirements and Design Parameters

The following FR\(_0\) and DP\(_0\) were defined based on the previously identified CNs:

**FR\(_0\)**  
Enable the inclusion of elderly people and people with disabilities in production

**DP\(_0\)**  
Workplace equipped with assistance systems to support elderly people and people with disabilities in production

In the following, the top-level FRs and DPs are listed which were defined by the research team:

**FR\(_1\)**  
Enable people with mental health issues the inclusion in daily work life

**DP\(_1\)**  
Workplace to assist people with cognitive or memory issues

This upper level FR-DP pair indicates one part of the target group, namely people with mental health issues, that must be included in daily work life. Further decomposition is required (see section 4.4.1).

**FR\(_2\)**  
Enable people with physical health issues the inclusion in daily work life

**DP\(_2\)**  
Workplace to assist people with physical health issues

This upper level FR-DP pair indicates the other part of the target group, namely people with physical health issues, that must be included in daily work life. Further decomposition is required (see section 4.4.2).

When looking at the interdependencies in the design matrix (see Eq. 1) a decoupled design can be seen. This displays the existence of an established order of the design solutions implementation concerning the compliance of the first axiom.

\[
\{\text{FR}1\} = \begin{bmatrix} X \\ 0 \end{bmatrix} \{\text{DP}1\}
\]

(1)

#### 3.2. FR1-DP1 – Enabling Inclusion of People with Mental Health Issues in Daily Work Life

As mentioned before, the top-level FR-DP pairs need to be further decomposed on more levels in order to get more palatable solutions for design and creation. The following sections 4.4.1 and 4.4.2 show the mapping process and decomposition results.

The following lower level FR-DP pairs were derived by the research team based on the top-level FRs and DPs in order to determine mental health issues of elderly people and people with disabilities in daily work life.
Table 1. Decomposition of FR₁-DP₁ pair.

| Level 1 | FR                  | DP                  |
|---------|---------------------|---------------------|
|         | FR₁.1. Overcome cognitive or memory issues. | DP₁.1. Solutions to overcome cognitive or memory issues. |
|         | FR₁.2. Overcome communication difficulties. | DP₁.2. Solutions to overcome communication difficulties. |
|         | FR₁.3. Overcome attention issues. | DP₁.3. Solutions to overcome attention issues. |
|         | FR₁.4. Overcome reading, linguistic and verbal comprehension issues. | DP₁.4. Pictures and videos in stand-alone or combined with multilanguage text. |
|         | FR₁.5. Message and inform the caregiver/supervisor. | DP₁.5. Andon button (physical or virtual). |
|         | FR₁.6. Overcome quantity control issues. | DP₁.6. Solutions for quantity control. |
|         | FR₁.7. Overcome quality control issues. | DP₁.7. Solutions for quality control. |
|         | FR₁.8. Increase attention to important subjects. | DP₁.8. System that ensures the clear visual understanding. |
| Level 2 | FR₂.1. Provide work steps. | DP₂.1. Dynamic instruction manual. |
|         | FR₂.2. Support the worker with information about what has to be done and what has already been done. | DP₂.2. Dynamic checklist. |
|         | FR₂.3. Structure the assembly process in several tasks. | DP₂.3. Assembly sequence workflow. |
|         | FR₂.4. Guarantee the easy accessibility of the work instructions. | DP₂.4. Easily accessible hard- and software. |
|         | FR₂.5. Calling up individual content that is difficult to remember. | DP₂.5. Customizable note/memo page. |
|         | FR₂.6. Send and visualize general company/product relevant content. | DP₂.6. Chat/news function. |
| Level 3 | FR₃.1. Provide motivational information. | DP₃.1. System that congratulates after each XX part. |
|         | FR₃.2. Bridge the time until the next break. | DP₃.2. Visualization of the timeline until the break. |
|         | FR₃.3. Manual counting of parts. | DP₃.3. Counting gauge. |
|         | FR₃.4. Automatic counting of parts. | DP₃.4. Scale combined with human interface. |
|         | FR₃.5. Check presence of parts. | DP₃.5. Vision system. |
|         | FR₃.6. Check functionality. | DP₃.6. EOL test bench. |
|         | FR₃.7. Check part for scratches and damage. | DP₃.7. Visual inspection station. |
|         | FR₃.8. Call up attention to important subjects within written text. | DP₃.8. Capital letter and/or bold/bigger for important words. |
|         | FR₃.9. Call up attention to the area of interest on the worktable. | DP₃.9. Thick outline of text and image fields. |
| Level 3 | FR₃.10. Make the digital instructions easy findable and accessible. | DP₃.10. Intuitive start of the software application. |
|         | FR₃.11. Make it wheelchair accessible. | DP₃.11. Wheelchair compliant workstation and instruction monitor position. |

