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Cognitive Ergonomics in production Concept Development for Optimized Configuration of the collaboration between Humans and New Technologies in production

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
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Vienna, 12.05.2020

Affidavit

I, **PHILIP FENNES**, hereby declare

1. that I am the sole author of the present Master's Thesis, "COGNITIVE ERGONOMICS IN PRODUCTION CONCEPT DEVELOPMENT FOR OPTIMIZED CONFIGURATION OF THE COLLABORATION BETWEEN HUMANS AND NEW TECHNOLOGIES IN PRODUCTION", 98 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

In this age of increasing digitization, the cooperation between humans and assistance systems has bred new demands or concerns. In the area of production, tensions exist on the safety of workers and workflow efficiency. In regard to human-robot collaboration (HRK), a question arises as to the framework conditions needed to allow for direct collaboration in common, overlapping areas of work while at the same incorporating cognitive ergonometric aspects.

The goal of this thesis was to develop an assistance-system in the area of production that is based on new technologies for the purpose of enhancing human-robot-collaboration and cognitive ergonomics. The aim was to have an assistance system that would make it possible for the production line to be connected to production targets so as to generate additional value for the company while at the same time increasing or enhancing the health of employees.

The thesis design was based on secondary research using the theoretical-heuristic approach. After defining goals and requirements, suitable entry points for assembly system planning were identified. Compatibility and consistency were met by use of clear parameters and the step-by-step description of procedures. In order to assess validity, completeness, comparability and reproducibility, an application of the procedure was required, as demonstrated below.

Principles of cognitive ergonomics were taken into account was well as well as the financial and efficiency aspects; this was achieved by examining its compliance with financial frameworks, comparing its implementation advantages to those of alternatives in the market, and identifying cost drivers within the process steps and system components. For the monetary valuation and audit of the overall system, normal methods of investment accounting must be used, such as cost, comparison, or amortization accounting.

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1 Introduction

In this age of increasing digitization, the cooperation between humans and assistance systems has bred new demands or concerns. Tensions exist on the safety of workers and workflow efficiency in the area of production. In regard to human-robot collaboration (HRK), a question arises as to the framework conditions needed to allow for direct collaboration in common, overlapping areas of work while at the same incorporating cognitive ergonometric aspects.

This thesis proposes an assistance-system in the area of production that is based on new technologies for the purpose of enhancing human-robot-collaboration and cognitive ergonomics.

1.1 Research Goal

The goal of this thesis is to develop an assistance-system in the area of production that is based on new technologies for the purpose of enhancing human-robot-collaboration and cognitive ergonomics. The aim is to come up with an assistance system that would make it possible for the production line to be connected to production targets so as to generate additional value for the company while at the same time increasing or enhancing the health of employees.

1.2 Methodical Description

After a theoretical introduction, description of definitions, and State-of-the-Art analysis, what follows is a plan for the implementation of new technologies in the area production and creation of a new working area, where machines and humans are able to interact efficiently and effectively. Basically, several primary research methods can be applied to this Cognitive Ergonomics project.

These methods include surveys, usability, and user experience studies, as well as experimental methods, which are explained in more detail below.[1] Surveys are cross-industry and cross-professional questionnaires on psychosocial activity characteristics.

They are used to determine general correlations between stress factors and the extent of psychological stress both in the field and in the laboratory. Aspects such as workability, work requirements, decision-making, leadership quality, or working environment are covered. These inventories are based on theoretical concepts of a cause-and-effect relationship between the external influences of the work situation, and individual effects on the employees, considering personal resources.[2]

Usability and user experience methods form the transition between survey methods and experimental methods. Usability refers to the extent to which digital aids or assistance systems can be used by logistics staff in the context of intralogistics to achieve their work objectives effectively, efficiently, and satisfactorily.[3]

User experience methods use investigation methods to evaluate aspects such as attitudes, expectations, trust, or well-being when humans interact with digital tools or assistance systems. For instance, survey methods based on analytical component models can be used to evaluate user experiences.[4]

[1] Fraunhofer, 2017, p.6.

[2] Nübling et al., 2005, p.2.

[3] Fraunhofer, 2017, p.7.

[4] Thüring/Mahlke, 2007, p.253.

Experimental methods used in laboratory environments include experimental paradigms from cognitive psychology, which are combined with intra-logistic tasks. For the purpose of this thesis, corresponding task batteries are developed in which different aspects can be simulated in the context of digital support systems.[5]

This thesis is designed as secondary Research, basing on the theoretical-heuristic approach. Secondary Research is one that uses already existing data. Therefore, a detailed analysis of data from the existing literature is done, which is then supplemented with well-founded Internet sources.

Focus is given to literature that is relevant to the topic under investigation - cognitive ergonomics, human factor engineering, and production.[6] A promising approach in this regard was the snowball system, in which footnotes and bibliographies of the existing literature are examined and organized in order to carry out similar steps.

Frequently cited sources can subsequently serve as basic literature. In order to fill any gaps, this procedure is extended to include structured Research in databases.[7] We searched in scientific databases of universities and supplemented them with case-by-case data from internet research – such as Google Scholar or high-quality media, where it was necessary to do so.

[5] Wille et al., 2013, p.267.

[6] Atteslander, 2010, p.13ff.

[7] Ebster/Stalzer, 2017, p.47.

1.3 Definition and Characteristics

Cognitive Ergonomics Describes how well the use of machines matches the cognitive abilities of users.[8]

Ergonomics/Human-Factors-Engineering Focuses on the modification of operational procedures and work equipment, by considering physical and psychological skills, and limitations of humans.[9]

[8] Vollrath 2014.

[9] Bubb et al., 2015.

2 Workplace Design and Cognitive Ergonomics

Modern management literature focuses on reorganization, business process optimization, lean management, and results orientation. These should lead to significant changes in work processes, tasks, and working time regulations so as to improve quality, flexibility, productivity, and reduced costs of production.[10]

Optimal work designs promote the performance of employees by addressing issues such as the motivation and health of workers. Workplace design should, therefore, be done in relation to work objects (including working materials), technology (processes), mechanization (automation), technical rationalization (e.g., faster process speed) as well as the economy.[11]

A workplace design that is human-friendly not only ensures that tasks in the workplace are friendly, but it also ensures that employees have a permanent interest, commitment, and motivation when completing tasks. It also ensures that the workplace is tolerable, reasonable, it promotes personality, it is optimally balanced, and employees are protected from work-related risks to their health or physical bodies.[12]

The ergonomic guidelines are summarized in the ergonomics DIN standards. In regard to workplace design, these standards aim to optimally align work to people (and people to work) in order to create stress-free and health-friendly activities, where people can achieve their expected performance. These guidelines cover anthropometric, physiological, psychological, information technology, organizational and security sub-areas.[13]

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[10] Bubb 2007, p.496

[11] Gerstenberger-Eirich, 2011, p.39.

[12] Schlick et al., 2010, p.629.

[13] Gerstenberger-Eirich, 2011, p.40.

2.1 Anthropometric Aspects

To begin with, workplace organization should be adapted or aligned to specific human– anthropometric–body dimensions. At the same time, the physiological and psychological aspects of work design must be considered. For optimal operational communication, information technology must also be aligned with organizational aspects. Taking safety-related aspects into consideration ensures that employees are protected from workplace risks. Aesthetic aspects do not play the last role in work design.[14]

Human characteristics must also be considered in ergonomic work design and when planning for technical products. The conditions in the workplace should be designed in such a way that they allow for checks of entire body systems to be largely avoided or excluded. Therefore, all employers – including smaller companies and the public sector – are obliged to inform themselves about the latest technologies, and to set up their workplaces in such a way that they correspond to scientific knowledge of ergonomic design.[15]

Considering the fact that workers or employees in the workplace have different body dimensions, joint angles, and other functional parameters, these factors must be considered during workplace design[16]

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[14] Gerstenberger-Eirich, 2011, p.40.

[15] Gruppe et al., 2005, p.382.

[16]: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2009, p.817.

2.2 Physical Aspects

Physiological work design considers the physiological functions of human bodies under the special conditions of work. Physiological design involves the adaptation of workplace factors such as work equipment, working methods, workflows, as well as the working environment to the physiological functioning of human beings.[17]

According to the systems theory, the human body is a complex, functionally indivisible unit. From an ergonomic point of view, the following anatomical and physiological aspects[18] are particularly important:

- Skeleton and muscle,
- Metabolism,
- Sense organs, and
- Nervous system.

The skeleton and muscle can be said to be representing a mechanical system. The musculoskeletal system is a solid body framework (consisting of individual limbs) that connects different body structures and functions. The skeleton is divided by flexible joints; the musculature transfers muscular strength to the bones and causes the joints to move.[19]

The human body is also an open system that is in a constant exchange of materials and energy with its environment. The circuit supplies the metabolism of the

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[17] Schlick et al., 2010, p.970.

[18] Schmidtke/Jastrzebska-Fraczek 2013, p.23ff

[19] Gerstenberger-Eirich, 2011, p.50.

mechanical system with energy.[20]

2.3 Psychological Aspects

Psychological workplace design involves the creation of a pleasant environment for the working person in order to, for example, provide variety in a monotonous workplace or for the general improvement of employee motivation. The safety and performance of workers can be increased by ensuring that the workplace is psychologically friendly.[21]

There are a number of measures that can be employed in psychological workplace design. For example, certain color schemes can be used to boost or influence the general mood of workers, and the rapid recognition of certain correlations regarding order and safety in the company.[22]

Placing plants, hanging or putting up personal pictures, and listening to music (within reasonable limits) can have a positive effect on employee moods and job satisfaction. It is important that the worker is involved as far as possible in the design of his work environment and that he is given enough freedom for his own initiative.[23]

Many employees agree that a healthy work environment is one that enables them to develop their individual skills, work on tasks responsibly, and where errors are dealt with effectively. This is a workplace in which all aspects of work are sensually and creatively created; work should be fun and meaningful.[24]

[20] Gerstenberger-Eirich, 2011, p.50.

[21] Gerstenberger-Eirich, 2011, p.65ff.

[22] Gerstenberger-Eirich, 2011, p.65ff.

[23] Gerstenberger-Eirich, 2011, p.65ff.

[24] Gerstenberger-Eirich, 2011, p.65ff.

Psychological work design also takes into consideration the social aspects of employees. For example, supervisors prefer to be primarily perceived and respected "like people," and not just as being part of the workforce; 84% of employees surveyed considered this social aspect of managerial behavior to be an important component of a healthy work environment.[25]

Additionally, 76% considered the promotion of mutual inter-departmental cooperation to be a very supportive and important aspect of a healthy workplace. The importance of mutual cooperation was also evident in the unwillingness of employees to behave in a competitive manner; about 60% of employees surveyed did not rate competition among colleagues as being an important aspect of a positive work environment.[26]

These aspects - which were listed by about two-thirds of the employees surveyed as being important aspects of a positive and healthy work environment - did not describe any formal business development paths (in regard to career prospects, or formal qualification opportunities). Developmental aspects mentioned started with tasks and the design of workplace tasks with the aim of developing one's own skills in daily work processes.[27]

Furthermore, surveyed employees attached surprisingly high importance to the quality of managerial skills possessed by their immediate supervisors; good supervisors ensure good work-planning, they support the professional and personal development of their subordinates, and they also enhance the efficiency of work processes.[28]

[25] Gerstenberger-Eirich, 2011, p.65ff.

[26] Gerstenberger-Eirich, 2011, p.65ff.

[27] Bieneck, 2002, p 87.

[28] Bieneck, 2002, p.87.

These are supervisors who understand the individual problems of employees; they recognize the efforts of workers by either praising or offering constructive criticism. About two-thirds of employees surveyed consider these leadership qualities to be essential in the workplace.[29]

Psychological stress is a common part of human existence. The negative effects of psychological stress are manifested through negatives, physical, psychological, or behavioral changes. Certain factors determine whether psychological stress is an issue in the workplace, degree, duration, and the ability of individual employees to deal with stress.[30]

Numerous studies indicate that there is a sharp increase in psychological stress in the workplace. The studies suggest that many workers Complain of severe fatigue due to hectic work schedules and unmanageable workloads. Mental illnesses, such as depression or anxiety disorders, are now the fourth most common reason for sick leave.[31]

For stress in the workplace to be minimized, tasks must be given and carried out systematically and consistently. Doing this will also lead to an increase in employee work performance, job satisfaction, and a reduction in the number of days that employees are absent from work. The concepts proposed here can be adapted by existing operating conditions. Criteria such as feedback (from superiors and colleagues), user orientation, time elasticity, and meaningfulness of service (for useful services or products) can be added to other concepts.[32]

[29] Bieneck, 2002, p.87.

