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ASSISTED PROCESS ASSURANCE AND DOCUMENTATION IN A SMALL BATCH ASSEMBLY OF RACING PARTS

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Affidavit

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Acknowledgement

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Patrick Herstätter

Abstract

Nowadays, production companies in industrialized countries are facing increased competition due to globalization of markets. One strategy of dealing with this situation, leads to the approach of serving customer's increasing desire for individualization and delivering high quality products.

Automation is a promising solution approach, to increase quality and lower production costs. However, especially small volume assemblies, with their often highly complex work processes and demand for flexibility, are still predominately operated by humans, since automation reaches its limits in these environments. As a result, process assurance and documentation of assembly processes is challenging and often not adequately secured.

This thesis investigates the challenges posed by a high variant small batch assembly and examines the differences between humans and machines. It takes a look at different categories of assistance systems and how they can deliver solutions to ensure quality and sufficient documentation in the assembly process, by combining the advantages of humans and innovative technical systems.

Data and findings were acquired during a project with a company in the high performance field of the automotive industry. The aim of this project was the development of a concept for the use of assistance systems during assembly in order to meet zero defect policy and full documentation of the assembly process.

Following a phase of analyzing the current state within the company, a research for potentially applicable technical systems was conducted, by investigating state-of-the-art technology as well as systems that are already successfully used in production facilities.

In a second phase, feasible concepts were developed and evaluated, considering the criteria prioritized by the company. The final concept was chosen and refined by including different departments involved in the assembly process, taking into account all relevant perspectives.

Finally, process models that depict assisted assembly processes were developed, by using business process model and notation standard. Allowing the implementation of further technical systems into these models, ensures maximum flexibility and adaptability.

This thesis results in an overview of how to use assistance systems in order to enhance process assurance and guarantee traceability of the assembly process by documentation. For a particular industry task, it delivers a conceptual solution, showing how assistance systems can provide cognitive information support while being able to record all relevant assembly process data.

Kurzfassung

Durch die Globalisierung der Märkte sind Produktionsbetriebe in Industrieländern heute einem zunehmend verschärften Wettbewerb ausgesetzt. Eine mögliche Lösungsstrategie bietet die Erfüllung der steigenden Individualisierungswünsche durch Kunden.

Automatisierung gilt hierbei als vielversprechender Lösungsansatz um die Qualität der Produkte zu steigern und die Produktionskosten zu senken. Doch gerade in Kleinserienmontagen, mit ihren meist hochkomplexen Arbeitsprozessen und dem erhöhten Bedarf an Flexibilität, werden weiterhin überwiegend menschliche Arbeiter eingesetzt, da Automatisierung in diesem volatilen Umfeld an ihre Grenzen stößt. Die Prozesssicherheit und Dokumentation der Montageprozesse wird dadurch zu einer oft nicht ausreichend abgesicherten Herausforderung.

Die vorliegende Arbeit beschäftigt sich mit den besonderen Schwierigkeiten einer variantenreichen Kleinserienmontage und betrachtet die Unterschiede zwischen Mensch und Maschine. Sie untersucht verschiedene Klassen von Assistenzsystemen und wie sie Lösungen zur Sicherung von Qualität und Dokumentation des Montageprozesses liefern können, indem sie die Vorteile von Menschen und innovativen technischen Systemen kombinieren. Die dafür verwendeten Erkenntnisse und Daten, wurden im Rahmen eines Projektes mit einem Unternehmen aus der Automobilindustrie erarbeitet. Ziel dieses Projektes war die Entwicklung eines Konzepts für den Einsatz von Assistenzsystemen in der Montage, um einerseits eine Null-Fehler-Quote zu erfüllen und andererseits den Montageprozess lückenlos zu dokumentieren.

Nach Analyse des derzeitigen Zustands wurden state-of-the-art Technologien und Systeme, die bereits erfolgreich in Produktionsanlagen eingesetzt werden, recherchiert.

In einer zweiten Phase wurden realisierbare Konzepte entwickelt und hinsichtlich vom Unternehmen priorisierter Kriterien bewertet. Um alle relevanten Perspektiven zu berücksichtigen, wurde das endgültige Konzept unter Einbeziehung der am Montageprozess beteiligten Abteilungen ausgewählt und verfeinert. Schließlich wurden Prozessmodelle unter Verwendung des Business Process Model and Notation Standards entwickelt um den assistierten Montageprozess abzubilden. Die Integrationsmöglichkeit weiterer technischer Systeme wurde hierbei berücksichtigt, um ein Höchstmaß an Flexibilität und Anpassungsfähigkeit zu gewährleisten.

Aus dieser Arbeit ergibt sich ein Überblick über den potentiellen Einsatz von Assistenzsystemen, mit dem Ziel die Prozesssicherheit zu erhöhen und die Rückverfolgbarkeit des Montageprozesses durch Dokumentation zu gewährleisten. Für eine konkrete Aufgabenstellung aus der Industrie liefert sie eine konzeptionelle Lösung, die zeigt, wie kognitive Assistenzsysteme durch Bereitstellung von Informationen unterstützend wirken und gleichzeitig alle relevanten Montageprozessdaten erfassen können.

Table of Content

1 Introduction

In today's industrialized countries, production companies increasingly face the challenge of globalization. One possible reaction leads to serving customer's increasing desire for individualization.[1] [2]

This is especially the case for companies in the high performance field in the automotive sector, where special requirements and needs regarding product characteristics pose difficult challenges on the production and in particular on the assembly of products.[3]

Small quantities and highly individual products require a high degree of flexibility,[4] an area in which man continues to outperform technical systems. Hence, assembly cells are predominantly operated by hand in highly variable small series productions.[5] [6]

As a result, however, process assurance and documentation of the assembly process is cumbersome and often a challenge to secure.[7]

Combining the flexibility of human workers with the modern technical systems' capability to process information can deliver a possible solution to meet the high quality requirements in which failures must be prevented under all circumstances and complete traceability represents a competitive advantage.[8] [9]

1.1 Objectives

This thesis aims to increase the process assurance for assembly processes in a highly variable small series assembly by assisting the workers through various technologies and systems.

As this thesis was written during a project in cooperation with a partner from industry, it will focus on special requirements and needs of a supplier in the high performance field of the automotive industry and develop several concepts for the existing assembly cells within the company.

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[1] Cf. Schirrmeister et al. (2003), p.31
[2] Cf. Ostgathe (2012), p.1
[3] Cf. Wiendahl et al. (2004), p.4ff.
[4] Cf. Picot et al. (2003), p.271
[5] Cf. Groover (2008), p.13f.
[6] Cf. Aehnelt (2016), p.4
[7] Cf. Wiesbeck (2014), p.4
[8] ibidem, p.56
[9] Cf. Aehnelt (2016), p.33

The concepts will give an overview of possible workspace designs, technologies and assistance systems which can be used in order to increase process assurance. Therefore existing technologies and assistance systems will be analyzed and evaluated. In addition, it is shown how the use of technical systems and assistance systems allows a documentation of the assembly process which is as comprehensive and complete as possible to be generated, in order to facilitate full traceability.

1.2 Limitations

It is not a goal of this thesis to increase productivity or efficiency within the assembly process, therefore these factors are not specifically considered, nor is process optimization. The cost factor is also not taken into account. This thesis delivers a detailed concept, but does not deal with the further implementation of the developed concept.

1.3 Structure of the thesis

At the beginning of this thesis, the challenges of a small series assembly are addressed. Subsequently, the terms process assurance and documentation are defined and outlined, and an overview of modern assistance systems is given. The focus lies on data collection and provision of information, as well as their application possibilities in a varied small series assembly.

In addition, the tools and methods used during the project, in the context of which this master thesis was written, are presented. This is followed by a detailed overview of the project.

Finally, a short summary of the results of this work and an outlook on potential development possibilities of this project will be given.

Furthermore, the concepts and process models developed during the project can be found in the appendix.

2 Terminology and theoretical input

The following chapter is intended to give an overview of the underlying theory and the basic terminology used in this work. It gives an insight into the challenges of a high variant small batch production and the reason why human workers still play an essential role in this production type. In addition, it summarizes relevant thematic areas such as process assurance, documentation and assistance systems. Furthermore, the methods throughout the course of the associated project are listed and described.

2.1 Terminology

To have a common understanding of the terms used in this thesis, this chapter describes and delimits their use, as different definitions may occur in literature.

2.1.1 Assembly

Assembly plays a major role in the production and manufacturing process of a product.

This fact becomes evident, when looking at a time perspective:

The assembly process takes up to 70% of the total production time, depending on the product and industry. For mechanical engineering this is typically between 20-45%, depending on the complexity of the object.[10]

In order to give a full understanding of which production processes are assigned to assembly, it is important to look at the existing definitions:

According to the VDI guideline 2860, published by the Association of German Engineers, the main task of an assembly is “the combination of parts or groups into products or groups of higher product levels”.[11]

It is usually the last value-adding process before delivery to the customer, and contains all maintained work-steps to put single parts together to a designed product.[12]

The following figure shows functions and processes of assembly. It takes into account the aforementioned definition of the Association of German Engineers, as well as the DIN-standard 8580 from the German Institute for Standardization (DIN).

[10] Cf. Lotter (2012), p.3
[11] Cf. VDI (1990-05)
[12] Cf. Wiesbeck (2014), p.9

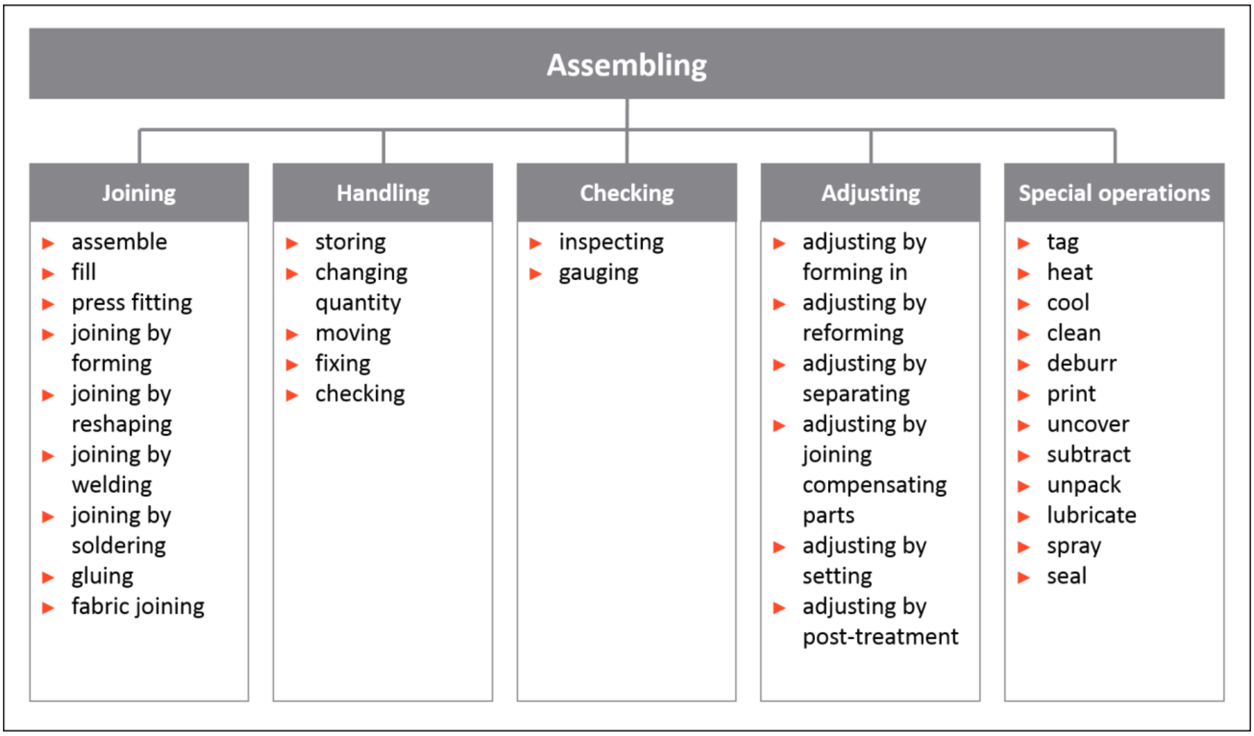

Figure 2-1: Functions and processes of assembly[13]

A further distinction between permanent or semi-permanent connection, can be made in the joining process, depending on how easily, if at all, a disconnection is possible.[14]

2.1.2 Process

An assembly consists of at least one, usually more, processes. Literature delivers various definitions for a process.

According to REFA, a process is defined as a *"sequence of tasks (work) with an internal (technological-organizational) connection for the fulfilment of customer orders involving several work systems."*[15]

A more general approach defines a process as activities that have an input, and create an output by value-adding transformation.[16]

[13] Cf. Lotter (2012), p.2, translated from German
[14] Cf. Groover (2008), p.33
[15] Cf. REFA Consulting (2018), translated from German
[16] Cf. Koch (2012), p.28

Christ summarizes typical characteristics for a process:[17]

- It has a certain pre-defined goal
- A process' activities are performed in a logical sequence
- Starting and ending points are defined for each process
- Input is transformed into output by performing activities
- Each input has a source and the output has a receiver
- For the performance of a process, resources are consumed

According to this definitions, the elements of a process are illustrated in figure 2-2.