3.3. FRI-DP1 – Enabling Inclusion of People with Mental Health Issues in Daily Work Life
The following lower level FR-DP pairs were derived by the research team based on the top-level FRs and DPs in order to determine physical health issues of elderly people and people with disabilities in daily work life.

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Table 2. Decomposition of FR2-DP2 pair.

| FR | DP |
|----|----|
| Level 1 | Level 2 | Level 3 |
| **FR2.1.** Overcome visual problems. | **DP2.1.** Solutions for visual problems. | **FR2.1.** Interact with voice. |
| **FR2.2.** Overcome hearing difficulties. | **DP2.2.** System that has loudspeakers. | **FR2.1.** Interact with gesture. |
| **FR2.3.** Overcome difficulties in accessing the workplace and reachability. | **DP2.3.** Reachability and accessibility of the workplace. | **FR2.1.** Interact with touch. |
| **FR2.4.** Overcome physical obstacles caused by heavy parts and/or devices. | **DP2.4.** Physical worker assistance systems. | **FR2.1.** |
| **FR2.1.1.** Provide instructions acoustically. | **DP2.1.1.** Aural guide with the most important steps. | **FR2.3.** Ensure ergonomic reachability of human machine interaction and reachability of tools, components and equipment. |
| **FR2.1.2.** Provide instructions readable for blind people. | **DP2.1.2.** Digital braille reading device. | **FR2.3.1.** Ergonomic design of the workplace. |
| **FR2.1.3.** Interact with the system in a non-visual way. | **DP2.1.3.** Natural human interaction technologies. | **FR2.3.2.** Barrier-free design of the workplace. |
| **FR2.1.4.** Provide an audio signal for condition monitoring. | **DP2.1.4.** Audible loud alarm/help system. | **FR2.4.** Overcome physical workload caused by heavy parts and/or devices. |
| **FR2.2.1.** Provide visual instruction and guidance. | **DP2.2.** Digital devices for visualization of information. | **DP2.4.** Cobots for handling of heavy parts. |
| **FR2.2.2.** Provide a visual signal for condition monitoring. | **DP2.2.2.** Visual alarm/help system. | **DP2.4.2.** Torque reaction arm for heavy devices. |
| **FR2.2.3.** Provide information regarding most important emergencies. | **DP2.2.3.** Info-field on monitor. | **FR2.2.** Overcome physical workload caused by parts. |
| **FR2.3.1.** Provide accessibility. | **DP2.3.** | **DP2.4.** Cobot for handling heavy parts. |
| **FR2.3.2.** Ensure ergonomic reachability of human machine interaction and reachability of tools, components and equipment. | **DP2.3.1.** | **DP2.4.2.** Torque reaction arm for heavy devices. |
| **FR2.4.1.** Overcome physical workload caused by parts. | **DP2.3.2.** Ergonomic design of the workplace. | **DP2.4.** Cobot for handling heavy parts. |
| **FR2.4.2.** Overcome physical workload caused by devices. | **DP2.4.1.** | **DP2.4.2.** Torque reaction arm for heavy devices. |