[30] Bieneck, 2002, p.87.

[31] Bieneck, 2002, p.87.

[32] Badura, 2009, p.17.

2.4 Cognitive Ergonomics

Cognitive ergonomics is a sub-discipline of ergonomics that deals primarily with the performance and resilience of human information processing processes (such as perception, attention, memory, decision-making, motor preparation, and execution) during interaction or cooperation with technical systems.[33]

The theoretical foundations of cognitive ergonomics are based on the findings of cognitive psychology and work psychology. Cognitive ergonomics generally helps us to understand the interactions between human information processing processes and the technical system. Its aim is to ensure human integrity and to optimize the overall performance of human-technology systems.[34]

Optimization, in this context, implies efforts to avoid impairing effects and promote facilitating effects. Optimal performance improves the effectiveness and efficiency of interactions between humans and technological systems. In designing work systems, therefore, humans are taken to be the main factors and the integral parts of the technological systems to be designed.[35]

[33] Fraunhofer, 2017, p.5.

[34] Salvendy 2012.

[35] Fraunhofer, 2017, p.6.

3 Digitalization and Industry 4.0

The first industrial revolution was triggered by the discovery of mechanization. The use of steam power, or hydropower, sets the foundation for the mechanization or automation of human labor. The second industrial revolution was fueled by the division of labor in Cincinnati slaughterhouses in 1870. Other drivers of this industrial revolution were the use of electrical energy for mass production, which was only made possible by the invention of internal combustion engines.[36]

The third industrial revolution began in 1969 with the development of the first digital and freely programmable control system; this is also the basis of the entire automation pyramid today. During the fourth industrial revolution, the so-called cyber-physical systems (CPS) were invented.[37]

The word digitization describes much more than the mere processing or distribution of data and information using communication technologies. It is a complex system that has changed our whole life at all levels and influences entire business models. Digitization, in its original sense, meant the transformation from analog to digital information systems - the digital representation of information and the implementation of digital communication.[38]

In the context of Industry 4.0, digitalization refers to the digital modification of instruments, devices, and vehicles and the increased use of digital technologies in private and business life. The terms "information age" and "computerization" are also prerequisite digitization concepts for Industry 4.0.[39]

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[36] Bauernhansl, 2014, p.5f.

[37] Drath, 2016, p.18ff.

[38] Lehmann, 2014, p.4.

[39] Lehmann, 2014, p.4.

Digitalization is basically characterized by three central factors. The primary factor is the specificity of converting physical data and information into binary characters and evaluating them. Binary characters mentioned are commonly referred to as bits and are the smallest units of information in regard to data storage. The coding of the binary characters forms the basis for further processing of the digital data and for transmission to other media.[40]

Rapid technological development is the second factor in digitization. This is described in Moore's law as the process through which processor performance is always duplicated in one or two years with falling costs. This law is generally referred to as Moore's law, and it symbolizes progress in computer technology.[41]

The third dimension of digitization focuses on the growth performance of digital storage media. Storage of digital information is essential if data is to be easily retrieved and evaluated at any time. All these three digitization dimensions are linked by information and communication technologies.[42]

In other words, information and communication technologies are the elementary factors of digitization. Therefore, knowledge of digital infrastructures that use these technologies is essential for the reduction of the number of interfaces. As such, attempts to increase competitive advantage should focus more on effective and efficient value creation processes.[43]

[40] Lehmann, 2014, p.4.

[41] Lehmann, 2014, p.4.

[42] Siepmann, 2016, p.22.

[43] Siepmann, 2016, p.22.

3.1 Basics of Digitalization

The so-called cyber-physical systems (CPS) form the basis of digital infrastructure. These are characterized by a combination of real, physical objects and processes that integrate information processing, virtual objects, and processes via open, global, and always interconnected information networks.[44]

Cyber-physical systems can be said to be the technological basis for the introduction of Industry 4.0. CBS can basically be divided into the Internet of Things, Ubiquitous Computing, and Cloud Computing.[45]

3.1.1 Internet of Things

Internet of Things (IoT) is a technological concept that is based on Mark Weiser's' idea of Ubiquitous Computing (UC). Ubiquitous Computing is an environment that is networked through embedded and unobtrusive information and communication technologies. UC differs from IoT in the sense that it networks people using objects that can be controlled by audio and video output devices.[46]

In this way, physical objects become "smart," i.e., capable of processing and providing information. Objects are considered to be smart "smart" when they are embedded into processors, data storage, sensors, and network technologies. Some objects are also equipped with actuators that receive signals and then convert them into influence processes.[47]

[44] Siepmann, 2016, p.22.

[45] Siepmann, 2016, p.22.

[46] Laudon et al., 2016, p.236f.

[47] Laudon et al., 2016, pp. 236ff.

Embedding sensors or actuator application technologies to machines simply means the application of machine-to-machine communication (M2M), which is considered the core technology of IoT that forms the interface between the physical and virtual world.[48]

The networking of intelligent objects or machines can be used, for example, to collect new data on inventories, machines, and systems in order to control them cost-effectively.[49]

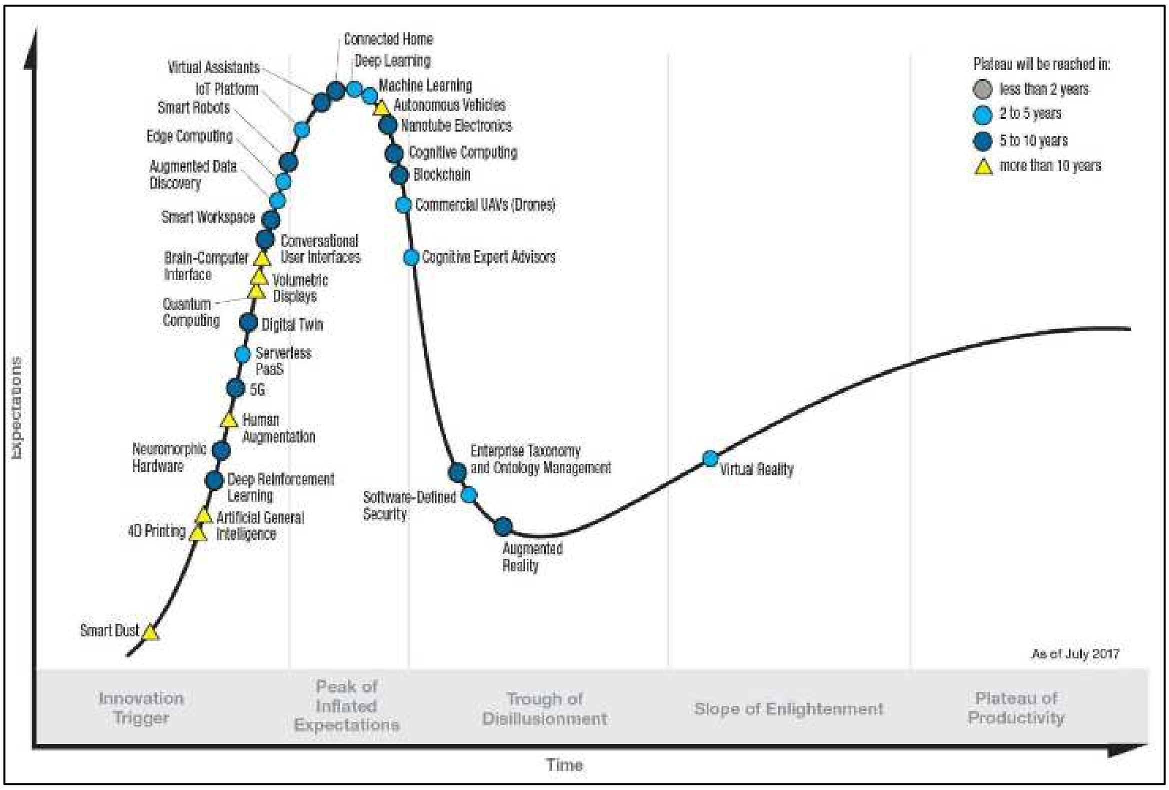

Figure 1: Gartner Hype Cycle (Panetta 2017).

48 Bechtold et al., 2014, p. 21.

49 Ermatinger, 2018, p. 5.

In order to classify the current status of the development of IoT technology, it is worthwhile to use the graphic shown in Figure 1. The Gartner Hype Cycle captures the general life cycle of technology. Thus, a (new) technology goes through different phases from technological triggering, to the peak of the hype, including excessive expectations to the productivity level, which signifies mature development.[50]

3.1.2 Cloud Computing

Cloud computing is another basic of digitalization. The term "cloud" first appeared in the United States in the early 1990s. Large telecommunications providers expanded their offerings by introducing an overall service for networks instead of individual service offers for routers, hubs, or switches.[51]

This service package minimized the complexity of the end-user. Google first used the term "cloud computing" at a Search Engine Strategies Conference and described it as a kind of cloud in which services and architecture can be accessed via the Internet. Cloud computing is based on six different basic technologies, which include broadband Internet, high-performance servers, virtualization, Internet browsers, interactive Web 2.0., and mobile devices. Broadband internet ensures that the services can be provided at all times. Cloud computing services can be offered via single or multiple central servers.[52]

[50] Panetta 2017.

[51] Reitz, 2017, p.248.

[52] Reitz, 2017, p.249f.

High-performance servers form the main infrastructure upon which the central applications run. Users can access them in real-time via the Internet, and computer capacities that are not used can be rented in parallel. Virtualization makes it possible for several users to access the hardware at the same time and to run different applications.[53]

Internet browsers provide the means through which users access the cloud services at all times without having to install any local software. Web 2.0 is responsible for display in internet browsers; it is a technology that facilitates interactive work. Mobile devices complete the list of technologies for cloud computing. Although they are secondary, mobile devices offer the option of accessing cloud services from anywhere.[54]

Cloud computing is a core technology for Industry 4.0, as it is often used for mobile value-added services, such as platform or infrastructure solutions. It guarantees limitless data flow and location-independent access to huge amounts of data, which is particularly important within Industry 4.0. If services are sourced externally, their capacity can easily be increased, and the financial risk of investment in the infrastructure is thus eliminated.[55]

In computer engineering, cloud computing is considered a central building block for data exchange between machines. Both process-related and external data, such as energy prices in real-time, can come together in the cloud for later evaluation.[56]

[53] Reitz, 2017, p.249f.

[54] Reitz, 2017, p 249f.

[55] Bechtold et al., 2014, p.20.

[56] Heckel 2015.

The Gartner Hype Cycle indicates that cloud computing technology was last mentioned in 2014.[57] In the past few years, however, technology has developed steadily and is now widely accepted. But despite the benefits offered by cloud computing, the use of the technology has also been associated with certain data protection, data security, and data misuse risks; these risks are classified as high risk, particularly within data-intensive Industry 4.0.[58]

Driven by affordable hardware and innovative processes, many businesses and companies in industries such as science and medicine have produced an enormous amount of data over the past two decades. This trend was further strengthened with the increasing number of social media users through Web 2.0. The analysis of huge amounts of data to optimize customer experiences ultimately led to the emergence of Big Data Analytics.[59]

3.1.3 Big Data Analytics

As the name suggests, big data forms the basis for analysis. Big Data is characterized by volume, velocity, variety, veracity, and value - the 5Vs. Volume refers to the amount of data that is generated every second. With cloud computing, it is now possible for everyone to save and access these huge amounts of data.[60]

Velocity is another characteristic used to describe the dynamics of big data, and it refers to the extensive volumes of data generated in the shortest possible time. Variety describes the many different data types that come together in big data analytics: unstructured, semi-structured, and structured data from various sources.

[57] Reitz, 2017, p.262f.

[58] Reitz, 2017, p.262f.

[59] Ravi/Kamaruddin, 2017, p.16.

[60] Ravi/Kamaruddin, 2017, p.16.

The fourth V – veracity - is used to describe the truthfulness, credibility, quality of big data. The last characteristic values, which describe the enterprise value of data, or the knowledge that can be gathered from it.[61]

Central data repositories form the basis for big data analyzes. To integrate this database type into a company, innovative technologies such as MySQL can be used. If data is available in the repository, it can be evaluated in detail or analyzed for recurring patterns. This allows companies to gain completely new insights and relationships from their operational activities.[62]

3.2 Integration of Digitization

The integration and networking of the vertical and horizontal value chains – whose foundation is digitization - is among the central elements of Industry 4.0. A study of German companies revealed the importance of such digitization; most companies studied indicated that they would readily digitize their integration of horizontal and vertical value chains.[63]

In the following sections, the terms vertical value chain, horizontal value chain, as well as their integration, are explained and illustrated. A summary of these two integrations – based on the explanation of Smart Factory – is also provided. The chapter concludes with a comparison of advantages and disadvantages.[64]

[61] Ravi/Kamaruddin, 2017, p.16.