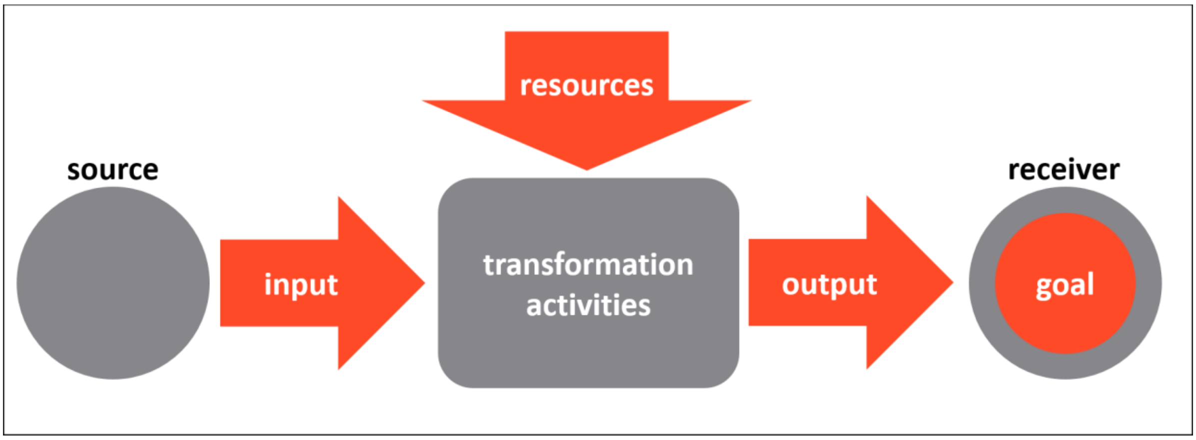

Figure 2-2: Visualization of a process[18]

2.1.3 Data, information, knowledge

Throughout the course of the project, the conception of assistance systems to gather data, deliver information and gain knowledge was conducted, giving the need to specify these terms.

For data, information and knowledge, different definitions are used, depending on the discipline. In this thesis, mainly the definitions from the information technology are mainly to be used.

[17] Cf. Christ (2015), p.40
[18] ibidem, p.40

Data is therefore defined as *"reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing"*[19], while information is *"meaningful data"*[20].

Knowledge is defined as the *"collection of facts, events, beliefs, and rules, organized for systematic use"*[21]

The linkage of the three terms is shown in Figure 2-3.

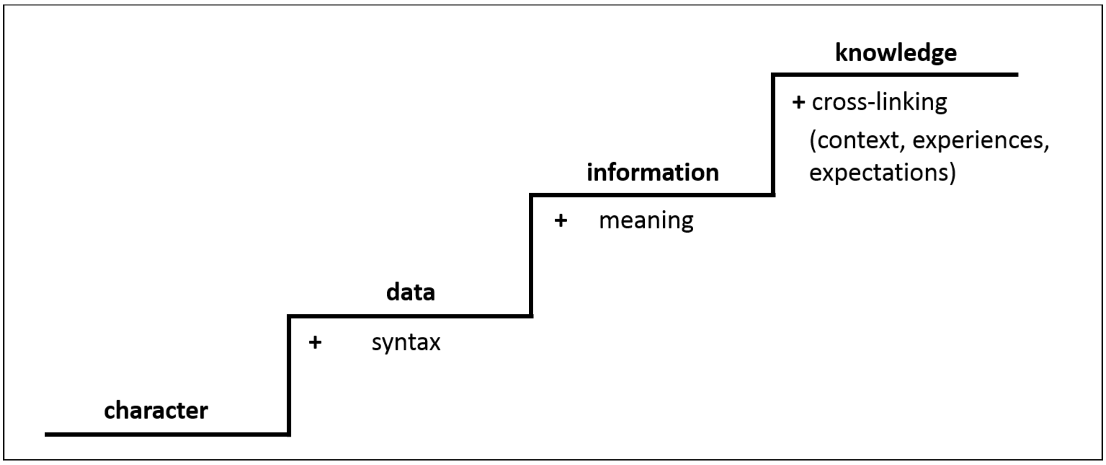

Figure 2-3: The ladder of knowledge[22]

2.1.4 Customer integration

Individualization is the main driver for an increasing number of high variant small batch assemblies.[23]

The degree of individualization is mainly influenced by the time the customer enters the order process, where two main individualization concepts are described in literature: Open individualization, also known as soft customization, is characterized by producing few variants in high numbers. Contrary to that, closed individualization, also known as hard customization, takes into account the customer's needs and wants at an early point in the order process.[24]

The order penetration point (OPP) is the time, when the customer is actively integrated into the production process for the first time. It is therefore usable as an indicator for the degree of customization and subsequently the number of variants produced. The OPP

[19] Cf. ISO/IEC (2015-05)
[20] Cf. DIN EN ISO (2015-09)
[21] Cf. ISO/IEC (2015-05)
[22] Cf. North (2016), translated from German
[23] Cf. Piller (2006), p.114ff.
[24] Cf. Ostgathe (2012), p.13f.

has significant influence on the production strategy, differentiating from a forecast-driven make-to-stock to a customer-driven make-to-order production.[25]

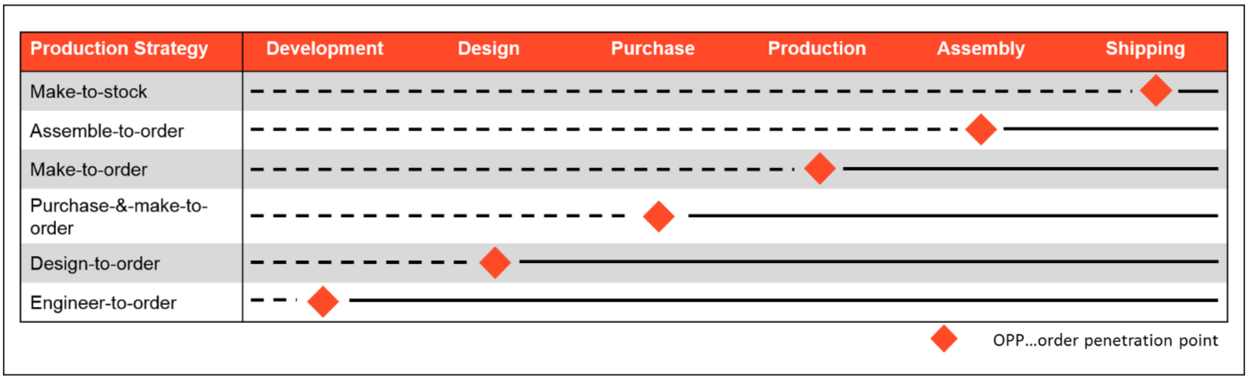

Figure 2-4: Customer Integration – Order Penetration Point[26]

This thesis deals with production strategies of an early order penetration point and the thus resulting high variant small batch assembly types. Early hereby refers to a customer entry point at the stage of development or design.

2.1.5 Variant and variety

When mass production started about a century ago, the main focus of production was standardization, resulting in simplified production process and a significant reduction of production time.[27]

A quote by Henry Ford is widely known: *"Any customer can have a car painted any colour that he wants so long as it is black"*[28].

Ford was very successful in reducing production time and costs. He was able to deliver an affordable product for the masses, but his statement also shows that individualization didn´t play a role at all. Nowadays, as markets in industrialized countries are challenged by globalisation and increasing customer-dependent individualization, companies try to counteract with diversification and serving niche markets.[29]

This results in a high number of variants.[30]

[25] Cf. Obermaier (2017), p. 3ff.
[26] ibidem, own representation
[27] Cf. Ostgathe (2012), p.1
[28] Cf. Ford (2010)
[29] Cf. Wiendahl et al. (2004), p.3f.
[30] Cf. Kestel (1995), p.23f.

According to DIN, a variant is defined as *"objects of similar shape and/or function with a generally high proportion of identical groups or parts"*[31].

By using the term "objects" the possibility of variants on various levels is implied, meaning that there are not only product variants, but module variants and part variants as well.[32]

This thesis' focus lies on the product level, where a different variant is existing, when at least one feature of a product differs from another product and they are therefore not identical. The number of different features is used as an indicator to differentiate between a new product and a variant from an existing product, but the transition is fluid.[33]

From these definitions, variant variety is derived as the number of variants of a part, a module, or a product.[34]

Transferred to products, product variety therefore gives an overview of the numbers of different product variants. Product variety is further divided into hard product variety and soft product variety:[35]

- hard product variety means that products share, if at all, only a few common parts and modules
- soft product variety means that products consist of many common parts and are only slightly different

By combining the definitions of Groover and Kestel, it can be concluded that hard product variety tends to be variety caused by different products and soft product variety tends to be variety caused by different product variants.

2.1.6 Production quantity

Product variety and production quantity cannot be treated independently. The challenges arising with variety lead to longer production times, due to increased set-up processes, and therefore lower produced quantities.[36] [37]

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31 Cf. DIN (2002-03), translated from German
32 Cf. Heina (1999), p.5
33 Cf. Kestel (1995), p.5ff.
34 Cf. Wiendahl et al. (2004), p.7
35 Cf. Groover (2008), p.35f.
36 Cf. Kesper (2012), p.5
37 Cf. Otto (2018), p. 223ff.

The production quantity is *"the number of units of a given part or product produced annually by the plant"*[38]. It therefore differs from the total quantity of all product units produced in a plant. If Q_j represents the production quantity of a product, using j as an index, and Q_f is the total quantity produced by the factory, the following equation shows their relation:[39]

$$Q_f = \sum_{j=1}^{P} Q_j \quad , \; P = product\ variety$$

Equation 2-1: Production quantity[40]

Figure 2-5 shows the correlation between product variety and production quantity.

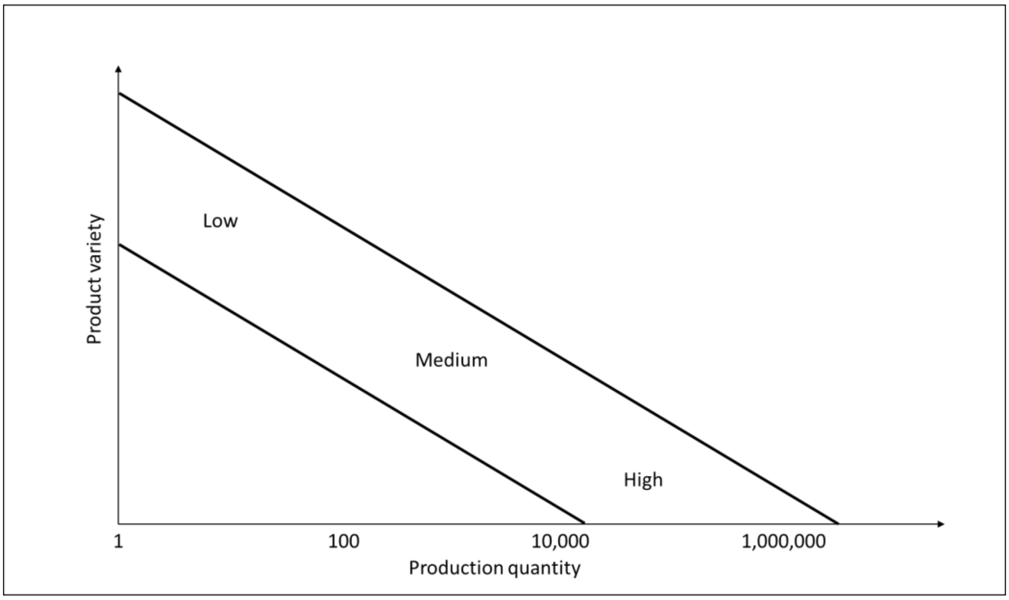

Figure 2-5: Relationship between product variety and production quantity in discrete product manufacturing[41]

Production quantity is classified into low, medium and high production. These classifications can be used to differentiate between three basic categories of production plants, each having different characteristic facility types and layouts, listed in table 2-1.[42]

[38] Cf. Groover (2008), p.35
[39] ibidem, p.39
[40] ibidem, p.39
[41] ibidem, p.35
[42] ibidem, p.36ff

Production quantity	Facility type	Production layout
Low production	Job shop	Fixed position layout
		Process layout
Medium production	Batch production	Process layout
	Cellular manufacturing	Cellular layout
High production	Quantity mass production	Process layout
	Flow line mass production	Product layout

Table 2-1: Characteristic facility types and layouts[43]

2.1.7 Quality and process assurance

Quality is derived from the Latin words “qualitas” and “qualis”, which means “of what”[44].

A modern definition comes from Juran, who gives two definitions for quality:

- *“ ‘Quality’ means those features of products which meet customer needs and thereby provide customer satisfaction”*[45]
- *“ ‘Quality’ means freedom from deficiencies […] ”*[46]

Within this thesis, the focus lies on Juran’s second definition, freedom from deficiencies. A deficiency is hereby defined as *“any fault (defect or error) that impairs a product’s fitness for use.”*[47]

Actions taken to generate trust that something will fulfill the quality requirements are summarized with the term of quality assurance, meaning that it aims for error prevention.[48]

[43] ibidem, p.39, own representation
[44] Cf. Westermeier (2016), p.5
[45] Cf. Juran et al. (1998), p.2.1
[46] ibidem, p.2.2
[47] ibidem, p.2.2
[48] Cf. Reinhart et al. (1996), p.27

In the past it was a more widely defined term, summarizing all actions relating to the quality of products.[49]

Consequently, process assurance is used in this thesis as the aim to ensure that all assembly processes are carried out in accordance with the quality requirements, in order to generate deficiency free products and/or components.