4. Final Design of an Assistance Workplace for Elderly People and People with Disabilities

The framework discussed shows a procedure to plan a systematic design of an assistance workplace for elderly people and people with disabilities. The final design of this workplace is illustrated in Fig. 1. It consists of three different worktable parts that can be connected via plug-in. The main worktable is equipped with a projection-based assistance system to show digital work instructions (workflow) in written form together with pictures and videos, enable automatic step recognition and to do vision checks. The industrial signal light tower can be used to let the person in charge know about the presence of the worker and as an opportunity for the operator to express the need of help by pushing the help/stop button. The monitor shows information, such as pop ups, counter, timeline and motivational content. The worktable itself is easily accessible for wheelchairs and has large legroom. For people without a wheelchair, it is equipped with an adjustable footrest and an ergonomic chair, and, in case the operator cannot sit for a long time, an ergonomic mat. Additionally, holding devices are available e.g., for crutches. The electric screwdriver is connected with a torque reaction arm. The second part of the workplace is equipped with a collaborative robot that can be gesture controlled by a device for gesture interaction (e.g., smart robot) to help the operator in the sense of a third hand. The third table consists of adjustable workplace lamps and additional concise lamps for quality control in different angles. Above is a quality control system, which can be used for end of line inspection. The
additional monitor can be used for information provision and a counting gauge for the physical counting of parts. The main worktable, as well as the other parts can be easily reached by the operator. Due to the plug-in connection of the tables, it is also possible to arrange the tables in a line, e.g., for the use of this workplace by two workers instead of one.

Figure 1. Design of a workplace equipped with different worker assistance systems for elderly people and people with disabilities.

5. Conclusion
The aim of this scientific contribution is to elaborate a design of a workplace equipped with worker assistance systems in production for elderly people and people with mental and/or physical disabilities. For this reason, the current situation had been analyzed by interviews with caregivers of elderly people and people with disabilities, elderly people and people with disabilities themselves, and companies. Based on the interviews and discussions with the different stakeholders, CNs were defined. In addition, these were transformed into a framework using AD mapping and decomposition in the form of FRs and DPs.

The input of this paper for practitioners is to split an initially complex problem, namely the design of a workplace equipped with worker assistance systems in production for elderly people and people with disabilities, into small packages, to discuss the possibilities and analyze their correlations. Based on this scientific contribution, a first step for the design of future oriented workplaces is to be laid, which gets more and more important due to the demographic change and the generally prevailing shortage of workers in manual production.

6. References
[1] Sendler U 2013 Industrie 4.0-Beherrschung der Industriellen Komplexität mit SysLM (Berlin/Heidelberg, Germany) pp 1-19
[2] Büttner S, Funk M, Sand O and Röcker C 2016 Using head-mounted displays and in-situ projection for assistice systems – a comparison (PETRA 2016) 44 pp 1-8
[3] Wolfartsberger J, Lindorfer R, Hallewell Haslwanter J D, Jungwirth M, Froschauer R and Wahlmüller D 2018 Industrial perspectives on assistive systems for manual assembly tasks (PETRA 2018) pp 289-291
[4] Habekuß F 2017 Europas demografischer Wandel DOSSIER Demografischer Wandel Available online: https://www.bpb.de/politik/innenpolitik/demografischer-wandel/196906/europas-
demografische-zukunft (accessed on 18 March 2020)

[5] Rütti N 2019 Europa sucht händeringend Fachkräfte Neue Züricher Zeitung Available online: https://www.nzz.ch/ wirtschaft/ europa-sucht-haenderingend-fachkraefte-lb.1507619 (accessed on 18 March 2020)

[6] Tomiyama T, Gu P, Jin Y, Lutters D, Kind C and Kimura F 2009 Design methodologies: industrial and educational applications (CIRP Annals) 58-22 pp 543-565

[7] Suh N P, Bell A, Gossard D, Suh N P, Bell A and Gossard D 1978 On an axiomatic approach to manufacturing and manufacturing systems (Journal of Manufacturing Science and Engineering) 100-2 pp 127-130

[8] Nam P. Suh 1990 The Principles of Design Oxford University Press

[9] Nam P. Suh 2001 Axiomatic Design: Advances and Applications Oxford University Press

[10] Brown C A 2005 Teaching axiomatic design to engineers – Theory, applications, and software, (Journal of Manufacturing Systems) 24-3 pp 186-195

Acknowledgements
This research project was funded by the Free University of Bozen-Bolzano; project title: Assist4Work: Social sustainability in production through age appropriate and disability friendly workplace design using assistance systems, grant number TN 200J.