[62] Ecker 2016.

[63] PwC 2016a, p.4.

[64] PwC 2016a, p.4.

3.2.1 Vertical Value Chain

The goal of vertical value chain digitization is to facilitate the effective flow of information or data between company functions and to ensure that such information is effectively acted upon in business processes. It is important that all internal systems in a company are effectively networked without any interface problems.[65] Optimally designed vertical value chain integration is one that uses uniform interfaces and standards. Such a design would ensure real-time information and communication exchange between the CPS and IT systems from the control and planning level of the company.[66]

Due to increasing dynamics that result in intensive networking and high data volumes, new process architectures are required, especially with regard to transmission speed. Industry 4.0 will, therefore, lead to a gradual dissolution of rigid automation systems to facilitate more flexible communication structures.[67]

3.2.2 Horizontal Value Chain

The aim of horizontal value chain digitization is to connect all internal and external value-added partners, from the suppliers to the customers. Digital networking in this kind of digitization aims at integrating all the actors involved in the entire value chain with the purpose of facilitating a holistic exchange of data and information internally and company boundaries. Horizontal integration creates a continuous and dynamic value-creation network that offers the opportunity to synchronize internal and external data of all network actors in real-time.[68]

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[65] Siepmann in: Roth 2016, S.29ff.

[66] Siepmann in: Roth 2016, S.29ff.

[67] Huber, 2016, p.39.

[68] Huber, 2016, p. 77.

In contrast, internal company integration does not offer the possibility of introducing cross-company integration software, such as cloud-based cross-manufacturer integration platforms, and the flexible development of value-added networks.[69]

Smart Factory is seen as a vision of Industry 4.0. Networking and vertical and horizontal integration, among other things, are essential for the nationwide realization of the Smart Factory. Smart Factory is fundamentally about achieving real-time, intelligent, and complete networking of people, machines, and objects. This facilitates communication between production machines and systems, it automates work processes, and it also ensures that systems are able to organize and optimize themselves.[70]

Besides full integration and networking, various technologies and other types of information are also required. For example, a sensor for all elements in the value chain is needed to facilitate the immediate recording, processing, and forwarding of data from immediate surroundings.[71]

Vertical and horizontal value chain networking and integration have a number of advantages. For instance, it promotes cooperation within the entire value chain network, it ensures a continuous flow of information, and it also provides a variety of options for evaluating available data. But despite these benefits, there are also downsides for integrating or networking value chains.[72]

[69] Siepmann in: Roth 2016, p. 38.

[70] Lichtblau et al., 2015, p. 35ff.

[71] Zillmann, 2016, p. 9ff.

[72] Zillmann, 2016, p.9ff.

For example, complex systems can be susceptible to errors, or they may inhibit the effective exchange of data and information within the network. Market transparency – which is sometimes associated with value chain networking and integration – can also lead to increased competition.[73]

Big Data Analytics is an important technological aspect for Industry 4.0. Due to the increasing number of Smart Products and CPS in production, it is expected that the amount of data will also increase significantly. This data can be evaluated or analyzed to identify and eliminate any inefficient processes, and to forecast future events.[74]

Big data analytics applications such as predictive analytics and in-memory analytics were last mentioned in the Gartner Hype Cycle in 2013 and 2014, respectively. These technologies were already well beyond the hype at the time, meaning that they are now well advanced.[75]

3.3 Applications of Assistance-Systems

The following section presents current trends related to Industry 4.0 and their areas of application. The trends listed here have their origins in space travel, in the private sector or in the military and are increasingly being used in businesses and industry to measure improvement potential and to generate competitive advantage.

[73] Zillmann, 2016, p.9ff.

[74] Bechtold et al., 2014, p.20f.

[75] Bechtold et al., 2014, p.20f.

Artificial intelligence, robotics, wearables, and drones were selected from the multitude of currently existing Industry 4.0 trends. The criteria for their selection were their advanced technological market uses, their wide-range use, and their great potential benefits. Explained below are these technologies – together with their trends, usage applications, and usage advantages and disadvantages.

3.3.1 Robotics

Robotics is one of the most important applications in Industry 4.0. The Robot Institute of America defines a robot as a programmable, multi-purpose handling device for moving material, work-pieces, tools, or other special devices.[76] Robotics is an interdisciplinary science that deals with the construction of robots, and it is closely related to computer science, electrical engineering, mechanical engineering, mathematics, and artificial intelligence. Because the motion of robots can be programmed, they are suitable for a wide variety of tasks.

The construction of the first industrial robot - the so-called Unimate - started in the late 1950s. It was completed in 1961 and used by General Motors in their production line, where it was used for automatic welding of die-cast parts and vehicle bodies.[77]

The aim of developing robots was to relieve workers of monotonous and dangerous tasks. Modern robotics technology was developed in the early 1970s. At the time, however, the robots were still unintelligent. Rapid technological advancements in recent decades – in computer software and sensors – have made it possible for robots to implement tasks using artificial intelligence (AI) methods.[78]

[76] University of Ulm 2007, p.2.

[77] Unger 2017.

[78] Kopacek, 2013, p.41.

Robotics is already being used in private service and industrial sectors[79] The humanoid robot, for example, is used in both the consumer and service sectors. Numerous sensors enable robots to imitate human senses and to understand human gestures and facial expressions. These robots are used to perform a number of tasks. Depending on their intended use, they can be individually configured using software and, if necessary, adjusted subsequently.[80]

They can, for example, be programmed to act as entertainment systems (such as the music systems in PCs or smartphones). Additionally, robots can be programmed to offer support to retailers, such as the ones used to offer purchasing or product advice.[81]

Robots can also be programmed to act as customs officials. These customs robots have flawless facial recognition, have no movement restrictions, and they can answer questions, and communicate with people. In the future, customs robots may have the task of photographing people, identifying smugglers, and notifying customs officers of any dangerous situations.[82]

In the industrial sector, robots collaborate with humans by, for example, using an integrated camera and a suction cup to pick up components from load carriers and passing them employees or workers. In productions, robots can be used to reduce the chances of errors occurring by, say, using them to select the correct component, such as the number of variants increases. By automating routine activities, robots afford employees certain ergonomic advantages.[83]

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[79] University of Ulm 2007, p.2.

[80] SoftBank Robotics, 2016.

[81] SoftBank Robotics, 2016.

[82] Hanser 2016.

[83] Heimann 2015.

Additionally, intelligent safety sensors enable new generation industrial robots to no longer work separately, but with people.[84]

There are a number of advantages that businesses enjoy using service robots. For example, they have the benefit of constant and unrestricted attention than their human users, they can be programmed in different languages (multilingual benefits), and they can lead to a reduction of personnel costs. But despite these benefits, programming robots to perform complex tasks can be very difficult, and the cost of acquiring robots can also be very high.[85]

3.3.2 Virtual Reality

The term virtual reality (VR) was coined in the late 1980s, and it literally means "imagined" or "possible reality." VR describes a computer-generated replica of a real environment; this replica environment is what is described as a virtual environment.[86] From the time the term was coined, a number of VR applications have been developed which are widely being used; technical components that favor VR systems have also been developed over the decades.[87]

Closely related to the concept of virtual reality is augmented reality, a technology that is used to superimpose a computer-generated image on to a user's real-world, thus creating a composite view. Because of their diverse fields of application and different interpretations of the two concepts or terms, boundaries between the two individual subject areas are blurred.[88]

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[84] Heimann 2015.

[85] Hanser 2016.

[86] Voß, 2008, p.4.

[87] Voß, 2008, p.4.

[88] Voß, 2008, p.4f.

In order to be able to virtually reproduce a real environment, the VR system must fulfill certain basic requirements[89]:

- A correct spatial representation of the virtual environment, including the distances and proportions of the virtual objects to each other.
- The Possibility of interacting with the entire virtual environment or individual objects.
- Stereoscopic representation of the virtual environment.
- Visualize the interaction and the processes in the virtual environment in real-time.
- Provide haptic feedback.

The reasons for using VR systems across industries are, in most cases, almost the same. By visualizing future worlds or objects, their evaluation is made possible. This means that VR systems make it possible to assess certain environments before they even occur. This can lead to the improvement of the quality of results by minimizing the need for complex changes at a later time.[90]

VR systems are very beneficial in fields such as architecture, automobile construction, or factory planning, where changes to real objects can be very expensive or not feasible. VR systems can also be used to identify cost-saving options in development processes by using them to create prototypes or development models.[91]

By assessing components in a virtual environment, the possibility of increasing their quality is also enhanced; making improvements to components assessed in the real environment can be costly.

[89] Hofmann 2002, p.5ff.

[90] Voß, 2008, p.5.

[91] Voß, 2008, p.5.

There are two possible uses for VR systems. They can be used for assessing visual or aesthetic protections, in which an object in a virtual environment is assessed, such as an architectural or art design. They can also be used to visualize technical relationships and components, such as proportions or areas. Aesthetic protection requires high image quality.[92]

In some areas, they are used for aesthetic hedging purposes where mono-displays are used to avoid the disruptive effects of artificially generated stereo impression. When used in this way, these systems cease to be considered as VR systems and will, therefore, not be discussed in detail here. Besides being used for aesthetic protection, VR systems may also be used for functional protection, where virtual environment issues are assessed interactively.[93]

This includes, for example, simulation installation and the testing of ergonomic factors such as accessibility. Appropriate Interaction tools such as data gloves may, however, be needed for functional protection. The quality of results will depend on the accuracy of visualized data (in terms of dimensions and positioning)[94]

In addition to their industrial applications, VR systems are also increasingly used in the Research. In this thesis, for instance, the contributions of virtual environments on human perceptions will be examined. The focus will be on Research, primarily on validation and further development of VR systems. Additionally, virtual test environments offer an infinite number of variants which allow for experiments to be carried out more easily and quickly.[95]

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[92] Stäbler, 2007, p.3ff.

[93] Voß, 2008, p.8ff.

[94] Riecke et a. 2001, p.16ff.

[95] Ernst, 2001, p.13ff.

Because virtual environments allow for different situations to be simulated in ways that would not be possible in reality, virtual test environments are increasingly being used in psychological research cybernetics.

3.3.3 Artificial Intelligence (AI)

The first experiments with artificial intelligence took place in the mid-1950s when attempts were made to formulate general problem-solving methods for computers. Even though initial experiments with AI were generally disappointing, the need to incorporate AI into databases grew with time.[96]

In the mid-1970s, the first knowledge-based expert systems were developed; the systems drew specialist knowledge from fields such as medicine or engineering. The expert systems had the capability to draw automatic conclusions to support decision making or to diagnose situations.[97]

The advancing technological development of industrial robots and artificial intelligence has also given rise to other technologies considered to be important for Industry 4.0. These technologies include machine learning, neural networks, deep learning, and natural language processing. Machine learning is a mathematical technique that enables machines to generate independent knowledge from experience.[98]

Information processing systems, such as neural networks, go a step higher. Their structure and functionality – which are modeled from the human brain - consist of many simple and parallel units that simulate human cognitive abilities (Figure 2).[99]

[96] Mainzer, 2016, p.11f.

[97] Mainzer, 2016, p.11f.

[98] Petereit 2016.

[99] Kruse et al., 2015, p.7.