2.1.8 Documentation

In a broad sense, documentation means the compilation and utilization of documents and materials of any kind.[50] Within this thesis, the focus lies on the more restricted term of technical documentation, which can further be divided into internal and external technical documentation. External technical documentation is delivered with the product to inform about it and leaves the company.[51]

It typically consists of an instruction manual for the customer, with content such as product descriptions, correct handling or performance specifications.[52]

An internal documentation on the other hand summarizes all product information that is acquired during the whole product's lifecycle, starting from product planning over production and testing until disposal.[53]

Internal documentation is the type of documentation this thesis deals with. Therefore, documentation, as it is understood in this thesis, contains all product-related data that is acquired throughout the production process, especially the assembly.

Particularly in the automotive industry, documentation plays an important role for quality, as it *"is both a support and a basis for the quality audit of the company"*[54].

As a result, several quality standards define quality and documentation. They provide pursuing information on quality and documentation. One of the most relevant is the ISO9001:2015 "Quality management systems – requirements", with documentation discussed under the term "documented information"[55]

[49] ibidem, p.27
[50] Cf. DUDEN online (2018)
[51] Cf. Barthelmey et al. (2014), p. 207ff.
[52] Cf. Juhl (2015), p.18
[53] Cf. Barthelmey et al. (2014), p. 207ff.
[54] Cf. Valastiak (2017/2018), p.86
[55] ibidem, p.87ff.

2.2 High variant small batch assembly

2.2.1 Trend for individualization

A trend for individualization can be observed both in the field of industrial goods and the consumer market, although for different reasons.[56]

For industrial goods, amongst others, the increase of supplier integration through procurement of finished sub-assemblies instead of single parts, is the main driver for individualization. In consumer markets, a change of values is observed, based on changes in the labour market, such as an enhanced need for qualifications on the one hand and changes in society, such as increasing education level, leisure time and income on the other.[57]

As these factors are dependent on the level of industrialization of a country, individualization plays an important role, mainly in industrialized countries, for example Germany:

According to an observation of the future of production in Germany, the competitiveness of German companies is heavily dependent on the ability to produce customer specific products of highest quality through flexible and potent production.[58]

The result is an increasing number of variants and therefore high variant variety, as already mentioned in chapter 2.1.5, is the consequential result. As chapters 2.1.5 and 2.1.6 described, a high variant variety leads to low to medium production quantities and therefore facility types such as job shop or batch productions.

When looking at the automation level of these facility types, especially for the assembly they are still characterized by a high proportion of manual work.[59]

The automation level of productions and assemblies can be subdivided into 4 categories, and is defined as shown in figure 2-6.

[56] Cf. Piller (2006), p.42ff.
[57] ibidem, p.42ff
[58] Cf. Schirrmeister et al. (2003), p.75
[59] Cf. Heina (1999), p.103

Automation Level		Description
manual		only manual tools available
mechanized		hand-operated machines available
partially automated		automated machines for some process steps
fully automated		automated machines for all process steps

Figure 2-6: Automation levels in production[60]

The long pursued aim of a fully automated “computer integrated assembly” has proven to be unfeasible and unachievable.[61]

2.2.2 Reasons for high manual work share

In order to understand the reason for high manual work share in low volume assemblies with many variants, it is necessary to take a look at the differences between humans and machines.

Due to their significantly different characteristics, humans and machines succeed over each other in disparate fields.[62] [63]

Humans have advantages regarding creativity, flexibility and fine motor skills. They are able to draw conclusions and have a memory, allowing them to fall back on experience. Machines on the other hand work with high accuracy and speed, do not suffer from performance losses due to fatigue and can calculate complex tasks within milliseconds. Furthermore they exceed the physical perception abilities of humans and are able to multitask.[64]

However, their flexibility is limited and this combined with the low number of repeated work steps in a high variant assembly makes their use expensive and inefficient, while

[60] Cf. Konold et al. (1985), p.71, own representation
[61] Cf. Wiendahl et al. (2004), p.4
[62] Cf. Groover (2008), p.6
[63] Cf. Gerke (2015), p.107f.
[64] ibidem, p.107

human's flexibility allows them to react quickly and efficiently to changing production conditions.[65] [66]

Especially under the following conditions, which correspond to those of a small series assembly and are listed by Groover, "*manual labor is preferred over automation:*

- *Task is technologically too difficult to automate. […]*
- *Short product life cycle. […]*
- *Customized product. […]*
- *Ups and downs in demand. […]*
- *Need to reduce risk of product failure. (economically, remark of the author) […]*
- *Lack of capital. […]"*[67]

2.2.3 Challenges of a high variant small batch assembly

High variant small batch assemblies underlie different environmental conditions than the mass production of a product with no significant number of variants. Production complexity is higher, due to individualization and a rising number of variants.[68]

This leads to a decrease in productivity, as a survey by Lay shows. Lay identifies that batch size and time of customer integration have a direct impact on companies' productivity numbers. The deviations from the branch average can be seen in figure 2-7, showing that individualization and maximizing productivity are diverging goals.[69]

[65] Cf. Bächler et al. (2015), p. 56ff.
[66] Cf. Wiesbeck (2014), p.1
[67] Cf. Groover (2008), p.13f.
[68] Cf. Piller (2006), p.130
[69] Cf. Lay et al. (2009)

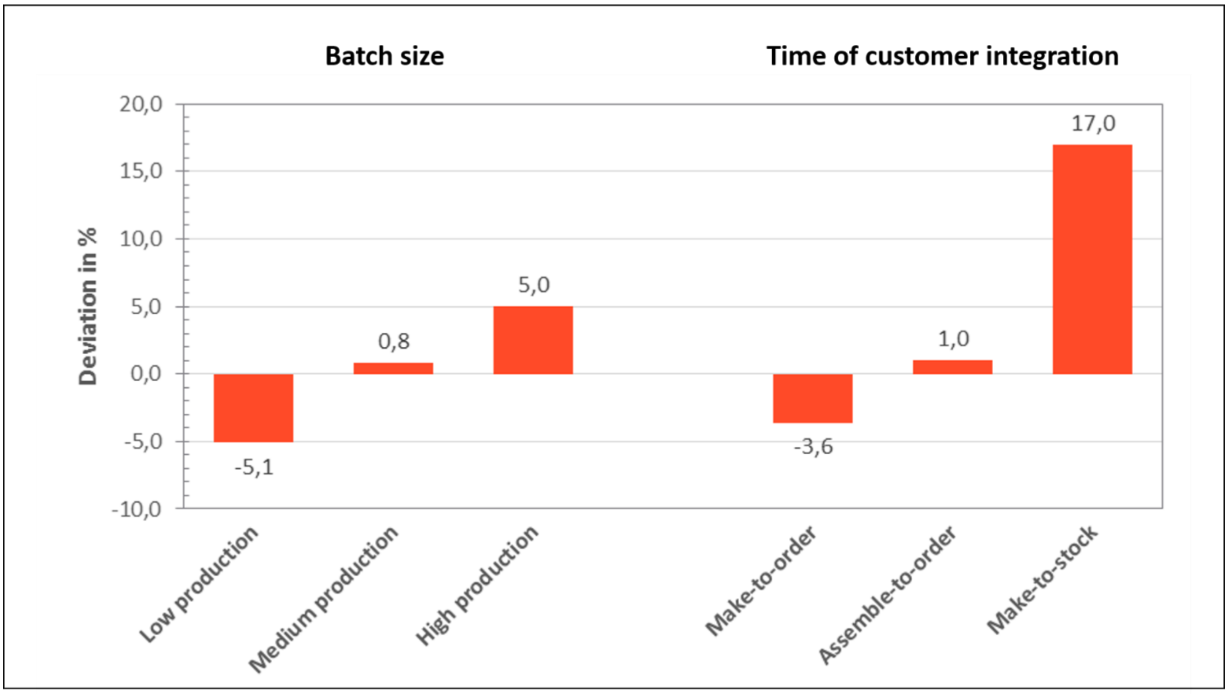

Figure 2-7: Average deviation of productivity[70]

Hesselbach and Menge name several challenges in a high variant assembly, causing the shown decrease in productivity:[71]

- malfunctions due to defects and changes
- less learning effects
- alternating bottlenecks
- high inventory
- high throughput time
- little to no scale effects due to small batch sizes
- increasing setup costs

An additional issue is that many production errors are identified and have to be fixed during assembly, lowering productivity further.[72]

The low automation level in a high variant assembly poses even more challenges, due to a resulting high manual work share.[73] [74]

[70] ibidem, p.8 own representation
[71] Cf. Hesselbach et al. (2002), p. 87ff.
[72] Cf. Riffelmacher (2013), p.5
[73] Cf. Groover (2008), p.13
[74] Cf. Wiendahl et al. (2004), p.4

A frequent change of assembled variants leads to an early abortion of the learning curve and its positive effects.[75]

In addition, variant specific processes with low repetition rates have a five- to six-times higher failure rate, mainly due to an inexperienced workforce.[76] This already implicates one major complexity regarding human workers: their uniqueness. Needs for information support, and consequently work performance, can differ greatly and are highly individual.[77] [78]

Through factors like genetics, social environment and education, humans differ from each other, while machines can be reproduced and adapted as needed.[79] Other factors which influence work performance are skills, qualifications and experience, as mentioned above. Moreover, the work performance of human workers does not stay the same over a whole work shift.[80] The human performance level varies over time, as figure 2-8 points out.

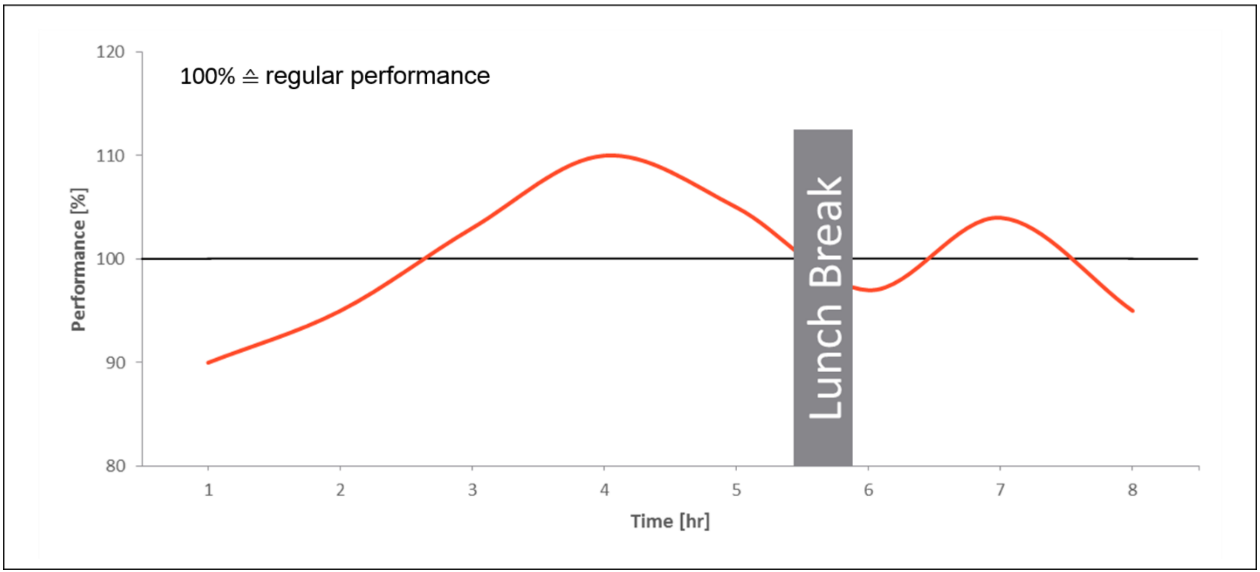

Figure 2-8: Course of human performance level[81]

Although work performances differ greatly, it is possible to level them to a certain extent through training and providing information to overcome lack of qualification.[82] [83]

[75] Cf. Wiesbeck (2014), p.2
[76] ibidem, p.4
[77] Cf. Aehnelt (2016), p.14ff.
[78] Cf. Schuh et al. (2014), p. 277ff.
[79] Cf. Gerke (2015), p.107
[80] Cf. Lotter (2012), p.109
[81] ibidem, p.110, translated from German
[82] Cf. Wiesbeck (2014), p.56
[83] Cf. Gerke (2015), p.107

However, human ability to process information is limited.[84] If humans need to process more than one task or piece of information at the same time, both require attention and can therefore interfere and hinder each other.[85]

Figure 2-9 shows that in a make-to-order production, typical for high variant small batch assemblies, there is a high demand for information and flexibility, combined with high uncertainty and coordination demand.

Figure 2-9: Characteristics of different production strategies[86]

As a result, workers face an abundance of information, forcing them to tediously search for the right instructions and documents, ultimately relying on existing knowledge and experience instead.[87]

Consequently, to ensure that a worker is able to process the information quickly and easily and is not overburdened instead, it is crucial to deliver the right information, at the right time and the right place.[88]

Digital assistance systems, with their ability to process a seemingly infinite amount of information within fractions of a second, can provide a solution to deliver the worker with sufficient context based information.[89] [90]

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[84] Cf. Zäh et al. (2007), p. 644ff.
[85] Cf. Gerke (2015), p.113
[86] Cf. Picot et al. (2003), p.271
[87] Cf. Wiesbeck (2014), p.4
[88] Cf. Unrau et al. (2016)
[89] Cf. Gerke (2015), p.107
[90] Cf. Aehnelt (2016), p.70

2.3 Assistance systems

Assistance systems combine the abilities of human workers with the abilities of modern technology and machines, hence providing promising solutions for problems that require both the flexibility of humans and the accuracy and efficiency of machines.[91]

2.3.1 Definition

Giving a precise definition of assistance and assistance systems is challenging due to the wide spread use of the term and the thus resulting high number of associations. With assistance meaning the solution of a task with the help of external skills or tools, each technical system becomes an assistance system, ranging from screw drivers to software systems.[92] [93]

In a narrower sense, an assistance system usually consists of a human-machine-system where at least one human cooperates with a technical system. Within this system, usually the human can usually either be a user or operator, depending on the work load of the machine. In the course of an assistance function, labor is divided between man and machine in a way that both can perform the same work task in parallel, meaning that the human can be a user or operator at the same time. If a technical system assists the human performance automatically in order to optimize the result, we are dealing with an optimizing assistance system.[94]

Implying that the assistance system must have the possibility for active intervention, this definition on its own is too narrow for this thesis, as this is not always the case, especially in manual assembly processes. Therefore it should be extended using the following definitions, describing different levels of assistance systems:[95]

- assistance systems are systems that can perform simple functions automatically without being triggered by the user

[91] Cf. Bächler et al. (2015), p. 56ff.
[92] Cf. Ludwig (2015), p. 5ff.
[93] Cf. Günthner et al. (2014), p. 297ff.
[94] Cf. Gerke (2015), p.23ff.
[95] Cf. Ludwig (2015), p. 5ff.