On the other hand, deep learning is considered to be a sub-area of machine learning. With the help of neural networks, deep learning machines can recognize structures, evaluate them, and in the process, improve themselves. Natural language processing aims at improving communication between humans and machines through natural language acquisition rules and algorithms; these rules and algorithms make it possible for humans to control machines through voice.[100]

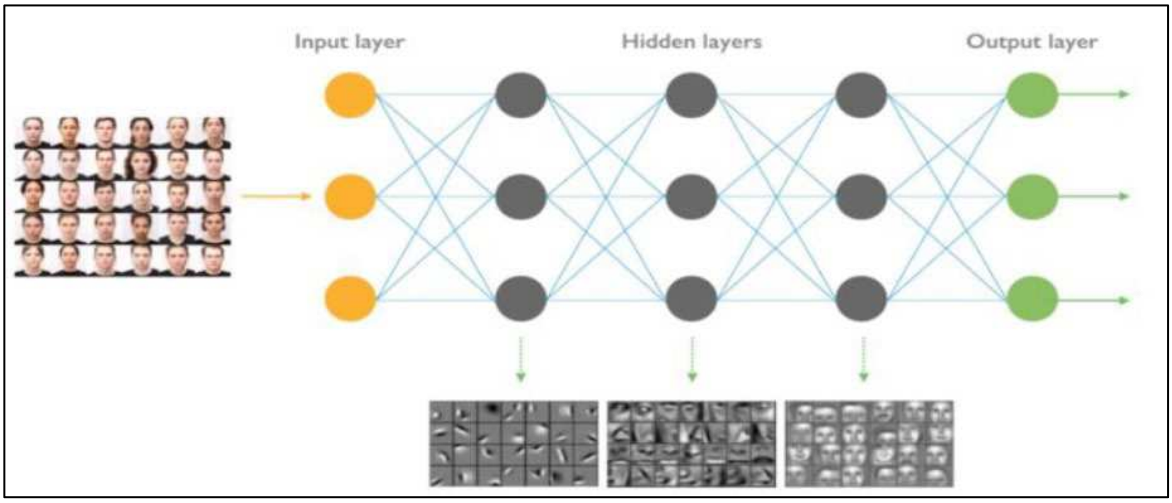

Figure 2: Example of an artificial neural network (Kelnar, 2016).

Artificial intelligence already plays an important role in Industry 4.0, especially in the field of mechanical engineering. One possible application scenario of AI is "predictive maintenance," where AI technologies are used to recognize when a machine is at risk of failure, thus paving the way rapid intervention.[101]

Predictive maintenance is already a broad and well-known application concept. And even though industrial robots have been around for decades and are being used by many production plants, integrating or incorporating them with these AI technologies might be worthwhile.[102]

[100] Litzel 2016.

[101] Klenk/Litzel, 2017.

[102] Panetta, 2017.

Besides being applied in robotics, AI is also integrated into autonomous systems to digital assistants and is also used for complex decision making.[103] AI has also entered our living rooms through digital assistance and speakers. For instance, speakers can now be connected to the Internet, and they can respond to user voice commands via in-built microphones. Through AI, technological systems can now make jokes, answer the question, make purchases, etc.[104]

With voice commands, we can now regulate heating temperatures, we can call the taxi, and we can tell the television or the lights when to be on and when to go off.[105] With AI, devices can – immediately after they are activated – record given voice commands and transmit them to decentralized servers where they are analyzed and answers or responses calculated.[106]

AI technology is also used in vehicles to drive and operate cars, where machine learning processes can, for example, be used to control the car through complex and new traffic situations. AI is used to predict the behavior of road users and to respond to complex traffic situations.[107]

AI vehicle computers gather information during the entire journey and store it in its artificial neural networks. The stored information, knowledge, or data is then validated by experts and transmitted or transferred to other cars or vehicles through updates.[108]

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[103] Heuzeroth 2017.

[104] Hörner, 2019, p.15ff.

[105] Hörner, 2019, p.15ff.

[106] Schäfer 2020.

[107] Schäfer 2020.

[108] Hörner, 2019, p.15ff.

But despite the many benefits that AI offers, there are also data protection issues associated with it. For example, there are concerns surrounding the security of collected audio data because users may not know what happens to the data when it stored.[109]

Additionally, users of AI devices may have knowledge of the country or countries where collected data is stored, they may not know how the collected data is used, and they may not have knowledge of the data protection laws that applies to the collected data.[110] Data protection is also the greatest concerns with autonomous vehicles. The protection of sensitive consumer data is very important, especially from possible hacker attacks.[111]

3.3.4 Wearables

Generally, wearables are technical aids used to solve mathematical or chronological problems. The first pocket calculator and the first wristwatch were wearables. Wearables in the “modern era” are intelligent miniature systems that are integrated into everyday objects and are worn on the body.[112]

Examples in the private sector include intelligent bracelets, intelligent watches, or intelligent clothing such as running shoes with chips to monitor runners during training.[113]

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[109] Hörner, 2019, p.15ff.

[110] Hörner, 2019, p.15ff.

[111] Schäfer 2020.

[112] IT Zoom 2015.

[113] Kusch et al., 2017, p.18.

All these items collect data that the owner can view via an app or a website. Some wearables – such as the smartwatch – dispel the need for people to own smartphones.[114] Another good example of a wearable is the intelligent armband which can monitor one's health status or performance during training.[115]

Wearables are increasingly being tested and used in many industries. Some companies, for example, use smartwatches to inform employers at the assembly line when a vehicle with special requirements approaches. The use of AI, therefore, minimizes the chances of risks occurring and makes it possible to avoid complaints.[116]

The use of audio with wearables is also being tested as a way of making work easier, such as barcode scanners which employees can wear on their wrists. This makes work processes more ergonomic because the employee has both their hands free to work with. Intralogistics processes also get accelerated.[117]

Another good example of wearables is the use of augmented reality glasses during engine assembly. The glasses make it possible for employees to receive important information for every assembly step, leading to reduced error rates, and shorter training periods because they need to master all engine types get eliminated.[118]

[114] Kusch et al., 2017, p.18.

[115] Kusch et al., 2017, p.18.

[116] Kusch et al., 2017, p.18.

[117] Kusch et al., 2017, p.18.

[118] PwC 2016b, p. 15.

3.3.5 Drones

Drones can be described as unmanned aerial objects (derived from the term UAV – Unmanned Arial Vehicle). They range from autonomously flying drones to drones that can be controlled remotely by humans.[119]

The use of drones varies from sector to sector or from industry to industry. In the private sector, drones may be used for aerial photography to generate new perspectives about our surroundings. Inventory drones are also used in some manufacturing industries by connecting them to automated push-up trucks to guarantee constant energy supply. Inventory drones can take photos of each pallet slot, verify barcodes on stored goods and send information to an ERP system.[120]

The recorded data (such as shelf positioning, corresponding barcodes and photo) is documented and can be called upon at any time using application software. With the help of the new and autonomous drones, inventory can be carried out flexibly regardless of the working time or the battery capacity, thus saving time and money.[121]

Drones are also used by some companies in the agricultural industry. The companies may use the drones to help farmers to determine the best harvest time, determine the exact wild boar nests for hunting, or to explore hail-induced crop failures. Drones are programmed so that they can identify these risks using thermal

[119] Drohnen, Multicopter, Quadcopter, 2014.

[120] Linde Material Handling 2017.

[121] Linde Material Handling 2017.

imaging cameras. This also makes it possible for farmers to increase the yield of their harvests by making agriculture safer and more efficient.[122]

The disadvantages of using drones lie in stipulated regulations and in their limited battery capacity. There are certain legal regulations that must be observed when using drones. For example, flights over crowds of people as well as residential areas are prohibited for security and privacy reasons.[123]

Additionally, occupational safety must also be observed when using drones in a company. The capacity of batteries used in drones is also limited, although this varies depending on the model.[124]

3.3.6 Software and Platform Solutions

These are significant digitization applications within industry 4.0. In recent years, software and platform solutions have led to significant restructuring in many companies. These two technologies have also had far-reaching impacts on mechanical engineering companies, forcing them to rethink and upgrade their tools, systems machines, etc. through incorporation of communication systems and sensors, so as to be able to collect and exchange information or data in meaningful ways.[125]

While system softwares have been used for a long time now, the development of new software systems that can optimize the life cycle of products is still considered to be a challenge. Many industries are implementing extensive digitization in product

[122] Multirotor 2017.

[123] Westphal 2017.

[124] Linde Material Handling 2017.

[125] Russwurm, 2013, p.24f.

manufacturing - which is noticeable in all processes – in an attempt to gain a competitive advantage.[126]

Digital platforms and the associated economic platform are trends that will play a key role in mechanical engineering in the future. These platforms form a kind of connection between the virtual and real manufacturing world.[127]

They are structured schematically in 3 different layers: data input, data aggregation and data utilization. The data input should be as heterogeneous as possible in regard to data formats and sources. For example, they should be structured in such a way that they can link data from the internet to data in machines, and vice versa.[128]

The aggregation layer should make it possible for data to be aggregated at a physical location or at a decentralized location. The third layer should make it possible for data to be accessed and utilized in control, marketing or services. Platforms are also widely used in many areas of the economy because of their many benefits or advantages. Platforms offer a lot of transactional benefits by creating spaces where traders and buyers can interact. As more users continue to participate or use in platforms, their participation creates a network effect.[129]

Another benefit of using platform solutions is that they make it possible for traders to offer products desired by individual customers. In other words, platforms make it possible to tailor products and services to the individual needs of customers.[130]

[126] Russwurm, 2013, p.24f.

[127] Russwurm, 2013, p.32.

[128] Baums et al., 2015, p.16.

[129] Baums et al., 2015, p.17.

[130] Baums et al., 2015, p17.

3.3.7 Blockchain Technology

The blockchain technology was developed in 2017. The technology is seldom associated with Industry 4.0 and was, therefore, hardly mentioned in researched literature. Blockchain technology is a new trend in technology that elaborates why technological trends must be followed, and their possible uses identified early.[131]

In order to shed more light on the relevance of this trend, however, a precise definition is required first.[132] Blockchain technology is a technology used particularly within the financial industry for processing transactions because of its ability to simplify payment and accounting processes. This application may seem irrelevant to a mechanical engineering company, but there is much more to the technological concept. The currencies transferred using blockchain are described as cryptocurrencies.[133]

Cryptocurrencies are digital currency that is cryptographically encrypted. Cryptocurrencies may not be issued by any central authority by they are extremely difficult to forge. Bitcoin is one of the best-known cryptocurrencies and, like all currencies.[134]

There are currently about 1, 6002 cryptocurrencies in the market today. One of these currencies is called IOTA and can be particularly interesting for mechanical engineering companies. IOTA is a machines cryptocurrency that is based on the

[131] Burgwinkel, 2016, p. 3ff.

[132] Burgwinkel, 2016, p.3ff.

[133] Schiller 2017.

[134] Bergmann 2016.

concept of IoT. With the aid of blockchain technology and the IOTA cryptocurrency, autonomous payments between the machines, i.e. an M2M payment, can be possible.[135]

Smart contracts software is software that can be used by mechanical engineering companies. One of the benefits of using this software is that it makes it possible to process transactions automatically. However, transactions done through the smart contracts software are subject to all parties meeting or satisfying previously set conditions. With this application, the distribution of chains can be shortened and more transparent.[136]

It is important to mention that blockchain technology is not considered or mention beyond this chapter in this thesis. The examples provided above are only meant to demonstrate that the exploration of certain technologies within industry 4.0 remain neglected. It should also be noted that the integration of only one of the technologies mentioned above does not constitute an Industry 4.0 – capable company. Interaction of several technologies in the company is needed as well as a coordinated approach on a strategic level. This will be dealt with in the following sections.

[135] Asma et al., 2017.

[136] Asma et al., 2017.

4 Production

4.1 Traditional Approaches towards Production

In the past, both human and technology-centred approaches were used in designing production systems because the product-focused work design resulted in dissatisfaction of workers, the state researched and developed a program for "Humanization of Working Life" in 1974.[137]

The central aspects of the program were the protection of the health of workers through the sustainable reduction of burdens, the human-friendly application of new technologies as well as the implementation of scientific knowledge and operational experience for the humane design of working conditions. Concrete design approaches were used to develop the system. The marked the introduction of flexible and self-determined working hours, work enrichment, hierarchization, and semi-autonomous group work.[138]

The core idea behind semi-autonomous group work was the need to assign variable degrees of responsibility to individuals in order to facilitate a comprehensive completion of tasks. This way, employees or individual group members would have a greater sense of responsibility and increased job satisfaction.[139]

In addition, such autonomy would ensure that jobs and working conditions are friendly and in line with economic goals so as to guarantee a consistent increase of productivity, such as the automation employed in the automobile industry.[140]

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[137] Deuse et al., 2014.

[138] Deuse et al. 2009

[139] Cohen/Bailey 1997.

[140] Ulrich 2011.

The concept of Computer Integrated Manufacturing (CIM) - also known as the computer-integrated product development process - received a lot of attention in Germany in the 1980s. The main objectives of the CIM approach were to facilitate quality control and a holistic completion of tasks by complete networking and integrating product development processes.[141]

The use of information technology resulted in a systematic integration and joint application of the various software solutions for production planning and control. The decisive advantages of the CIM concept were the increase in production flexibility with a simultaneous reduction in output times, as well as the merging of all company areas by bundling information on to a common database.[142]

However, a closer look at past developments in Germany reveals that pursued goals could only be achieved to a limited extent. A key disadvantage that was often cited by critics was that technology led to the loss of jobs.[143]

The successful implementation of the production systems designs was further worsened by the failure to consider people, both in their capacities as consumers and as employees.[144] In contrast to the design paradigms presented so far, the organisation-centred approach of lean management focuses on the design of a lean, waste-free and customer-oriented organization. The aim of lean management is to avoid any form of waste, unplanned variability and overloading of employees and resources.[145]

[141] Scheer 1994.

[142] Deuse et al., 2014.

[143] Jentsch et al., 2013.

[144] Deuse et al., 2014.

[145] Ohno 2009

Lean management also focuses on the production of the best possible quality in order to achieve maximum customer benefits along efficiently designed value chains. In recent years, the implementation of the principles of lean management in manufacturing, mechanical and plant engineering companies in Germany has led to an increase in customer benefits and reduced manufacturing costs and time.[146]

Evidence suggests that neither pronounced technology nor human-centred design paradigms contribute to sustainable and significant improvement in competitive advantage; they may rather result in negative effects. In contrast, organisation-centred approaches to designing production systems have proved to be effective in improving competitiveness.[147]

Human and technical aspects must, therefore, be adapted and aligned with organizational structures and processes. In the modern dynamic and complex, competitive business environment, companies have the opportunity to design their organizations in different directions.[148]

Within the organisation-centred approach or framework, a systemic process must be considered from the perspective of socio-technical work and production system design, especially CPPS design.[149] This will, in turn, lead to decentralized forms of management and control, new forms of organizational collaboration with a high degree of autonomy, and an efficient technical-support system that aligns to employee needs.[150]

[146] Schuh 2007.

[147] Deuse et al., 2014.

[148] Deuse et al., 2014.

[149] Deuse et al., 2014.

[150] Wahlster 2011.

4.2 Lean Management

The concept of lean production is based on Toyota's economical and effective production of the 1990s. Researchers established that lean management led to the reduction of Toyota's production time by almost half and an increase in productivity by approximately 25% compared to mass production. Recent studies in different industries that employ lean production have also produced almost similar findings.[151]

Learning from the automotive industry, other manufacturers adopted Toyota's lean production system and modified it to suit their own needs. Many companies today used lean production systems, principles and methods. As a matter of fact, it is the production system used by many companies.[152]

The structuring and coordination of all aspects of production towards a common goal in recent years have led to the advancement of the concept of a Lean Production System (LPS). Guideline 2870, a publication by the Association of German Engineers (VDI), has been publishing standardized structures, content, principles, and tools for holistic production systems since 2012.[153]

4.3 Cyber-Physical-Systems and Production

The core purpose of cyber-physical systems (CPPS) is to have all associated planning and control systems exchange information independently and within

151 Dombrowski/Mielke 2015.

152 Gerberich 2011.

153 VDI 2012.

precisely defined limits, and to make decisions independently. CPPS systems facilitate the complete integration of all resources and systems.[154]
In the context of industry 4.0, this integration would involve having production systems integrated with ICT to create intelligent factories (Smart Factory).[155] CPPS ensures a continuous process within the life cycle of products, and it also promotes sustainability and flexibility in industrial production. It is expected that CPPS will create more opportunities for the implementation of responsive, customer-specific and environmentally friendly processes by facilitating a distributed and highly heterogeneous use production resources.[156]

The use of technology for networking spatially distributed production facilities requires consistent standardization of the entire value chain in order to grasp its complexity. In addition, it is important to ensure that any emerging forms of intelligent technologies are incorporated into the production systems to enhance the productivity of employees.[157]

When designing CPPS, certain structural and infrastructural prerequisites, together with employee skills and abilities, must be considered during the design stage. When factors such as people and an organization's technological ability are considered when designing and implementing production systems, the competitiveness of manufacturing companies also increases substantially.[158]

Increasing socio-technical interactions coupled with networking of all actors and resources involved in value creation, as well as the increased use of new forms of ICT within Industry 4.0. are likely to lead to decentralized production. The downside

[154] Kagermann et al., 2013.

[155] Deuse et al., 2014.

[156] Kagermann et al., 2013.

[157] Deuse et al., 2014.

[158] Ulich 2011.

of this is that it may lead to increased lead times, and lower adherence to delivery dates, factors that eventually translates to lower customer benefits or satisfaction.[159]

To address this challenge, uniform rules for process-oriented organizations must be formulated. Structured and directed value streams are essential factors that must be considered when thinking about a targeted use of technology. Therefore, structures and processes along the value chain must be comprehensively standardized for intelligent autonomy to be achieved through CPPS and decentralization of production processes or systems.[160]

Once implementation rules have been defined, robust processes, interfaces and processes with controllable and predictable variability create the necessary transparency in complex production structures. For autonomous processes to be effectively implemented, monitoring rules, correct solutions to problems and references must be clearly defined.[161] This can be achieved by categorizing and systemizing model types, establishing classification concepts and the configuring production systems appropriately.[162]

Besides the technical aspects of industry 4.0, humans are also an essential factor that must be taken into consideration when designing CCPS. It should also be remembered that the creativity and flexibility of humans cannot be entirely replaced by autonomous systems. Instead, the automated systems are only meant to supplement human efforts and skills through the intelligent use of ICT.[163]

Therefore, mechanisms must be put in place for collaboration between humans and machines, and within such collaboration mechanisms, humans must act as the

[159] Deuse et al., 2009.

[160] Deuse et al., 2009.

[161] Deuse et al., 2009.

[162] Deuse et al., 2014.

[163] Ulrich 2011.

active carriers of decisions and controllers of optimization processes. In future, therefore, humans will control, regulate, and coordinate spatially distributed and networked production resources depending on situation and context.[164]

The nature of work or tasks to be completed and the technologies used in the workplace continue to change with each passing day. The dynamic nature of tasks and the complex technologies demand that employees acquire new skills and abilities. As such, the competence level and profile of employees must be regularly checked and checked and adjusted if necessary. Companies can also come up with training programs to equip their employees with the needed technological or competence skills for them to be able to operate or use technological machines or systems.[165]

Technical competence involves or includes the ability to recognize the functional elements of a production system, identify system boundaries, understand functions and relationships, and to make predictions about system behaviour. System competence, therefore, serves as a basic qualification and prerequisite for employees as decision-makers in CPPS.[166]

Some years back, traditional teaching methods were used to train employees, although they were only suitable to a limited extent for teaching system competence. For companies to achieve competitive production, employees must have the skills to operate demand-driven competence management systems. Competence profiles, employee tasks and competence development programs must all be aligned to the workings and technicalities of these systems.[167]

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[164] Deuse et al., 2014.

[165] Ulrich 2011.

[166] Deuse et al., 2009.

[167] Deuse et al., 2014.

Besides the need for employees to continuously expand their system competence skills, the dynamic nature of workplace tasks also places new demands on the design of work systems within Industry 4.0 from the work science perspective. The future designs of CPPS will be linked to demographic changes, challenges, and effects.[168]

The average age of employees, product life cycles, innovation rates, work processes, and new technologies in the workplace are not constant; these factors are always changing. As such, subject areas such as work physiology, cognitive ergonomics, and software ergonomics are increasingly becoming increasingly important. Companies or businesses must, therefore, develop processes and structures for continuous qualification employees. Additionally, tasks in the workplace must also be assigned to employees according to their individual abilities and competencies.[169]

An effective and efficient design approach should allow for the innovative implementation of automation solutions and should simplify the handling and processing of tasks. Using stationary or mobile individual assistance systems with intuitive user interfaces can relieve employees of physical and mental activities.[170] Assistance systems or automation relieves employees of monotonous and stressful tasks.[171]

Nevertheless, it is particularly important to create suitable framework conditions for cooperation between people and technology. Instead of a purely rule-based mode of operation of the assistance systems, dialog-based procedures should be used instead. When using dialog-based assistance systems, employees are considered to be the last decision-makers, and they can control and coordinate tasks.[172]

[168] Kagermann et al., 2013.

[169] Kagermann et al., 2013.

[170] Deuse et al., 2014.

[171] Deuse et al., 2009.

[172] Deuse et al., 2014.

The integration of innovative automation solutions and the support of specialists through intelligent assistance systems offer the opportunity to compensate for fundamental shifts in a company's age structure and at the same time an opportunity for a positive influence on the ergonomic design of the workplace.[173]

4.4 Human-Robot-Collaboration and Assistance Systems

Several terms are used in literature to describe interactions of collaboration between humans and robots: human-robot-cooperation[174], coexistence[175], collaboration or even interaction[176].

Assistance-systems are basically robots or technological systems that assist humans in carrying out assembly or manufacturing processes and sub-process autonomously or semi-autonomously. Assistance functions can have preventive, inclusive and re-integrated effects in regard to performance conversions.[177]

Interaction describes activities that occur between two or several subjects. Accordingly, human-robot interactions describe actions or activities that occur between humans and robots such as cooperation, collaboration and coexistence. Cooperation refers to joint activities or actions that take place between several parties. Human-robot cooperation, therefore, refers to joint actions between humans and robots to complete or fulfil tasks.[178]

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[173] Deuse et al., 2014.

[174] Thiemermann 2005.

[175] Henrich et al. 2008.

[176] Bortot et al. 2012, p. 253.

[177] Helms, 2006, p.23.

[178] Helms, 2006, p.24.

Collaboration is synonymous to cooperation except that it describes the cooperation of humans and robot to complete tasks in the same workspace. Collaboration can also be described as 'direct human-robot cooperation' or 'direct physical human-robot interaction'. Coexistence encompasses the simultaneous (side-by-side) existence of several parties. Human-robot coexistence is understood as the safe, simultaneous and independent execution of work by humans and robots in the same working space.[179]

There are certain regulations and general considerations that must guide cooperation and collaboration between humans and robots. These are discussed below.

4.4.1 Protection and Safety

Strategies must be put in place to ensure the safety and protection of personnel and non-participants during human-robot interactions. Contact between human and robots can sometimes lead to accidents, especially if the two are in direct contact, or if they are working in close proximity, hence procedures must be put in place to minimize or avoid accidents or injuries. Safety measures should minimize the chances of collisions occurring (collision avoidance) or reduce the consequences of such collisions (damage limitation).[180]

4.4.2 Networking of technologies

The software and hardware of modular robot assistance systems can be configured as desired to meet changing needs in the workplace. However, the duration and costs of commissioning and maintaining such assistance systems should be kept at a minimum, and their technical requirements or integrated technologies should be

[179] Helms, 2006, p.24.

[180] Oberer et al., 2006, p.17.

friendly to users.[181] If possible, employees should be able to configure their own assistance systems according to their individual needs.[182] There are two approaches to doing this:

Modular peripherals: Simplified networking, integration and commissioning of peripherals, end-effectors for ease of use and control by users. A core concept is 'Plug and play, i.e. after plugging in the peripherals, they should be ready for use. For this to be possible, supply lines and data interfaces should be integrated into quick-change systems or machines, data configuration should be automatically exchangeable, and libraries should be aligned with device information.[183]

Modular kinematics: individual modules should be appropriately arranged and connected, for example, to display degrees of freedom, range or morphological functions of a robotic system. Actuator arrangements can also be used as effectors, or as docking point or for locomotion.[184]

4.4.3 Implementation in the Company

The use of robot assistance systems comes at a cost and must, therefore, be selected wisely. The design of selected assistance systems must meet the constraints of the workplace, work or tasks, and employees must have the competence skills to operate them. Businesses must, therefore, consider a number of things before settling on specific assistance systems: costs, employee skills, convenience, etc.[185]

[181] Spröwitz et al., 2008, p.423.

[182] Reinhart/Spillner, 2010.

[183] Ehrmann/Seckner, 2006, p.56.

[184] Spröwitz et al., 2008, p.423.

[185] Helms, 2006, p.40.

5 Planning and Introduction of Assistance-Systems

In this chapter, a methodical framework for planning and development of assistance-solutions for handling tasks in the assembly is created. The planning of assembly-systems can be divided into five phases: preparation, rough planning, detailed planning, implementation and operation.[186]

Preparation: At this stage, an organizational framework is defined to govern the management of the project. After a situation analysis, goals, responsibilities, framework conditions, deadlines and budgets are defined. This is followed by a further specification of the requirements, a selection of planning measures to be carried out and the collection and provision of relevant planning data.