- assistance systems can combine several functions of devices, hence assisting the user with the conduction of a pre-defined process by delivering all necessary functions for one task in a comprehensive way
- in the most complex specification, an assistance system is able to recognize the users intention, derive the task to be performed and propose possible approaches to solve the task

What unites all of them is that, if applied correctly, every assistance system should unburden human workers and enhance their work performance.[96]

2.3.2 Classification

Due to the already widespread definition of assistance systems, the same applies to classification of assistance systems. There are various approaches in literature to classify assistance systems, focusing on different characteristics.

One approach is the amount of physical work that the human worker actually spends on the execution of the actual work process, providing three possible classifications:[97]

- systems that leave physical work to the human, but support make work easier through cognitive support
- systems that cooperate with humans in order to share the physical work load
- systems that conduct the physical work processes, leaving the human with control functions only

Two further factors that allow the classification of assistance systems, initiative and adaptability, are described by Ludwig:[98]

- initiative defines whether the assistance system acts actively (autonomous) or passively (activation is carried out by user)

[96] Cf. Martin (2014), p.13
[97] Cf. Brea et al. (2013), p.8
[98] Cf. Ludwig (2015), p. 5ff.

- adaptability defines whether the system's assistance functions are able to recognize context and act accordingly (adaptive), can be adapted by the user (adaptable) or are not adaptable at all (static)

Another approach with specific focus on assembly assistance systems classifies assistance systems according to their types of input and output system. For this classification, it is assumed that an assistance system requires at least one input and one output system to allow communication and cooperation with the human worker.[99] Figure 2-10 depicts this classification.

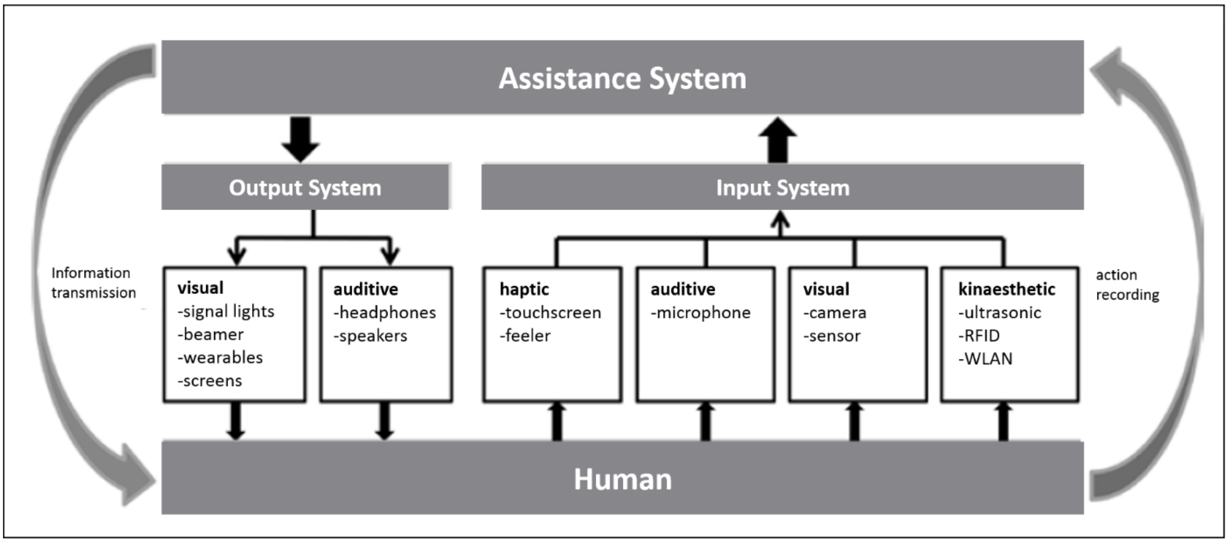

Figure 2-10: Classification of assistance systems regarding to input and output systems[100]

Cognitive automation can also be used to classify different assistance systems. It describes the procedure of an assistance system conducting cognitive processes for the human operator. The degree of cognitive automation is defined by the extent and depth of the cognitive processes conducted by the assistance system, distinguishing four stages: perception, integrate information, decide and act.[101]

A high cognitive automation level reduces the responsibility of the worker and can therefore pose challenges regarding acceptance and attentiveness. [102] [103]

[99] Cf. Merazzi et al. (2017), p. 413ff.
[100] ibidem, translated from German
[101] Cf. Aehnelt (2016), p.25f.
[102] ibidem, p.24
[103] Cf. Wiesbeck (2014), p.77

As described in chapter 2.1, human workers will keep their important role in high variant small batch productions, leading to the need for an assistance system that makes work easier. Due to different skill and experience levels, the assistance system should act context sensitive and the main purpose of assistance in the aforementioned production environment is the provision and acquisition of meaningful data, by using appropriate input and output systems. Additionally, the system should provide the ability to make decisions about quality aspects. The following table delivers a morphology of assistance systems which summarizes the classifications outlined in this chapter and additionally shows which assistance system should be preferably used for a high variant small batch assembly, as investigated throughout this thesis.

<table>
<tr><td>physical work</td><td colspan="4">human</td><td colspan="4">cooperation</td><td colspan="4">machine</td></tr>
<tr><td>initiative</td><td colspan="6">passive</td><td colspan="6">active</td></tr>
<tr><td>adaptability</td><td colspan="4">adaptive</td><td colspan="4">adaptable</td><td colspan="4">static</td></tr>
<tr><td>input system</td><td colspan="3">haptic</td><td colspan="3">auditive</td><td colspan="3">visual</td><td colspan="3">kinaesthetic</td></tr>
<tr><td>output system</td><td colspan="6">visual</td><td colspan="6">auditive</td></tr>
<tr><td>cognitive automation</td><td colspan="3">perception</td><td colspan="3">integrate information</td><td colspan="3">decide</td><td colspan="3">act</td></tr>
</table>

Table 2-2: Assistance system classification and preferred system

2.3.3 Advantages and impacts

There are various reasons for implementing an assistance system in production.

Assistance systems with their intuitive provision of information can increase the speed and efficiency of manual work steps. Integrating cyber-physical-systems can further deliver instant feedback on faulty performances and thus increase quality and efficiency of the assembly process.[104] [105]

The challenges of a high variant small batch assembly, described in chapter 2.2.3, will not only impose both physical and mental stress on workers but likely lead to quality

[104] Cf. Günthner et al. (2014), p. 297ff.
[105] Cf. Wiesbeck (2014), p.56

issues. Assistance systems can help human workers to compensate their limitations in order to meet performance requirements, by providing situative support.[106]

Human workers need for support will increase not only due to changed product conditions but also because of demographic changes.[107]

The average age of the work force is increasing due to an aging society, posing additional challenges for companies, especially regarding to the integration of performance-changed employees. A survey from 2013 investigating German companies showed that as of this year, the share of performance-changed employees was already 20%. Using adaptive assistance systems compensates for these impairments.[108]

Support can take place in numerous situations such as maintenance, monitoring of production processes, quality controls, provision of sufficient information and planning processes.[109]

Industry 4.0 (cf. chapter 2.3.4) can increase the quality of the work in terms of better work-life-balance or compatibility of work and family.[110]

Especially in view of an increasing number of single parents, this factor should not be neglected either. But industry 4.0 also increases complexity of production and leads to a shift in work types, such as an increase in high-value tasks and less repetitions, where intuitive assistance systems will provide guidance and simplification.[111] [112]

2.3.4 Driving factors for assistance systems – industry 4.0

Assistance systems have gained increased importance in industry since the upcome of industry 4.0. Industry 4.0 is a term, characterized in Germany, for the 4th industrial revolution by the implementation of cyber-physical-systems (CPS) in production. Cyber-physical-systems are smart systems, able to interact with their environment. The linkage of this CPS is also referred to as internet-of-things (IOT). Industry 4.0 was mainly driven by and is still building on the fast development in the field of information and communications technology (ICT) over the last few decades.[113]

The four industrial revolutions are shown in figure 2-11.

[106] Cf. Hold et al. (2017), p. 143ff.
[107] Cf. Bächler et al. (2015), p. 56ff.
[108] ibidem
[109] Cf. Gorecky et al. (2014), p. 525ff.
[110] Cf. Kagermann (2014), p. 603ff.
[111] ibidem
[112] Cf. Brea et al. (2013), p.12
[113] Cf. Kagermann et al. (2013), p.17

Industry 4.0 aims to react to the changes in production environments caused by various factors like globalization, demographic change or climate change. It enables high-wage countries to stay competitive and keep a high share of value adding in the field of production nationally.[114]

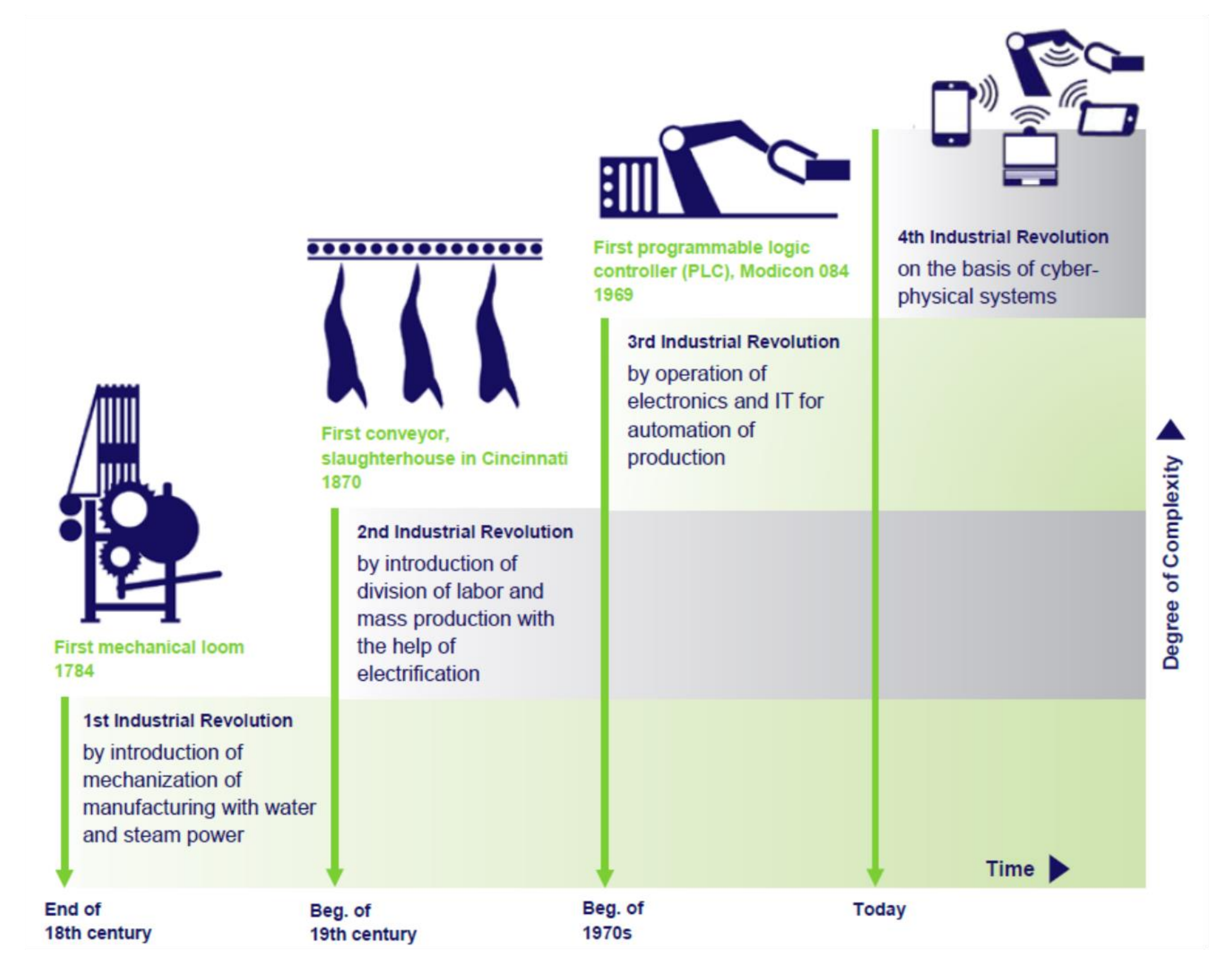

Figure 2-11: The four industrial revolutions[115]