Rough planning: Rough planning focuses on product-characteristics. Here, all assemblies and individual parts of the product are listed, described, evaluated, etc. in terms of their suitability to convey and handle systems, required tools, etc. An assembly plan is then created that defines the possible order of assembly steps or partial operations. This is then followed by an analysis of the cost factors of the specified products.

Detailed planning: After an initial plan has been tested on a representative product, the entire spectrum is planned in detail. A concrete, ergonomic arrangement and design of control panels, handles, work surfaces, etc. is made; automatic assembly stations are designed separately.

Implementation: this is the phase where equipment construction, procurement, personnel deployment planning, system setup and system start-up takes place. Individual employee requirements are addressed in the personnel deployment

[186] Bullinger 1993.

planning by checking the suitability of assistance systems to individual employee needs and characteristics.

Operation: in this phase, the assistance systems are deployed, and their operation evaluated.

5.1 Derivation of a Planning and Development Process

The planning procedure summarized above can also take into consideration the three points mentioned below:[187]

- The appropriate time when the assistance systems will be deployed must be specified.
- The tasks to be completed by the assistance systems must also be defined.
- Mechanisms must also be put in place to evaluate the effectiveness of the assistance systems once they are deployed.

The following section provides a detailed explanation of the three points above.

5.1.1 Requirements

The people needed to plan for the development of the assistance systems are assistance systems developers and assembly systems planners, and their objectives[188] are as follows:

- Integration: To plan for assembly assistance system that takes into account the future needs of the workforce.

[187] Spillner 2014, p.99.

[188] Jonas 2000, p.10.

- Intervention: The adaptation of an existing assembly system to compensate for power changes or to reintegrate modified power.
- Compatibility: Terms and parameters used should ne uniform and unambiguously at all levels.
- Completeness and efficiency: The structure and order of the procedure should provide an overview, ensure full consideration of all relevant factors and work steps, and enable targeted and efficient implementation.
- Innovation: The development of new or improved existing solutions; the focus is on assembly cells and stations.
- Applicability: In order to develop a close-to-use application, the method should be based on existing and familiar methods for potential users.
- Comparability of the solution: The result of the procedure must be sufficiently detailed to enable comparability with alternative solutions.
- Consistency: The clarity and comprehensibility of procedure descriptions should facilitate their general use as much as possible.
- Reproducibility: repeated use even by different users should generate almost identical results. Evaluation criteria must, therefore, be objective.
- Validity: Specified procedures must solve the intended problems.

5.1.2 Conceptional Design of an Assistance-System

The goal of this procedure is to come up with a detailed, valid assistance solution for the respective application. According to Bullinger et al. (1993), planning involves creating a layout. Subsequent steps (detailing, evaluation, comparison, selection, or implementation) can be implemented with state-of-the-art methods and do not require separate consideration.[189]

The layout defines the arrangement of the system within the workplace. A healthy system comprises of a different technical element. The layout should specify any

[189] Bullinger et al., 1993.

necessary changes in workplace design. In addition, description tasks and the overall sequence of tasks performance must be specified, and this can be done in the form of a schedule.[190]

Expected results must also be specified and sufficient measures defined to address identified or specified hazards.[191] Care must also be taken to minimize barriers of acceptance, and the economic usefulness of the assistance systems must be evaluated by estimating investment and operating costs.[192]

5.1.3 Schedule

Organizational and design decisions made at different times during assembly planning should build on each other to narrow down the scope of solutions. It can be complex, costly and time-consuming to make adjustments to solutions that turn out to be insufficient.[193] Therefore, planners and developers should comply with all requirements at all stages. If possible, planners should provide appropriate action proposals and examples at respective planning-stage.[194]

It becomes necessary, therefore, to make reference to proven assembly procedures and design tools assistance robots. Potentially suitable procedures and design tools ate those that comply with employee requirements and those that will be helpful for integrating performance conversions into the robot-assistance systems.[195]

[190] Spillner, 2014, p.101.

[191] Spillner, 2014, p.101.

[192] Spillner, 2014, p.101.

[193] Lotter/Wiendahl, 2006.

[194] Reinhart et al., 2010. P.9.

[195] Spillner, 2014, p.102.

Timings should be differently adjusted to suit different performance measures or changes. Furthermore, proposal level details and descriptions of measures increase as the planning process progresses. Identification and discussion of the dates are also applicable in an analogous manner to other planning procedures.[196]

5.1.3.1 Rough Planning Time

It is assumed that workforce data collected during the preparation phase is enriched with profile data or information on existing operational restrictions. It is also possible that the planning for assistance systems may not take into consideration the specific tasks of employees. This should, however, not be the case because planning should involve a consideration of needs. A plan that does not take into consideration the needs of employees may also not be economical because it may lead to inappropriate allocation of resources.[197]

The first step in assistance systems planning should involve an evaluation of assembly parts in regard to their economic suitability and automation. Rough-time planning is generally necessary for human-robot cooperation and coexistence (HRC). Planning at this phase provides an opportunity for the economic assessment of HRC or for the assistance-systems to be tested by using them to carry out partial operations. These evaluation procedures have been lacking for a long time.[198]

Furthermore, limited use of assistance systems in the industry makes it difficult to develop formal, quantifiable and appropriate evaluation criteria. A catalogue of measures and examples has to be used instead to evaluate economic viability and for applicable design requirements.[199]

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[196] Bullinger et al., 1993.

[197] Spillner, 2014, p.103.

[198] Spillner, 2014, p.103.

[199] Spillner, 2014, p.103.

A breakdown of tasks to be completed or executed is also done in this phase. Tasks breakdown basically involves relating certain execution measures to specific tasks or contents of work: job enlargement, the establishment of assistance workplaces, and the establishment of dedicated service activities.[200] This begins with the identification of tools to be used in stages where tasks were initially performed manually, followed by aligning work to time specifications and specific employee requirements (bottleneck analysis or a profile comparison).[201] Planners should be furnished with information such as performance conversions and activities or tasks that need to be solved. Other measures taken into consideration at this stage include: stress limitation, the establishment of assisted workplaces, integration of robotic aids and ergonomics, age appropriates, age-appropriate workplace design.[202]

Also addressed during the rough classification of performance conversions are factors such as 'force' and 'time regime'. Workstations also get designed according to the designed layout. Here, HRC gets introduced as an equivalent alternative to the automatic and manual station.[203]

Synergy effects can be obtained from rearrangement and recombination of different workstations. This will then make it possible for HRC to be integrated in areas where it previously seemed unsuitable, thus leading to costs reduction through the close integration of processes. A general rule to be observed during this approach is to incorporate a simplified summary of all work areas within the workplace design.[204]

[200] Spillner, 2014, p.104.

[201] Spillner, 2014, p.104.

[202] Spillner, 2014, p.104.

[203] Spillner, 2014, p.104.

[204] Spillner, 2014, p.104.

The catalogue of measures can also be referred to for planned examples or design instructions for layouts of assisted workplaces. After assessing or evaluating the feasibility of work contents and work stations, performance changes must also be considered.[205] Using the evaluation results, appropriate actions to be integrated into the assistance robots must also be specified.

5.1.3.2 Schedule of Detailed Planning

Detailed planning makes it possible to identify harms that assistance systems may cause in the workplace. The use of assistance systems in the workplace can be reconsidered if they are likely to cause damages or harm. Eligible measures must also be put in place to ensure that injuries are either minimized or avoided. Assistance systems should not interfere with performance. Instead, they should enhance performance. The catalogue of measures should be detailed and provide preferable examples that can be integrated into the workplace with minimal interference.[206]

5.1.3.3 Times during Operation

During operation, the needs of the workforce may change; new performance requirements may replace old ones. When this happens, assistance systems should be reconfigured to meet new demands. Old commands within the assistance systems can then be discarded and replaced with new ones.[207]

As stated above, catalogues of measures must be detailed enough to allow for a smooth integration of solutions into the assistance systems. Catalogues must also

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[205] Spillner, 2014, p.104.

[206] Spillner, 2014, p.105.

[207] Spillner, 2014, p.105.

contain detailed information on how long the assistance robots can be expected to be operational; this will allow for effective planning of system upgrades and the establishment of measures to deal with downtimes.[208]

5.1.4 Description of Measures

A detailed description of planning facilitates or supports assembly planning by describing relevant solution examples. A detailed description of measures not only speeds up the planning process, but it also facilitates solution-finding. Therefore, manufacturers of assistance systems should capture in detail the product information according to the corresponding planning phase.[209]

Information on the catalogue[210] may include the:

- General measures,
- Concrete examples of assistance-systems, and
- Elements or technologies.

A catalogue should be a source of appropriate solutions; it should provide specific general information about suitability and should refer users to other sources of information for full details. Individual points or content should be addressed in the table justified in the selection. Furthermore, the table shows which content points are relevant for which planning dates and whether the points address general

[208] Spillner, 2014, p.105.

[209] Lotter/Wiendahl, 2006.

[210] Lotter/Wiendahl 2006.

measures, complete assistance systems or individual technologies. Feedback can be implemented by filling in or adjusting the description of the measures.[211]

5.2 Planning of Assistance-Systems

This section introduces the procedure for selecting and synthesizing robot assistance systems. Reference is made to assembly planning procedures as proposed by Bullinger et al. (1993); the procedure is iterative and not linear.

According to Bullinger et a. (1993), later sub-steps are re-jumped back to earlier ones when a need for change is detected that cannot be solved in subsequent sub-steps.[212] The entire procedure may also be completed in several steps or phases, with the level of detail increasing with each iteration.[213]

The methods listed in the sub-steps do not exclude the application of other approaches; the procedure remains consistent as long as the input and output variables of the sub-steps match. The procedure is carried out in parallel with the ongoing assembly system planning and begins with the identification of a need for action. [214]

The objectives, planning data and framework conditions (analogous to the preparatory phase) must be formulated or inherited from the previous planning stage. In particular, it is necessary to check whether specific budgets are available for the integration of the ones for performance-changed.[215]

[211] Lotter/Wiendahl, 2006.

[212] Lotter/Wiendahl, 2006.

[213] Spillner, 2014, p.111.

[214] Spillner, 2014, p.111.

[215] Lotter/Wiendahl, 2006.

An assessment of the follow-up costs should also be made in the event that no action is taken (alternative injunction). The existing project organization can be maintained as well as extended. As a recommendation for measures addressed to the workforce, a working group should be formed or for steps. Each sub-step is discussed below. The result of the procedure is a sufficiently detailed description of the assistance-system, which then enables an evaluation with solution alternatives and integration of the solution into the parallel continuous assembly planning.[216]

5.2.1 Analysis

The general need for assistance can be understood as the discrepancy between the skills offered by the employees and the requirements of tasks to be completed. In order to determine these discrepancies, the employee skills or restrictions, as well as the requirements needed for tasks to be completed, must be recorded as a first step.[217]

A description of requirements can include a detailed description of workstations and individual handling steps. Everything should start with a rough description; further refinement will only make sense up to the level where assistance systems and functions are also to be addressed.[218]

If profile characteristics are assigned number series, then assistance requirements can be determined from the difference of related skills and requirement characteristics. Numerical values are proportional to the quality of requirements and abilities. At least one rating level in the set of requirements should be higher than

[216] Lotter/Wiendahl, 2006.

[217] Spillner, 2014, p.111.

[218] Spillner, 2014, p.111.

the values of the associated capability characteristics in order to be able to represent an overload of fully operational employees.[219]

The value levels denoted by assigned numerical values should also be as quantifiable as possible, and equidistant between skills and requirements of the same quality. Accordingly, standardized needs for assistance should be based on the following points[220]:

- **Frequency**: When resources are resources, the frequency can be the best way to identify priorities for action. Frequency can be used together with the height of individual requirements (which is to be determined or computer through column-by-column summation).

- **Maxima**: In order to be able to use as many employees as possible in a selected group, the highest assistance requirements must be used. This is represented by a column-by-column determination of the maxima within the assistance requirements. For the purpose of this thesis, there are two embodiments that relativize maximum demand in favour of economic constraints.

  First, a difference of assistance needs between employees must be defined or determined. Second, prescription of admissible exclusions on the part of the employees or workplaces can be introduced. Optimization problems (exclusion of employees or workstations) cane solved by common optimization or testing methods. The resulting characteristics profile then becomes the starting point for further robot assistants detailing.

219 Lotter/Wiendahl, 2006.

220 Spillner 2014, p.114.

- **Individual cases**: This applies when only a few or individual employees or workplaces are to be taken into account, or if outstanding assistance requirements have to be assessed individually. This is achieved through a line from the line-by-line alignment of employees or workstations to the profile characteristics, groups and patterns: If regularities or patterns occur during the distribution of assistance requirements, it might be advantageous to consider them separately.

  In the event that similar assistance requirements are encountered in successive workplaces, subtasks or handling steps, they should be represented through a single assistance system. In other words, if assistance needs are recurrent, then the multiple requirements into the assistance system.
  Irrespective of analysis methods, the results of this process should be in corresponding profile characteristics for which robot assistance solutions are to be determined.

5.2.2 Pre-Selection of Solutions

Once the target profile has been determined, it becomes necessary to determine known solutions that meet the target conditions sufficiently. Target profiles should consist of the assistant profile, application area, boundary condition for search results. Boundary conditions can include a description of actions or solution, such as investment costs. The boundary conditions should correspond to the level of information at the time of planning. Searches in the database can also be performed using known methods.[221]

The viewfinder results can match target profiles in different ways, but results can be confusing when large numbers are involved; narrowing down may be necessary when this is the case. With the introduction of cost functions to describe the degree

[221] Schmitt 2005.

of fulfilment of the respective criteria, boundary conditions, and the weighting of composite solutions over individual solutions, the use of optimization algorithms is possible. The effort-benefit ratio for creating and maintaining such automatic planning seems questionable, considering the complexity of the planning process.[222]

A simple step-by-step procedure is proposed, which can also be used for manual searches. One has to pass through four staggering steps. The limit of deviation or similarity to be considered is at the discretion of the members planning member. The increasing planning effort is also another demolition criterion, which is not shown.[223]

Within the passes, the solution quantity is first reduced according to the exclusion principle before optimality criteria are applied. The KO criteria are derived from the boundary conditions.[224]

There are three optimality criteria for the selection of single or composite solutions.[225]

- Minimum costs,
- maximum assistance, or
- Wide range of applications, each with minimum compliance with all other criteria.

In addition, a minimum level of cooperation or maximum employee participation can be sought in order to avoid under-reliance. If all requirements are sufficiently met, selected can then be transferred for further. But if all requirements are not met, the

[222] Schmitt 2005.

[223] Schmitt 2005.

[224] Schmitt 2005.

[225] Spillner, 2014, p.116.

process ends with the selection of suitable partial solutions, while the remaining assistance requirements are noted for further consideration.[226]

5.2.3 Design of New Assistance Systems

If assistance solutions do not meet workplace needs or employee needs, three alternatives options can be pursued: First, alternatives that do not depend or robot assistance can be sought or pursued. Second, iteratively predetermined requirements can be adapted. Third, the robot-assistance system can be designed anew or afresh.[227]

5.2.3.1 Rough Concept Design

Rough concept design begins with a concept presentation. Procedures should be chosen or formulated in such a way that they can be implemented with the aid of computers or through 'paper-and-pen method'.

By the time this planning phase begins, a detailed description of the assembly priority graph should be available. Tasks must also be broken or sub-divided into sub-tasks that can be completed or handled in phases. Procedures for handling tasks at different phases by either machines or individuals should be collected and compared.[228] Requirements for humans should be defined in terms of assistance needs discussed before.

Since a complete profile of the assistance needs can only be created as assembly planning progresses and when the level of workstation details increases, the

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[226] Spillner, 2014, p.119.

[227] Spillner, 2014, p.120.

[228] Ross, 2002, p.52.

process can begin with an incomplete. If no employee data or no assistance requirements are available, an assessment of executable tasks at each step can be used instead.[229]

Requirements for automatic execution are determined qualitatively using automatability assessment procedures. Automatability here describes the technical demands or the economic viability of automating processes in question. This, according to Ross, is a practical evaluation procedure, since it can be used early in assembly system planning, it requires little experience, and works with initial quantitative data.[230]

Besides considering factors such as production duration, number of pieces and batch size, criteria (such as object shape, stability, object symmetry, accessibility of the positioning area, etc.) are also evaluated four stages and their ratings summarized.[231]

When considering automation of tasks or processes, it is assumed that the higher the automatability of a task or process, the easier it is to integrate automation procedures into a robot-assistance. Nevertheless, a high degree of automatability may also not be economically viable; hence tasks and processes must be automated with a certain degree of preference.[232]

And while automation of employee tasks may be seen as a way of supporting or relieving employees, full automation may require changes to be made recruitment

[229] Ross, 2002, p.52.

[230] Ross, 2002, p.52.

[231] Ross, 2002, p.52.

[232] Ross, 2002, p.52.

requirements. Based on this reasoning, five action areas have to be identified in regard to assistance requirements and automatability (Figure 3).[233]

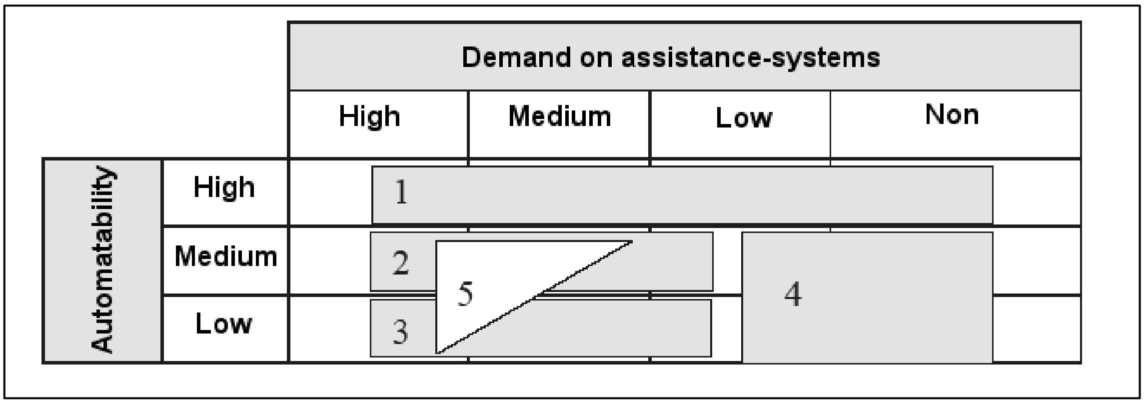

Figure 3: Need for action concerning automatability and assistance-systems (Spillner 2014, p.121).

Box 1: If the process is highly automatable, the first step is to automate the sub-step. As much as possible, a separation of robot and human is preferable to human-robot coexistence. Coexistence should only be considered if local proximity to human-led processes is required or if there is a general lack of space.

Box 2: human-robot cooperation should only be considered when conditional automatability becomes necessary. However, evaluations must be done to determine how such cooperation can compensate for the existing automation barriers and assistance requirements.

Box 3: when automatability is low even when assistance requirements exist, then ways must be sought to eliminate automation barriers so as to increase cooperation between humans and robots. This may require a detailed review of the whole process below.

[233] Spillner, 2014, p.120.

Box 4: when automatability is low because of minimal assistance needs or because assistance needs do not exist, manual or human-guided version of the partial steps should be sought.

Box 5: This area represents a task of workstation that may benefit from human-robots cooperation.

This consideration should result in a rough preliminary classification of target embodiments per process step (automatic, coexisting, cooperating, and manual) based on presented technological and economic considerations. This embodiment is classified in the next step.[234]

For the purpose of the project, the assistance potential of the embodiments per profile characteristic and process step must be determined first. If necessary, potential assessments must be adapted to the "state of the art" and transferred to a finer structure of operational capability or profile characteristics.[235]

The previously created preliminary rough selection of the embodiments will now be evaluated to determine the embodiment that will satisfy or meet assistance requirements. The evaluation or assessment can be carried out heuristically or by means of profile comparison. When planning for subsequent steps, the following rules[236] Must also be considered:

[234] Reinhard et al., 2011.

[235] Reinhard et al., 2011.

[236] Kaltenbrunner/Spillner 2013, p.244.

- At least one automated partial step should be integrated, preferably at the beginning or at the end of task handling. Doing this is advantageous in two ways: first, it can promote acceptance. Second, automation can have a positive effect on the overall economic balance of the assistance system.
- When embodiments are of similar suitability, they should both be considered to the complexity of implementation.
- Little or minimal changes should be made to embodiments as much as possible to reduce complexities, interruptions or interferences in process, as well as to reduce the employee's conversion effort in cooperation.
- An embodiment should be applied in as many consecutive sub-steps as possible to reduce conversion effort for the employee during cooperation.
- No arbitrary order of execution types is allowed.

If execution methods are defined, assistance functions must be allocated in the final step of the rough concept development. These functions can be taken from the prior art and can be assigned to one or more embodiments or assistance profiles (if they are stored in a database and described accordingly).[237]

5.2.3.2 Detailed Design

The design concept discussed in this section may still turn out to be unfavourable, and it may need modifications to suit different needs. Nevertheless, implementation obstacles are limited. For this concept to be appropriately adopted for the development of new assistance systems, implementation barriers must be identified and dealt with as elaborated in the steps that follow.[238]

Just like the rough concept design, work contents must be divided into subtasks and handling steps. Incomplete or unsuitable handling steps can hinder man-robot

[237] Beumelburg 2005.

[238] Zülch/Becker, 2010, p.41.

cooperation. It is true that sensory capabilities, such as measuring and testing, are to be counted for handling. But the mapping of, say, decision-making processes is not considered. Therefore, where obstacles to implementation arise, a further subdivision and extension of the handling steps must be introduced.[239]

For expansion, a model of cognitive systems is available, which encompasses the capabilities of people and autonomous systems in the following aspects: perception, knowledge, and planning, decision-making, action.

After subdivision of a process, the known obstacles to use or implementation at each sub-process should be identified, and remedies sought as much as possible. The most relevant barriers to use including low automatability (high level of automation inhibition), unfulfilled assistance requirements, lack of acceptance by employees, high and uneconomical safety requirements, high costs of acquisition or operation, and long execution times. While all obstacles must be removed in principle, the search for solutions should be hierarchical with the areas or sub-processes with the largest or most common obstacles.[240]

Two approaches can be taken to determine a new solution. First, a combination of existing partial solutions can be done per each sub-process step. Second, a new solution can be generated. In the first approach, alternative solutions for priorities specified must first be collected and assigned to respective sub-processes and embodiments.[241]

Each alternative solution must be evaluated to determine if it has the potential to eliminate barriers to implementation. In the second approach, however, new solutions must be composed and applied using rules such as the coarse concept. It

[239] Zülch/Becker, 2010, p.41.

[240] Bannat et al., 2011, p.148.

[241] Bannat et al., 2011, p.148.

is unlikely that a plan will nearly complete database of all technical solutions and approaches.[242]

Similarly, it is unlikely that large amounts of data can be analyzed with reasonable time limits using solutions. Therefore, heuristic methods are preferred for the identification and selection of alternative solutions. If sufficient detailing, simplification, or focus on individual characteristics are otherwise applicable, optimizing methods are also applicable, see.[243]

For the second approach, supportive, creative techniques can be used for the generation of new partial or total solutions.[244] Rough or detailed concepts must further be evaluated using planning procedures planning procedure and checked against the requirements.

5.2.4 Examination of Work Content

Assistance and automation procedures to be integrated into concept development as well as employee tasks to be executed through human-robot cooperation must be specified. It is also necessary to determine whether tasks are monotonous, one-sided and whether they are personal. Employees that will use the machines should also be specified, or their titles/work positions.[245]

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[242] Bannat et al., 2011, p.148.

[243] Takata/Hirano 2011.

[244] Orloff 2006.

[245] Neumann et al., 2002, p.4059.

5.2.5 Integration of Additional Tasks

In this sub-step, an evaluation or examination is done to determine whether assistance systems can perform other tasks (autonomous or assistive). Typical time periods to be integrated into the assistance systems include work breaks, non-working shifts, intervals and waiting times between individual process steps or assistance needs. The aim of this consideration is to improve the overall cost-benefit ratio of the assistance system.[246]

Time periods when the assistance systems will not be needed must also be specified or determined. This will enable the systems to search for automatable tasks or assistance requirements (in order of priority) and determine when and where the tasks are to be completed or executed.[247]

These requirements (especially performance, mobility, security) must, therefore, be considered in the following detailing of the system and layout. The selection and design of additional automation content must be carried out in parallel with the further detailing of the assistance system and must be revised and adapted iteratively if necessary. Priority should be given to the requirements of the assistance functions.[248]

246 Reinhart et al., 2011, p.17.

247 Reinhart et al., 2011, p.17.

248 Reinhart et al., 2011, p.17.

5.2.6 Layout

Once the concept has been developed, a layout must be created in the same way as the installation system planning (and according to Bullinger). The aim of the step is to first determine a valid, then an advantageous arrangement of the assistance-system at the workplace. The procedure is chosen in such a way that it can be carried out in 2D or 3D without any special requirements with sketches and modelling.[249]

5.2.6.1 Kinematics

The first step is to define the kinematics of the assistance-system and the way in which it will be integrated into the workplace. Tasks to be handled and boundary conditions must first be specified.[250]

Boundary conditions refer to those properties and objects of the workstation that can affect the handling, such as the type of object provided, available space, existing fixed and moving objects, employees, concatenation and integration between adjacent workstations, or organizational principles. These must be defined in advance or in parallel during regular assembly system planning.[251] Accessibility and orientation of objects must design based on boundary conditions and tasks before, during and after the implementation of assistance objects. Effectors must also be determined on the basis of object properties (weight, shape, surface, etc.), and centres of gravity and weight dimensions must be determined or estimated.[252]

[249] Bullinger et al., 1993.