To cope with the challenges of high complexity (cf. chapter 2.2), CPS are used to build up smart factories. CPS can act as a base for assistance systems, especially in the sense of ambient intelligence, meaning that the environment recognizes the human's presence and reacts accordingly. By using ICT, ambient intelligence connects smart objects in the human's work environment in order to deliver context-based information and functions.[116]

[114] Cf. Bauernhansl (2014), p. 5ff.
[115] Cf. Gehrke et al. (2015), p.5, original graphic by Kagermann et al. (2013)
[116] Cf. Wölfle (2014), p.26

Smart factories and CPS, with their ability to communicate autonomously and decentralized, are able to acquire and process real-time data, hence allowing to create a virtual image of the real world.[117] With their ability for cognitive processes, smart factories will combine the advantages of automated systems with the advantages of human workers, by providing a previously unattained level of support.[118]

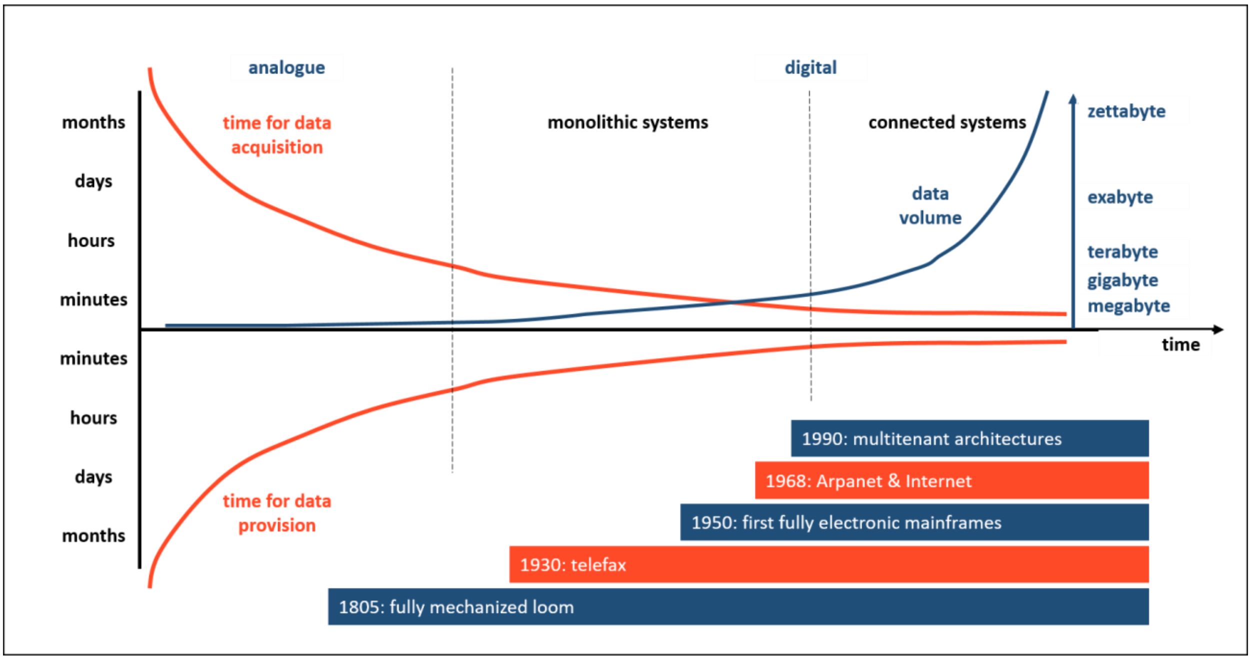

Figure 2-12: Digitalisation of production and IT-technology[119]

Figure 2-12 shows how digitalization has changed data in production over time. The upper orange curve represents the time for data acquisition, while the lower orange curve represents the time for data provision and the blue curve represents the amount of data. Through significantly lower times for acquisition and provision, the amount of data processed has increased substantially, whilst also creating new possibilities for information support.[120]

2.3.5 Information assistance systems

Over the course of this master's thesis, the focus lies on providing the worker with adequate information at the right time. Furthermore, process data should be acquired for

[117] Cf. Bauernhansl (2014), p. 5ff.
[118] Cf. Zäh et al. (2007), p. 644ff.
[119] Cf. Bauernhansl (2016), p. 453ff., translated from German
[120] ibidem

documentation and traceability reasons. A cognitive information assistance system, as described by Aenehlt, is therefore the preferred solution.

Assistance systems for information support are cognitive assistance systems with the aim of analyzing the current work condition and providing suitable information. The information can thereby be gathered and summarized from different sources. Additionally, the information content and detail level is adapted to the individual worker in order to provide all information needed for the proper performance of tasks. Lastly, a cognitive information assistance system is able to learn independently from the worker's behavior and environmental change.[121]

In order to ensure that the provided information is processed correctly, it is important to know how the cognitive process of human's work.

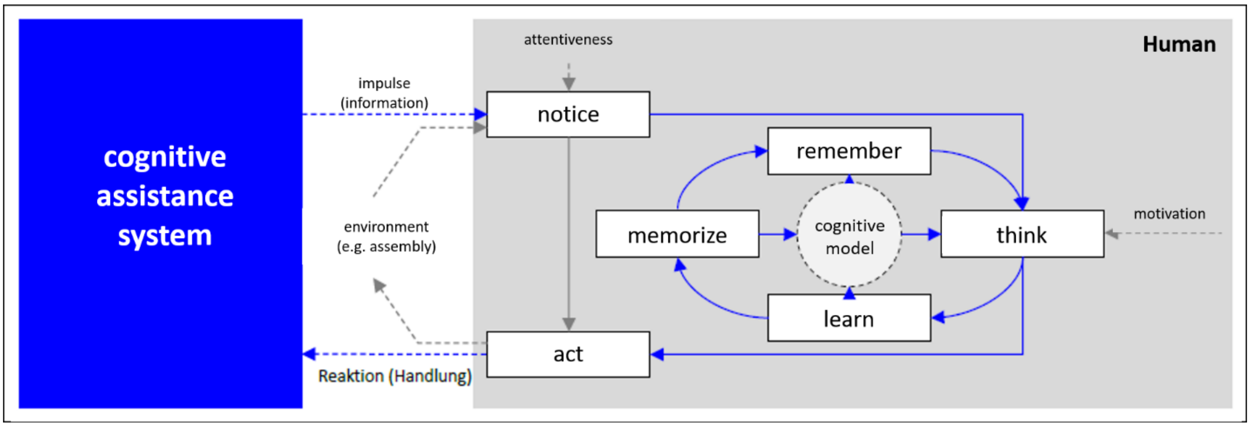

Figure 2-13: Processes of human cognition[122]

Within the field of information assistance systems, a distinction must also be made between the approaches of a cognitive factory and the approaches of a cognitive workplace. If the cognitive factory primarily aims to take over the cognitive tasks and associated decisions, these are left to the human in the cognitive workplace. The cognitive workplace aims to decrease complexity and cognitive stress for the human worker in order to enhance his performance of production processes. Information flows are automated by the system, but the physical work load is still carried out by humans.[123]

[121] Cf. Aehnelt (2016), p.4
[122] ibidem, p.20, translated from German
[123] ibidem, p.31f.

2.3.6 Requirements and Challenges

The following requirements have to be fulfilled by an assistance system in general:[124]

- Flexibility, meaning the system should be usable for versatile work tasks
- Scalability, meaning that the system takes into account the worker's skills, qualifications and experiences, responds accordingly and does not overburden the worker with information
- Moral-increasing mechanisms, meaning that there are some motivating element implemented, e.g. an indicator showing the work progress
- Simple human-machine-interfaces, meaning the system is easy to use and the presentation and processing of information is done in a way which is known for the worker[125]

From a software perspective, algorithms that are designed to provide assistance need to consider the following requirements:[126]

- goal-orientation: an assistance system needs goal-orientation in order to decide whether an action has unwanted consequences for the future
- interactivity: in scenarios without objective parameters, reliable decisions, as required for autonomous assistance, cannot be ensured
- duration: assistance is provided over several steps
- observability: in case of partial observability, assistance still can be provided
- uncertainty: assistance has to deal with "non-deterministic" actions, as the behavior of the environment cannot be controlled

Regarding information assistance systems, Aehnelt lists several challenges which must be considered during the planning, some of them human related, other system related.[127]

[124] Cf. Martin (2014), p.17
[125] Cf. Gerke (2015), p.136f.
[126] Cf. Ludwig (2015), p. 5ff.
[127] Cf. Aehnelt (2016), p.6f.

The challenges resulting due to the information assistance system are:[128]

- modelling: the perception of the working environment by the system must be interpreted in a similar way as it is by the human worker, leading to the requirement for similar background knowledge, which is not available. It therefore must be identified and modelled manually.
- level of automation: an information assistance system aims to automate the information flow between human workers and production systems, therefore requiring a high integration and automation of information, interfaces and work processes within the production system in both directions (human <–> technology).
- efficiency: the cognitive processing of information is used for the preparation and checking of physical actions. This leads to a decrease in quality in case of faulty information interpretation. Interpretation errors must therefore be avoided in the first way and rectified if they happen.

Human related challenges are:[129]

- perception: human ability to process and perceive information is limited, especially when performing physical actions and a thus resulting focus on the object of action. The information assistance system therefore needs to be implemented in a way that ensures the perception of information despite the performance of actions.
- cognition: human cognition is highly individual and dependant on a high number of different factors, such as motivation, attention or performance. As a result, it is necessary to adapt to the individual human worker by providing situative information.
- acceptance: the acceptance of information provided by the human worker is dependent on his acceptance of the information assistance system itself.

[128] ibidem, p.6f.
[129] ibidem, p.5f

According to Unrau the following factors impact the acceptance of assistance systems by the workers:[130]

- the worker's possibility to influence the assistance system
- transparent work processes by the assistance system and an understanding of its characteristics
- information must be provided in a reliable and understandable way
- consideration of individual needs and wishes

2.3.7 Application in small batch assemblies

In order to apply assistance systems generally, the following figure shows a possible procedure for system design. During the associated project the first two steps were applied:

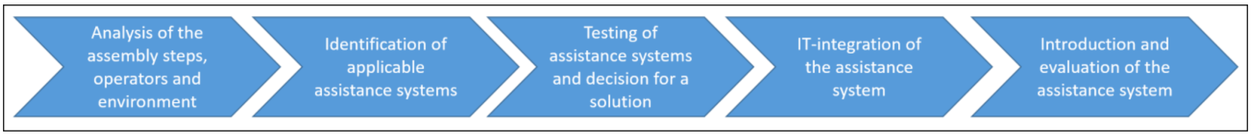

Figure 2-14: Procedure for system design of assistance systems[131]

The information assistance system needs to provide the worker with an assembly construction, which consists of information about what must be assembled when and why. Complemented with the worker's individual knowledge and experience, a proper performance of the work task needs to be ensured. Provided information typically needs to be gathered from the following entities:[132]

- **technical design:** contains the customer requirements
- **design engineering:** contains the specifications of a product, including a 2D or 3D construction model, structural geometrical and technical product data and a bill of materials

[130] Cf. Unrau et al. (2016)
[131] ibidem, translated from German
[132] Cf. Aehnelt (2016), p.43ff

- **technical documentation:** contains assembly instructions for the worker, including explosion drawings, illustrations, specific instructions, notes and inspection plans
- **production planning:** plans the manufacturing and assembly process and creates a work plan
- **assembly:** during the assembly, work steps and assembly data is acquired and documented

For cognitive information assistance systems, the embedding in existing information technology infrastructure is crucial in order to be able to acquire, process and provide all necessary data and further information. A proper embedding ensures access to all relevant data and allows communication between the different levels of information processing.[133]

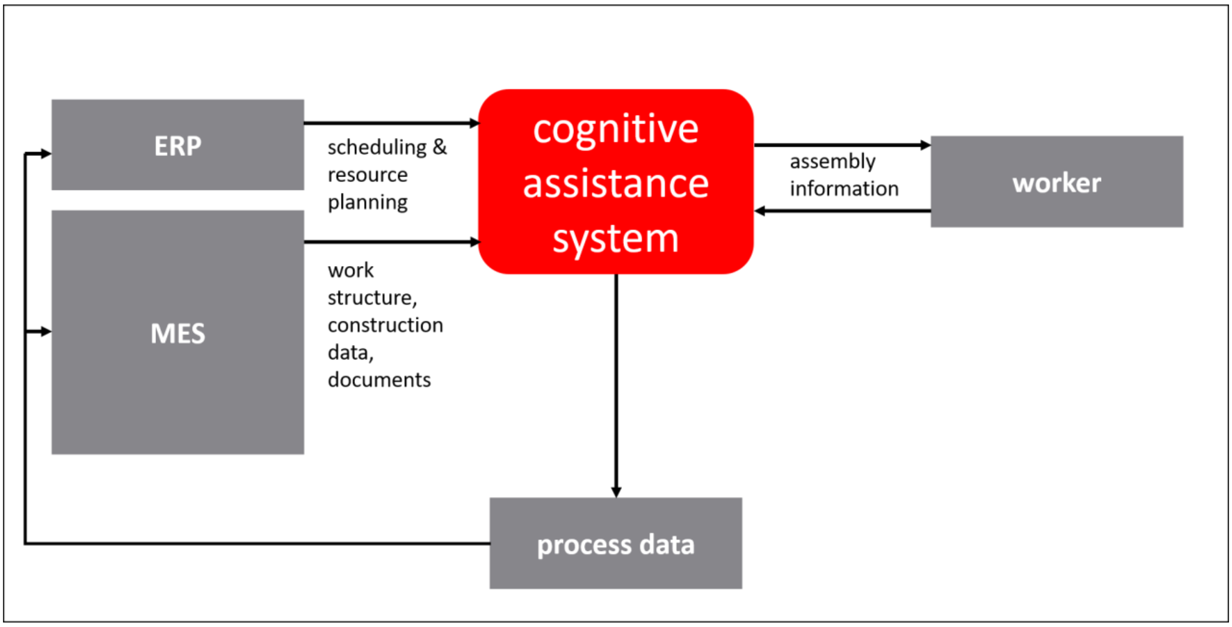

Figure 2-15: Embedding of cognitive assistance systems in existing structures[134]

These levels of information processing can be depicted in the automation pyramid. The automation pyramid shows the communication within industrial companies and divides the processes into different layers, hence giving an easily understandable picture of industrial manufacturing and reducing complexity of data acquisition and processing.[135]

[133] ibidem, p.47
[134] ibidem, p.47, own representation
[135] Cf. Siepmann (2016), p. 47ff.