[250] Zülch/Becker, 2010, p.41.

[251] Spillner, 2014, p.127.

[252] Spillner, 2014, p.127.

The minimum required load is determined by object and effector weights. Between the starting and target position of the object to be handled, a collision-free object path is determined in rough approximation, either automatically or through cooperation.[253]

If deviations from the given path or orientation are to be foreseen by regulation or through human intervention, the maximum expected or required deviations shall be laid on the surface or envelope volume around the sections of the object runway affected by it. The largest distance from the output and target position to the points of the object orbit or its envelope surfaces determines the minimum range of the robot. The change of orientation of the handling object via the object path determines the minimum required degree of freedom of the kinematics.[254]

Based on the minimum load, minimum range, trajectory and orientation of the object, a pre-selection must be made among the available assistance-systems. Assistance-systems, which do not have a secure control system or are not inherently secure, must be excluded at an early stage.[255]

5.2.6.2 Arrangement of Interface

[253] Spillner, 2014, p.127.

[254] Spillner, 2014, p.127.

[255] Spillner, 2014, p.120.

Once an assistance system has been chosen, it should then be deployed in the workplace to handle specified assistance tasks. But before placing assistance systems in the workplace, a sketch of the model must be developed that displays the actual positioning of known or defined objects in the workplace.[256]

The assistance system shall be positioned and orientated in such a way that the entire web (including the envelope surfaces and volumes of possible trajectory deviations) in the working area are given. It is then necessary to check whether a valid singularity- and collision-free configuration of the kinematics exists for all points of the web. This can be determined numerically (for complex cases) or simulatively (for simple cases).[257]

This is to be carried out analogously for those surfaces or volumes which by regulation or human by intervention, span as beyond the solution spaces of the flange runway. Experts describe a formalized procedure for the placement of mobile assistance-system. In order to facilitate any necessary repositioning, it is advantageous to show valid and invalid solution spaces in the results of the tests.[258]

When the assistance-system is positioned, required sensors, peripherals and input devices are placed at the workplace or at the assistance system. The selection of input devices should be made heuristically, taking into account the selected types of execution or cooperation and assistance functions.[259]
Based on the location and accessibility of the human-machine interfaces as well as the execution methods of the handling steps, the employees cooperating with the assistance system are then positioned in the layout. The controls must be in the

[256] Craig 2005.

[257] Reinhart/Tekouo, 2009, p.25.

[258] Helms, 2006, p.25.

[259] Tekouo 2012.

gripping chamber and displays in the employee's field of vision, considering each individual handling step.[260]

For example, templates or models can be used to represent the person in the layout, whereby standard dimensions must be adapted to known performance changes if necessary. During the positioning of the employees, several stress factors can be determined or estimated and tested against employee requirements.[261]

These include posture (with 2D sketches the working height must be supplemented), space conditions and proximity to environmental influences. The vector of force-based inputs can be determined along with the handling steps or object path from the position of the input device, the direction of movement of the object, and the position of the employee. The required amount of the (operating) force is limited by the execution method of cooperation and the choice of input devices.[262]

In situations where the robots or assistance systems are to be led or guided employees, it might be necessary to ensure that system user interfaces are friendly. One way to do this is to look at the prominent points selected by the planner (with appropriate kinematics configuration and operator pose) and adjust them accordingly.[263]

For a more detailed examination, simulative and calculating methods should be used in which permissible poses or orbits of the Kinematic are determined, taking into account geometric and functional boundary conditions. See.[264]

[260] Tekouo 2012.

[261] Tekouo 2012.

[262] Tekouo 2012.

[263] Tekouo 2012.

[264] Tekouo 2012.

Employee needs must be taken into considering when designing or configuring the operating interface of assistance systems or kinematics so as to ensure that the interaction between humans and assistance systems is meaningful.

5.2.6.3 Security Measures

After all, tasks that would require interaction between humans and machines have been specified, the next thing that should be done is to analyze potential hazards and propose potential solutions to hazards.[265] Potential or possible factors that may lead to danger or hazards at each handling step must be specified, their probability of occurrence calculated or determined, and the severity of consequences evaluated.[266]

Evaluation of security risks must also be reflected in detail in the layout design. All unacceptable risks shall then be gradually eliminated by means of measures, starting with the highest risk. Risk elimination must also be considered in all the previous specification for layout, robot or object movement, Kinematic or cooperation types. Assigning risks to individual handling steps or process steps as well as their graphical entry in the layout makes it possible to create or generate a simple overview of risks. This will also make it possible to easily identify, grouped and made adjustments in a more targeted manner.[267]

If the above-mentioned measures are not used to prevent risks, then technical and design measures should be taken to prevent them; the level of safety measure must correspond to the degree or level of risk specified or classified. It seems reasonable

[265] Tekouo 2012.

[266] Ostermann et al., 2011.

[267] Ostermann et al.

to define a sequence of consideration according to planning and implementation efforts as well as technical maturity.[268]

Damage-limiting measures should also be applied to provide inherent security to the systems, modules or functions. As a rule, these measures can only be used for small or limited kinetic requirements of the handling task. Individual handling steps can also be monitored using sensors, starting with measures for 'work-space monitoring'.[269]

If the use of sensor-based work-space monitoring seems too coarse, sensory monitoring of kinematics should be considered. Approaches that involve sensors being attached to kinematics are preferable if available space is small, nested, or if there are few or no occlusions.[270]

The use of sensors, however, seems to only suitable for safety-promoting of uncritical functions, e.g. for slowing down the robot movement at subcritical distances. If the assistance system is to be able to avoid obstacles, then this requirement or need must be. In addition, a separation of safety devices should be considered (although this may limit the cooperation capacity of the system) to allow for use with little or no kinetic limitations. Separation is, however, only possible if several contiguous process steps can run automatically.[271]

The last technical-design measure is to use the release. Although this can be used very flexibly, it is expensive for longer process periods in operation, since two resources are tied to one task (with man and an assistance system). Another

[268] Ostermann et al., 2011.

[269] Ostermann et al., 2011.

[270] Ostermann et al., 2011.

[271] Krieger 2010.

drawback is the systematic integration of human sources of error. If there are any remaining risks, it must be determined if they can be organizationally resolved, e.g. by means of operating instructions. Otherwise, previous provisions must be adapted, or the overall concept rejected as unworkable.[272]

Once safety concepts have been selected, their components (such as sensors) must be integrated into the layout, and technical compatibility must also be specified. Once dynamic sizes are determined, the geometric limits (safety distances, workspace restrictions) can be defined. Software tools may be used to support this.[273]

Next, the validity of the previous layout (collision in movements, accessibility) must be ensured, and the safety concepts prom from interference by third parties. The sub-step concludes with the release and definition of the security concept on the rough layout.[274]

5.2.7 Assessment of Assistance and Ergonomics

The objective of this step is to determine the requirements for the employees to be integrated into the assistance systems. For this purpose, common methods for stress analysis and profile comparison must be used. Details such as employee's location, paths, times, and actions should be defined in the rough layout planning.[275]

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[272] Krieger 2010.

[273] Krieger 2010.

[274] Krieger 2010.

[275] Lunze 2013.

Other factors such as load factors (summarized under ambient condition), posture and time regime must be determined. For the general determination of the loads in the fields of force and sensorimotor, the following data[276] should be used:

- Kinetic description of task handling, e.g. by defining the webs of flange, object or operating or interaction media,
- Kinetic interaction between operating media and employees,
- Kinetic interaction between operating media and assistance system, and
- Relative positions between employees and operating media.

Tracks and positions are defined by the previous layout planning. The kinetic interactions can be determined using the following methods[277]:

- Assessment, experience,
- Measurement, Experiment,
- Determination via characteristic curves and
- Determination via transmission function.

It is also necessary to check whether the assistance system impairs the performance of individuals or whether employees are under-utilizing them (under-relying on the assistance systems). If assistance requirements or employee requirements are not sufficiently met, an adjustment in layout or concept must be made. If a corresponding change is not possible, non-robot-assisted approaches shall be considered.[278]

[276] Lunze 2013.

[277] Lunze 2013.

[278] Ostermann et al., 2011.

5.2.8 Assessment of Acceptance

The aim of this sub-step is to identify avoidable potential design defects in regard to assistance-systems so that they can be avoided as a way of increasing acceptance. Factors that contribute to acceptance should be described in the rough concept.[279] Avoidance factors must be evaluated by means of a checklist procedure derived. Proposed solutions must not be rejected simply because all criteria are not met. Instead, they should be examined and improved step-by-step.[280]

5.2.9 Calculation

Three objectives are pursued in this sub-step: evaluation of compliance with financial frameworks, comparison and selection of advantageous implementation alternatives, and the identification of cost drivers within the process steps and system components. For the monetary valuation and audit of the overall system, normal methods of investment accounting must be used, such as cost, comparison, or amortization accounting.[281]

When assessing compliance with the financial framework, it should be remembered that the system boundaries of the assistance system may have extended when additional automation tasks were integrated. Since the use of assistance systems targets the workforce, benefits and effects on the workforce must also be monetarily reflected as far as possible[282]

[279] Kaltenbrunner/Spillner, 2013, p.249.

[280] Kaltenbrunner/Spillner, 2013, p.250.

[281] Kruschwitz 2005.

[282] Falck/Rosenqvist 2012, p.8260.

Comparison and selection of implementation alternatives must also be carried out via the investment invoice. If the alternative solutions differ in their performance or if relevant factors cannot be measured quantitatively or monetarily, a utility analysis can be applied instead. In order to identify cost drivers, an assignment of costs, or in general the expected payment series, must be evaluated in respect to the process steps; an average and a specific assignment can be made, and then formalization carried out after detailed explanation.[283]

Considering the fact that opportunity costs can be proportionally high, further usage possibilities (such as additional automation tasks) can be added or considered.[284]

This is particularly important if the overall system is found not to feasible economically. Expenses are allocated to each process step depending on the cost of resources that the process step requires. Non-attributable costs should be equally distributed to allow for a cost comparison of different execution variants at the process steps. When costs are high for each individual process steps, an iterative review and revision should be carried out at the level.[285]

5.2.10 Description of Measures

A detailed description of measures is the only way to obtain sufficient details for detailed planning and development of work assistance systems. The design for workplace characteristics (which does not get affected by the robot assistance system) should be parallel to the regular assembly system planning.[286]

[283] Falck/Rosenqvist, 2012, p.8262.

[284] Spillner, 2014, p.138.

[285] Spillner, 2014, p.138.

[286] Spillner, 2014, p.139.

The decision for continuous implementation is also made within the framework of regular assembly system planning. If a new assistance system is designed, this must be included as a further solution in a catalogue of measures and examples. In order to supplement the catalogue, the actual use and effect of the measure must be checked in the company and feedback from the users must be sought.[287]

[287] Spillner, 2014, p.139.

6 Results

The goal of the thesis was to arrange a plan for the introduction of an assistance-system in the area of production based on new technologies, human-robot-collaboration and cognitive ergonomics. The expected result was a production line linked with targets to increase the health of the employee's and to generate additional value for companies.

After goals have been defined, suitable entry points in the assembly system plan are identified. This is followed by a detailed description of the preparation and use measures in the catalogue of measures and examples for planning. The developed planning procedure is closely based on the approach of Bullinger et al. (1993).

In the beginning, the procedure, assistance needs are identified and suitable solutions from the catalogue of measures and examples assigned. The handling process is then subdivided into sub-steps to be supplemented by proposed cognitive abilities to arrive at iterative solutions. To ensure applicability of the assistance system, reference is made to well-known procedures. Consistency and compatibility are met through the clear use of step-by-step parameters and procedures.

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