In literature, many different variants of the automation pyramid are described, but for this thesis a classic model, developed by Siepmann is used.

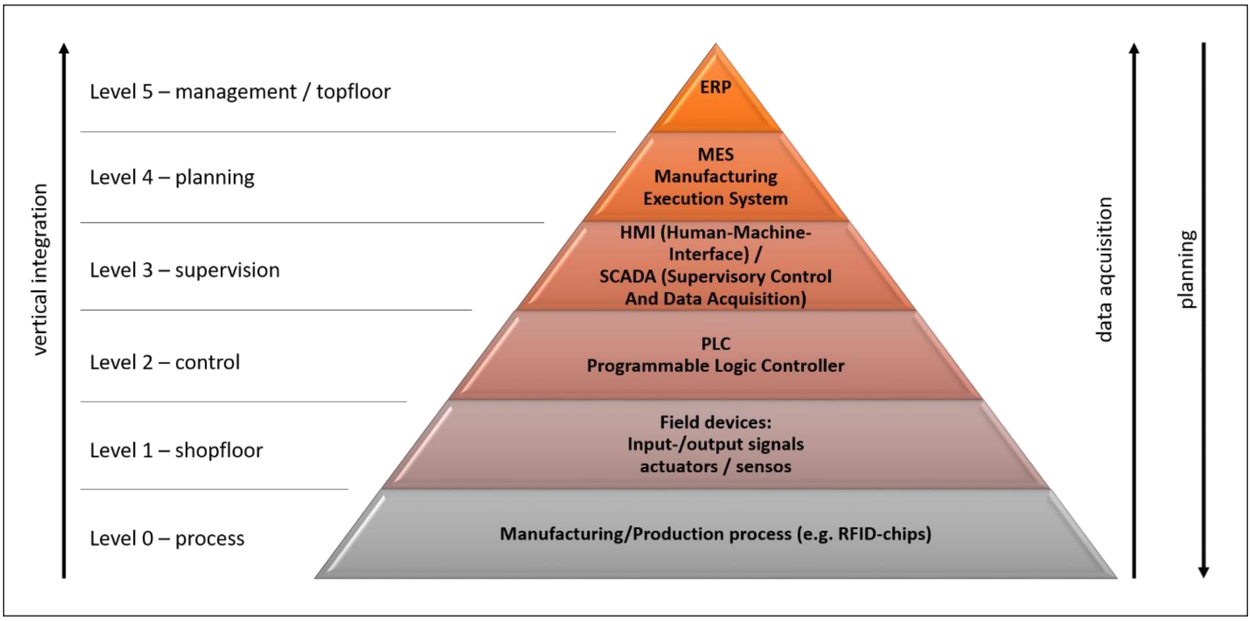

Figure 2-16: Automation pyramid[136]

There are six different levels of the automation pyramid that have to be considered for a holistic approach, pictured in figure 2-16:[137]

- **level 0** - process level:
  includes manufacturing and production processes
- **level 1** – field level / shop floor:
  includes actuators and sensors and processes production relevant input and output signals
- **level 2** – control level
  includes logical controllers such as PLC, and plays a major role in decentralized machine and plant control
- **level 3** – (process-)supervisory level
  acts as a human-machine-interface by visualizing production relevant processes
- **level 4** – planning level
  is responsible for the control of production and acts as “connector” between the topfloor and machine control

[136] ibidem, own representation
[137] ibidem

- **level 5** – management level
  also known as topfloor, this level is responsible for production management and order processes

2.3.8 Approach to achieve context sensitivity

It is important to provide the worker with needed information at the right time and in the right amount, meaning that the information has to be provided context-sensitive.[138]

Context sensitivity requires knowledge about the current product condition, hence two factors should be considered:[139]

On the one hand, it is important, that the assistance system is able to acquire information to identify environmental conditions, context and changes. On the other hand, the system needs to be able to react and adapt the provided information accordingly, which requires the availability of sufficient data.[140] [141]

The concept of state-dependent generation of assembly instructions could provide a meaningful approach, to implement context-sensitivity in assistance systems.[142]

Figure 2-17 shows the concept visualized in a graph, with an initial state Z_0 and a target state Z_{End}. The circles in the graph represent current conditions of the product to produce and the arrows represent instructions and information that are provided to the worker in order to convert the product from one condition into another. If a condition has more than one outgoing arrow, it means that there are several possible ways to continue with the assembly. D_{max} represents the maximum step size within the graph, thus determining the level of detail of the instructions.[143]

Work instructions and information are generated in such a way that they always represent the shortest possible path along this graph in order to reach the target state, taking into account that the maximum step size is not surpassed.[144]

This ensures a maximum flexibility for the worker, as there is no pre-defined sequence of work steps and the instruction and given information adapts to the workers needs and

[138] Cf. Unrau et al. (2016)
[139] Cf. Wiesbeck (2014), p.52
[140] ibidem, p.52
[141] Cf. Wölfle (2014), p.16f.
[142] Cf. Zäh et al. (2007), p. 644ff.
[143] ibidem
[144] ibidem

style of work. It should be noted, that this concept has limitations, as disassembly processes are not considered or allowed.[145]

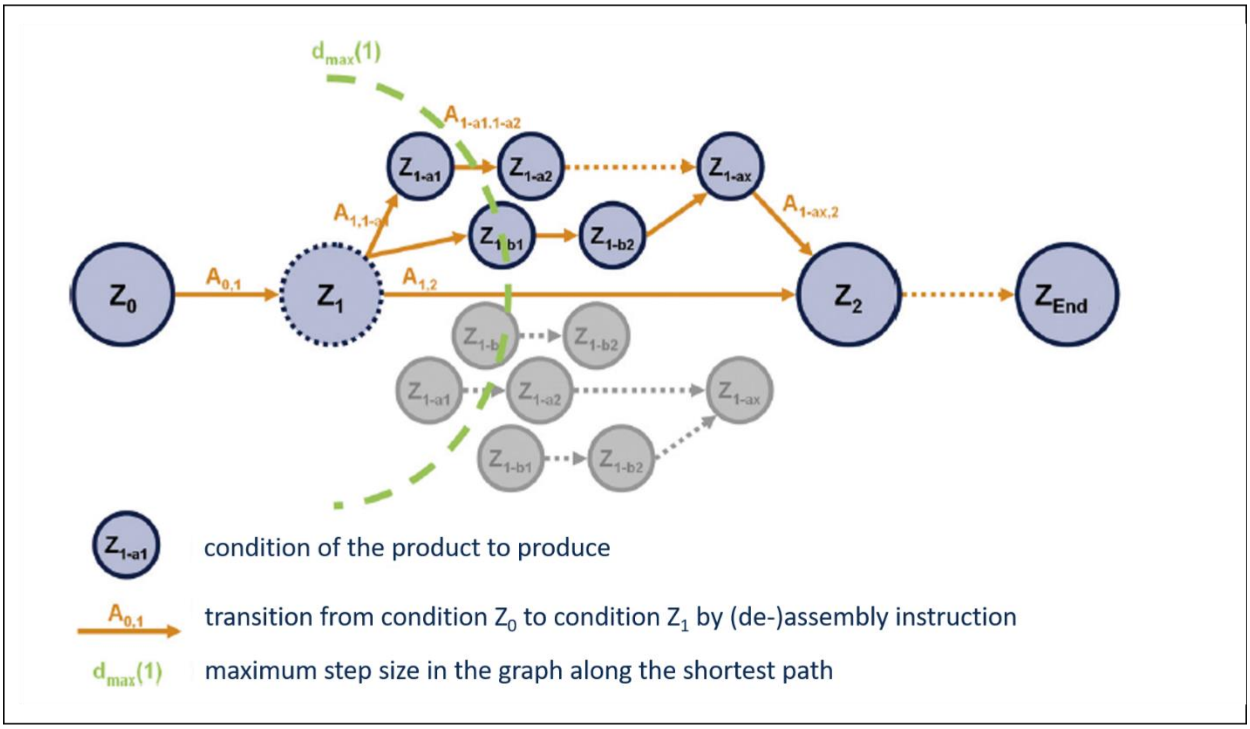

Figure 2-17: Graphic model for creation of context based assembly instruction[146]

Like mentioned above, an essential ability for an assistance system for allowing the provision of context-based information, is to know and to understand its environment at first. Therefore, systems use sensors to acquire information about the environment and recognize changes.[147]

Some of these “input” systems were already discussed in chapter 2.3.2.

For example, using sensors to position products or tools, allows the system to adapt the provided information appropriately depending on their location. By the identification of workers, combined with knowledge about their qualifications and skills, additional guidance can be provided. On top of that the type of presentation can be adapted to the workers level of experience.[148]

Through a meaningful combination of different sensors and acquired information, it is further possible to gather insights about worker’s cognitive condition, for example their

[145] ibidem
[146] ibidem, translated from German
[147] Cf. Aehnelt (2016), p.60
[148] Cf. Kröger et al. (2016), p. 299ff.

attentiveness or stress level. Consequently, this information can be used to adapt the maximum step size and thus the detail level of instructions accordingly.[149]

2.4 Methods and tools

Several methods and tools are used during this thesis, and the associated project and therefore described within this chapter for general understanding.

2.4.1 Morphological box

The morphological box is a creativity technique, invented by Fritz Zwicky, a physicist from Switzerland. It can be assigned to the morphological creativity methods, a sub-group of the systematic-analytic creativity method.[150]

It was originally intended to break down objects or problems in an analytic way into possible assorted characteristics of different parameters, in order to find new ideas and solutions.[151]

Table 2-3 gives a short overview over creativity techniques and common examples.

Intuitive methods		Systematic-analytic methods	
Intuitive association	• Brainstorming • Brainwriting • 635-method • …	Systematic-analytic-association:	• Morphological Box • …
Intuitive orientation	• Incubation • Bionic • …	Systematic-analytic-confrontation	• Morphological Matrix
Intuitive confrontation	• Six-thinking-hats • TILMAG • ...	Systematic-analytic-problem specification	• Relevance tree • …

Table 2-3: Overview over creativity techniques[152]

[149] Cf. Zäh et al. (2007), p. 644ff.
[150] Cf. Becker (2018), p. 89ff.
[151] Cf. Kneß (op. 2006), p.125
[152] ibidem, p.39

Zwicky and Wilson describe five steps for “the method of the morphological box”[153].

Firstly there must be an exact formulation for the problem that should be solved. In a second step, the problem must be separated into independent parameters. Thirdly, all possible solutions for each parameter should be found, allowing the construction of the morphological box. Fourthly, all solutions, built by designating one solution for each parameter, should be analyzed and evaluated. In a last step the best solutions should be selected.[154] [155]

One big advantage of this method is the large number of theoretical solutions occurring already at small morphological box, but usually, not all of the theoretical solution can be realized, either for logical or empiric reasons.[156]

A further reduction of solutions is possible by either describing only meaningful solutions from the beginning or dividing the problem into several sub-problems.[157]

For the associated project, the method of the morphological box was adapted to allow the visualization of possibilities and potential usable technologies for an assembly system that fulfills all necessary requirements. (cf. chapter 3.3.5) It was used to derive several concepts which were then analyzed and evaluated in order to make a decision as to which concept fits best for the given situation.

2.4.2 Business Process Model and Notation

The Business Process Model and Notation, in short BPMN, was first developed by Stephen A. White in the year 2004[158] and further developed by the Object Management Group (OMG), a not-for-profit computer industry standards consortium that maintains computer industry specification.[159]

It is a standard for graphic notations of business processes, with the goal to be easily understandable by all users[160], thus being the reason why it is used in the course of the associated project to develop process models that give a comprehensive but easy-to-understand overview of the application of the chosen concept.

[153] Cf. Zwicky et al. (1967), p.285
[154] ibidem, p.285
[155] Cf. Becker (2018), p. 89ff.
[156] Cf. Johansen (2018), p. 116ff.
[157] Cf. Knieß (op. 2006), p.131
[158] Cf. Rempp et al. (2011), p.27
[159] Cf. Object Management Group (2013)
[160] ibidem

As the main goal was to visualize the process in the simplest way, the basic elements of BPMN are mainly used. Basic elements, showed in figure 2-10, are needed for the modelling of processes.

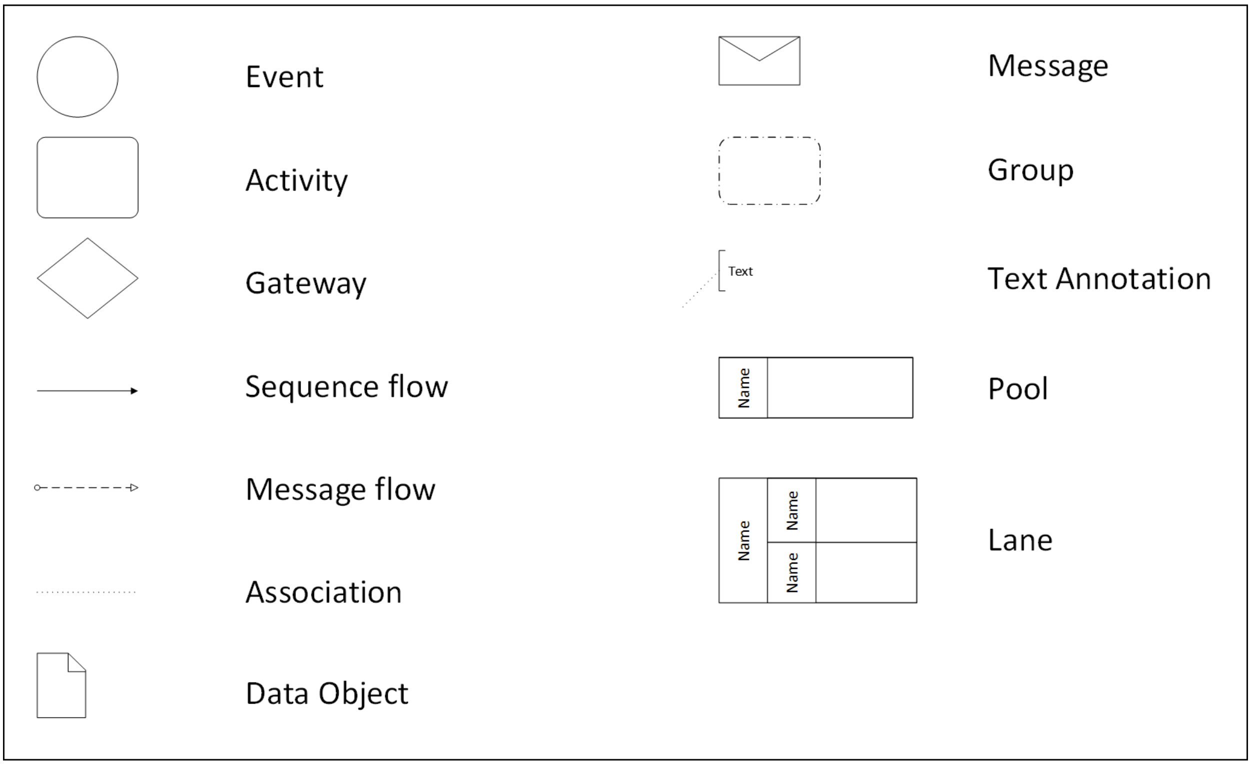

Figure 2-18: Basic BPMN modelling elements[161]

The following elements were used in order to create the process models for the final concept, the descriptions are according to OMG:[162]

- **event:** an event usually has a cause or a result and therefore usually starts or ends a process. It is something that "happens".
- **activity:** an activity describes a process step ant therefore the performed work steps. They can be sub-processes or tasks necessary for the process.
- **gateway:** a gateway controls the sequence flow. There are several different types of gateways leading to different flow paths. They can be seen as decision points.
- **sequence flow:** the sequence flow shows the order of the process's elements such as events, activities and gateways.
- **message flow:** a message flow shows how two "participants" communicate with each other

[161] ibidem
[162] ibidem

- **pool:** a pool represents a “participant”, it can be subdivided by lanes
- **lane:** a lane is used to organize the process elements for better overview
- **message:** a message represents a communication’s content
- **data object:** a data object can be used for input or output and provides information about requirements and/or results

An event can be distinguished as a start, intermediate, or end event, depending on whether it indicates the start of a process, occurs somewhere between start and end or terminates the process.[163]

Gateways can have various different control types. The two gateways which are used over the course of this thesis are exclusive and parallel gateways. An exclusive gateway, which is either visualized with or without a marker, indicates that only one of the outgoing sequence flows is followed. It therefore also refers to “XOR”-gateway. At a parallel gateway all outgoing sequence flows are conducted parallel which is why it is also known as “AND”-gateway.[164]

Figure 2-19 shows the graphic notation for specific event and gateway types.

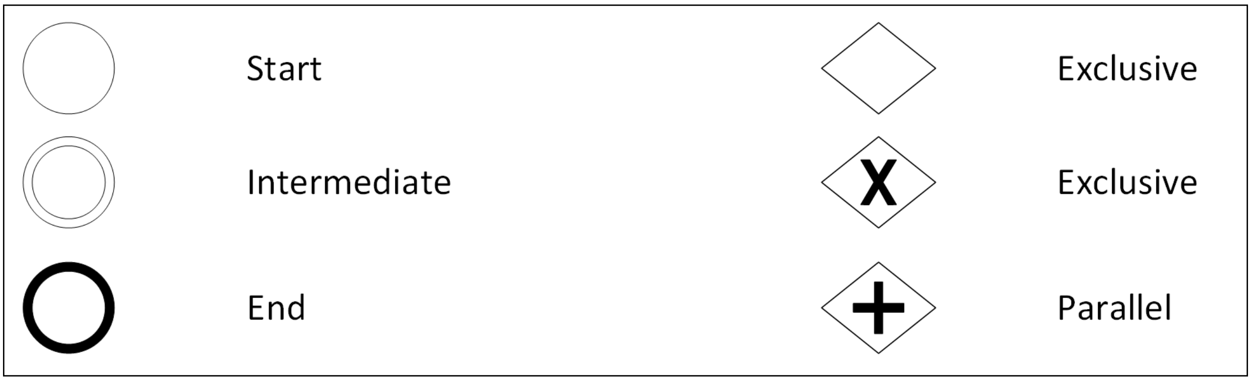

Figure 2-19: Extended BPMN modelling elements[165]

In order to group and summarize processes, the modelling element of an expanded sub-process was used. It uses the same notation as an activity.[166]

[163] Cf. Rempp et al. (2011), p.29
[164] ibidem, p.33ff.
[165] Cf. Object Management Group (2013)
[166] ibidem

2.4.3 Method of decision making – benefit analysis

In order to evaluate elaborated concepts and come to a decision, the method of a benefit analysis is used in this thesis.

A benefit analysis is a type of decision matrix that allows the best solution out of several possibilities to be found, by comparing them and calculating a benefit score for each solution, delivering a quantifiable decision criteria and a ranking.[167]

Decision criteria can be categorized into quantifiable and non-quantifiable criteria, with the difference that quantifiable criteria is calculated and consists of a specific value while non-quantifiable criteria is rated according to experience and comparison.[168]

The choice to use it throughout the course of this thesis is based on following prevailing conditions, where the use of a benefit analysis is meaningful:

- both quantifiable and non-quantifiable decision criteria has to be taken into account or the decision criteria is mainly non-quantifiable[169]
- the number of criteria is high and the decision process is influenced by several people with different backgrounds[170]

Kühnapfel lists following steps for the procedure of a benefit analysis:[171]

- creation of a team and a working environment
- definition of the investigated problem
- definition of solution alternatives
- definition of decision criteria
- prioritization of decision criteria
- valuation of criteria
- benefit score calculation
- optional: sensitivity analysis
- documentation of the results

[167] Cf. Wappis et al. (2013) p.258
[168] Cf. Konold et al. (2009), p.136f.
[169] Cf. Kühnapfel (2013), p.87
[170] Cf. Kühnapfel (2014), p.2f.
[171] ibidem, p.6ff.

Although most of the steps are self-explanatory, some require further specification:

The prioritization, or weighting, of the decision criteria can be carried out using several methods. For this thesis, the method of pairwise comparison was used. In this method, all criteria is listed in a cross table, with a followed comparison between pairs of criteria.[172]

Figure 2-20 shows an example of a filled in cross table. A cell value of "1" indicates, that the column criteria is prioritized over the compared row criteria.

	Preparation time	Fexibility	Implementation	Compatibility	Time exposure	Mobility	Usability	Degree of detail	∑	Weighting
Preparation time		0	1	1	0	1	0	0	3	11%
Fexibility	1		1	1	0	1	0	0	4	14%
Implementation	0	0		1	0	1	0	0	2	7%
Compatibility	0	0	0		0	1	0	0	1	4%
Time exposure	1	1	1	1		0	0	0	4	14%
Mobility	0	0	0	0	1		0	0	1	4%
Usability	1	1	1	1	1	1		0	6	21%
Degree of detail	1	1	1	1	1	1	1		7	25%

Figure 2-20: Example of a pairwise comparison

The results from each team member are summarized, ultimately delivering a prioritization of the criteria.

For the valuation of criteria it is possible to use various scales,[173] but for this thesis an inverse school grades scale, ranging from 1 to 5, with 5 being the best possible value, was used.

Conducting a sensitivity analysis is an optional step, used to investigate how resilient, relating to varied estimations of the project team, the results of the benefit analysis are.[174] It was not conducted during this thesis and is therefore not specified further.

[172] Cf. Kühnapfel (2013), p.94
[173] Cf. Kühnapfel (2014), p.16ff.
[174] Cf. Kühnapfel (2013), p.100

3 Associated Project

This thesis is based on the data and findings gained over the course of a project, which was conducted in cooperation with the company Pankl Racing Systems AG. Furthermore, the conclusions of the previous chapters, were taken into account for the final results of this project.

3.1 Introduction

The project, associated with this thesis, was initiated by Pankl Racing Systems AG to increase the quality and traceability in the assembly process.

Some customers demand individual and specific documentation of the production and assembly processes. Especially in the field of assembly, a documentation is cumbersome and error-prone, as it is compiled manually. In addition it has to be ensured, that the high quality requirements can be fulfilled and the assembly processes are reliable.

3.1.1 Pankl Racing Systems AG – Pankl Drivetrain Systems

Pankl Racing Systems AG is an Austrian company with its headquarters in Bruck an der Mur, and was founded 1985 by Gerold Pankl. It is a globally operating company with, as of 2017, 1600 employees[175] and a turnover of 195.4 million euros.[176]

The company specializes in the development and manufacture engine and drivetrain components with a wide portfolio of products. It is subdivided into the three main core areas - racing, aerospace and high performance.[177]

This project was conducted with the subdivision Pankl Drivetrain Systems, situated in Kapfenberg, which specializes in developing, designing, manufacturing and testing of drivetrain components for racing cars. Figure 3-1 gives an overview of Pankl's main divisions and branches.

[175] Cf. Wikipedia (2018)
[176] Cf. ORF (2018)
[177] Cf. Pankl Racing Systems AG (2018)

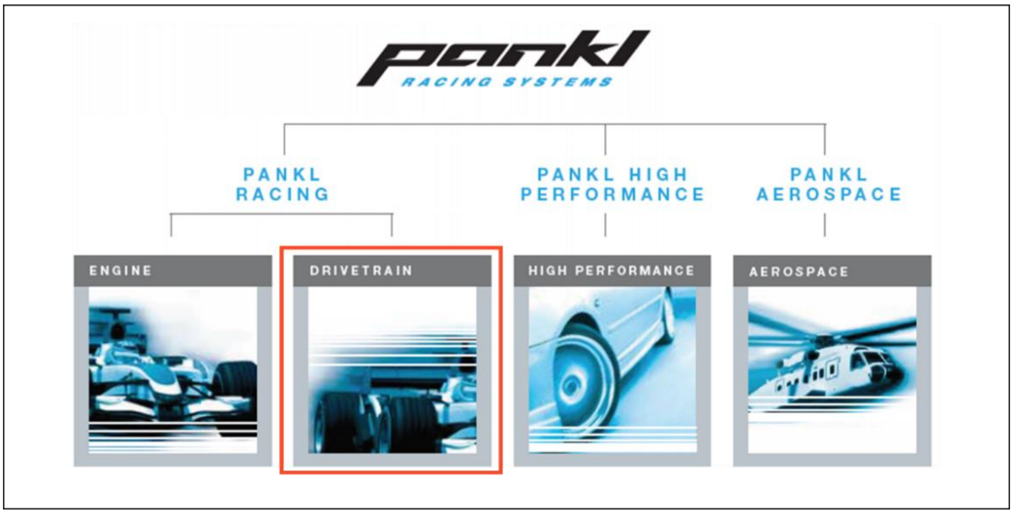

Figure 3-1: Divisions of Pankl Racing Systems AG[178]

3.1.2 Product drive shaft

Pankl Drivetrain Systems is part of the core area Pankl Racing and its portfolio ranges from single parts to complete drivetrain assemblies. An excerpt of the products offered is shown in figure 3-2.

A non-integrated drive shaft was chosen as the product to be investigated.

Drive shafts are a mechanical component needed to transport torque and rotary motion of the engine or gearbox over a spatial distance. Additionally, they have to compensate displacements in angle and length, induced by relative movements of the components to be connected. To achieve this, drive shafts have at least one universal joint.[179]

The joint type typically used by Pankl for the racing area is a tripod and, at a small share CV-joints. CV-joints are able to realize angles of up to 45° within a short distance.[180] They are used for extreme demands concerning steering angle or suspension travel, for example in rally cars, where the use of tripods is not feasible.

Tripods usually consist of a hub with three pivots with ball-shaped rollers and a tubular counterpart, called “tulip”, with lanes to retain the rollers.[181]

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[178] ibidem
[179] Cf. Trzesniowski (op. 2014), p.748ff.
[180] Cf. Muhs et al. (2007), p.432
[181] Cf. Trzesniowski (op. 2014), p.762

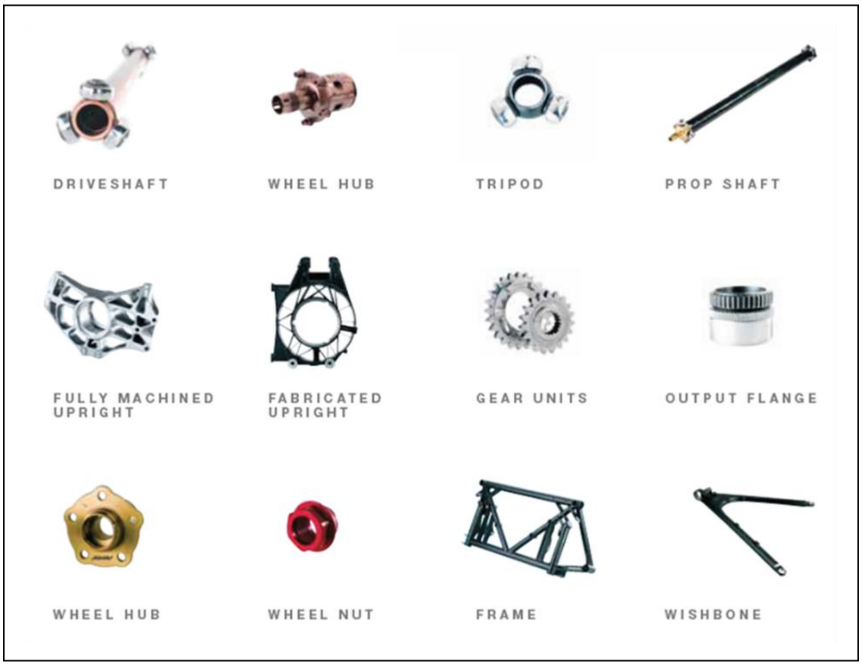

Figure 3-2: Pankl Drivetrain Systems – product portfolio[182]

At Pankl, two forms of drive shafts with tripod joints are produced, non-integrated and integrated drive shafts. In case of an integrated drive shaft, the tripod pivots are already integrated in the shaft. For non-integrated drive shafts, the tripod joint is an independent sub-assembly, connected with the shaft through a serrated profile. The choice to investigate a non-integrated drive shaft was made, as its assembly contains all steps of an integrated drive shaft and it additionally requires some further assembly steps.

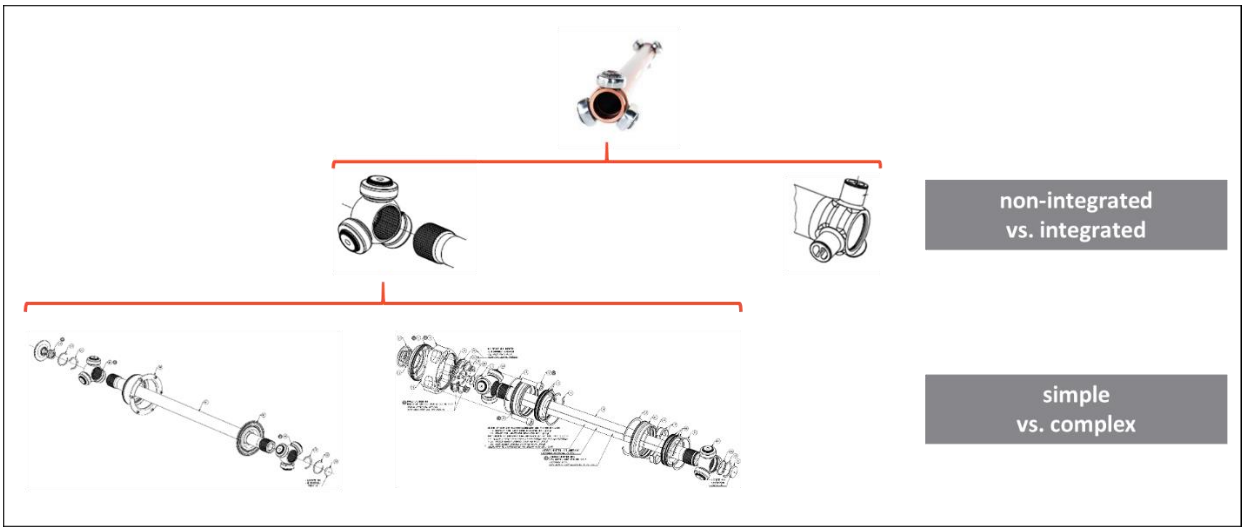

Figure 3-3: Different drive shaft variants

[182] Cf. Pankl Racing Systems AG (2018)

Pankl Drivetrain systems produces highly customer-specific drive shafts, thus ranging from simple variants to rather complex ones, as the examples in figure 3-4 and figure 3-5 show. The production is therefore characterized by a high number of variants and typically small batch sizes.

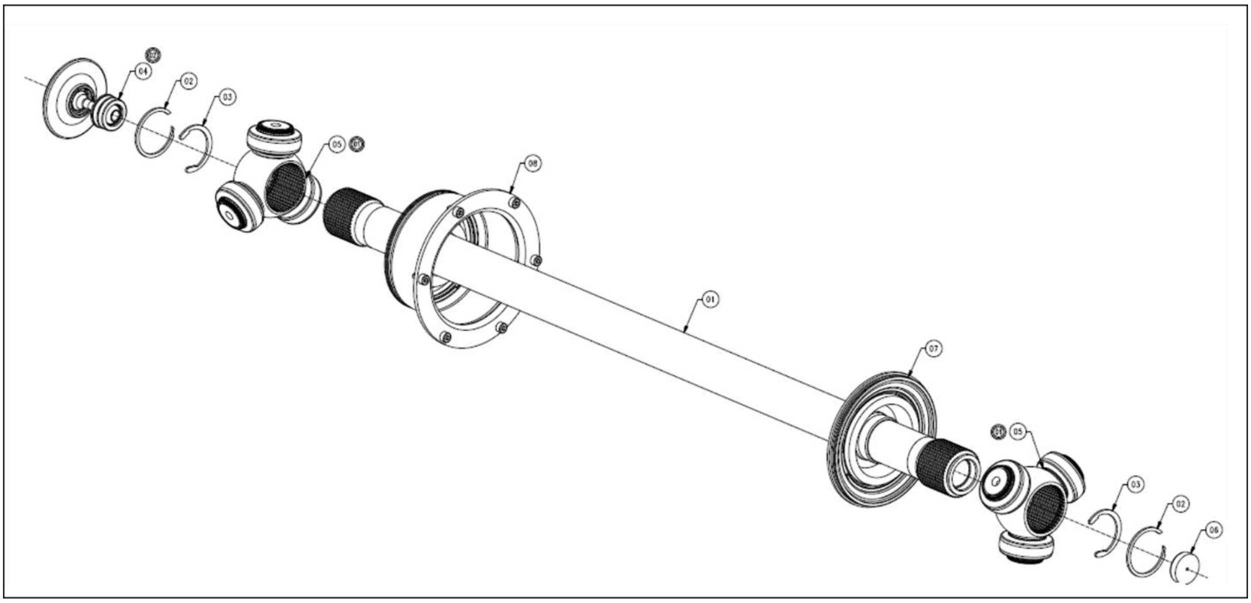

Figure 3-4: Drive shaft example – simple variant[183]

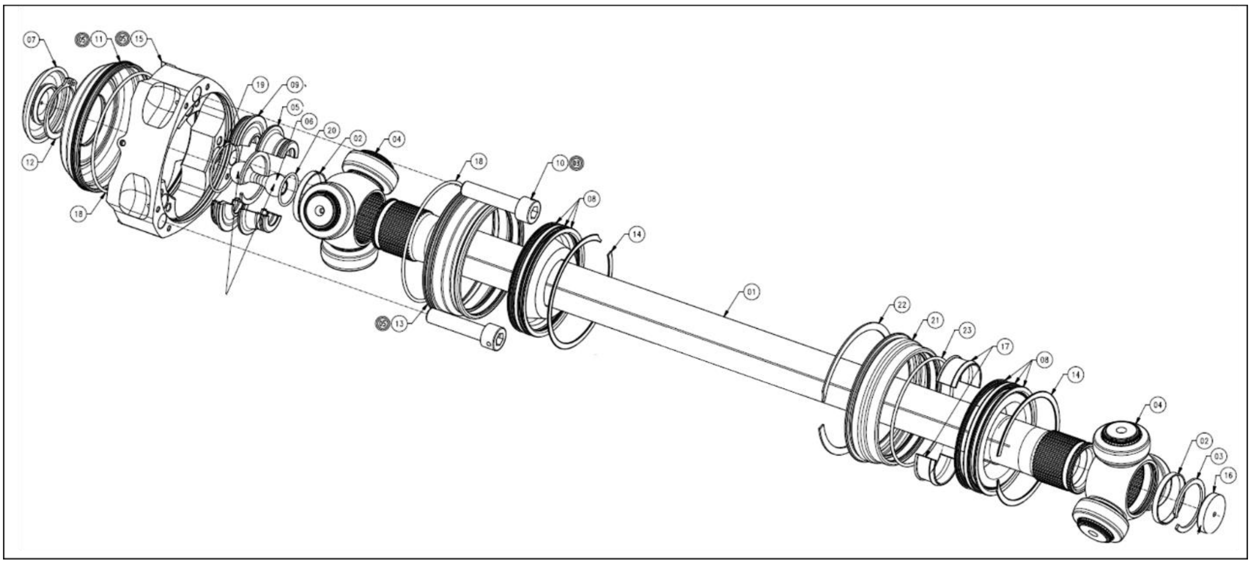

Figure 3-5 Drive shaft example – complex variant[184]

[183] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017c)
[184] ibidem

3.1.3 Objectives

Using the specific example of assembly for non-integrated drive shafts in the motorsports segment, solution concepts for the creation of seamless documentation and process assurance through the use of assistance systems are to be developed.

Regarding documentation, it is important to be able to guarantee the traceability of potential failures and problems. In order to exclude possible failures in the first place, the solutions considered should also actively contribute to and improve process assurance.

Workers at the assembly of Pankl Drivetrain Systems are well-trained and skilled specialists, who face the challenge of a high product variety and should therefore be supported by the project results.

The following key targets were defined at the beginning of the project:

- data collection and analysis of the drive shaft assembly's current state
- investigation of state-of-the-art in the field of documentation and assistance of assembly processes
- conception of possible workplace designs and potential technologies to support process assurance
- conception of an automated and standardized creation of assembly documentations
- detailed elaboration of a final concept

Non-targets were defined as:

- optimization or changes to the assembly processes
- time recording of the assembly process
- increase in efficiency
- cost optimization

As mentioned in chapter 3.1.2, as an exemplary product for this project, non-integrated drive shafts for the motorsports segment were chosen. The system limit was set on its assembly, although for the sake of completeness, the processes with direct connection and influence on the assembly such as design engineering, work scheduling, warehouse, production planning and quality assurance, were also examined. Figure 3-6 gives an overview over the project's system boundaries.

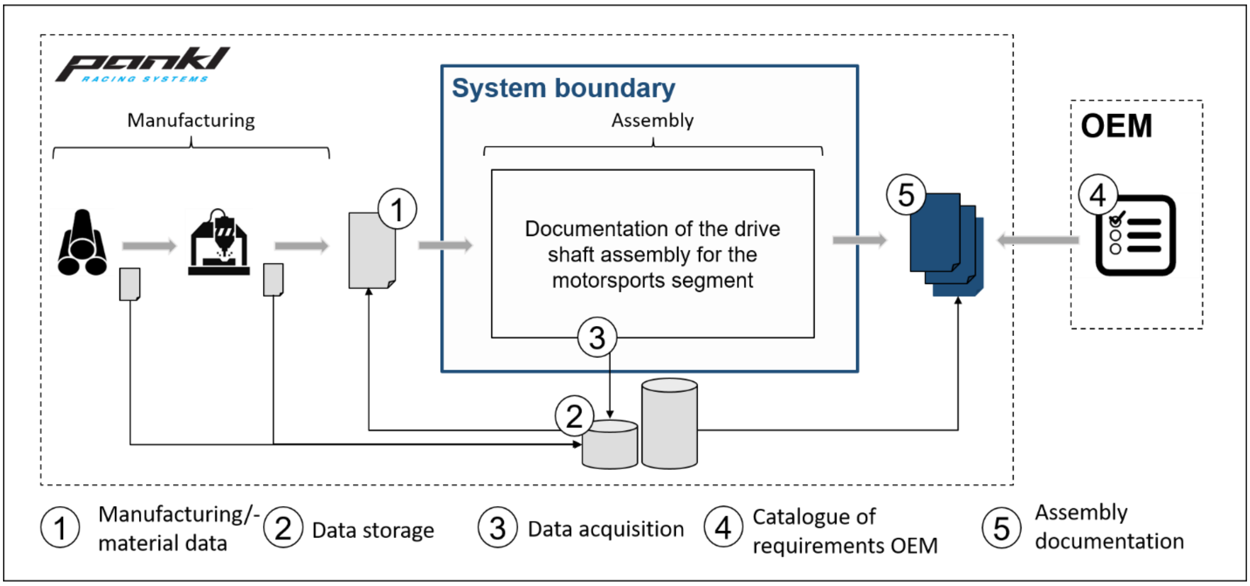

Figure 3-6: System boundaries

3.1.4 Procedure

The project was separated into three main phases, as illustrated in figure 3-7. Each phase represented a milestone, with each phase building up on the preceding one. The separation was made to allow a better structure of the project and additionally better involvement of the project team as a checkpoint meeting was conducted at the end of each phase, to discuss intermediate results.

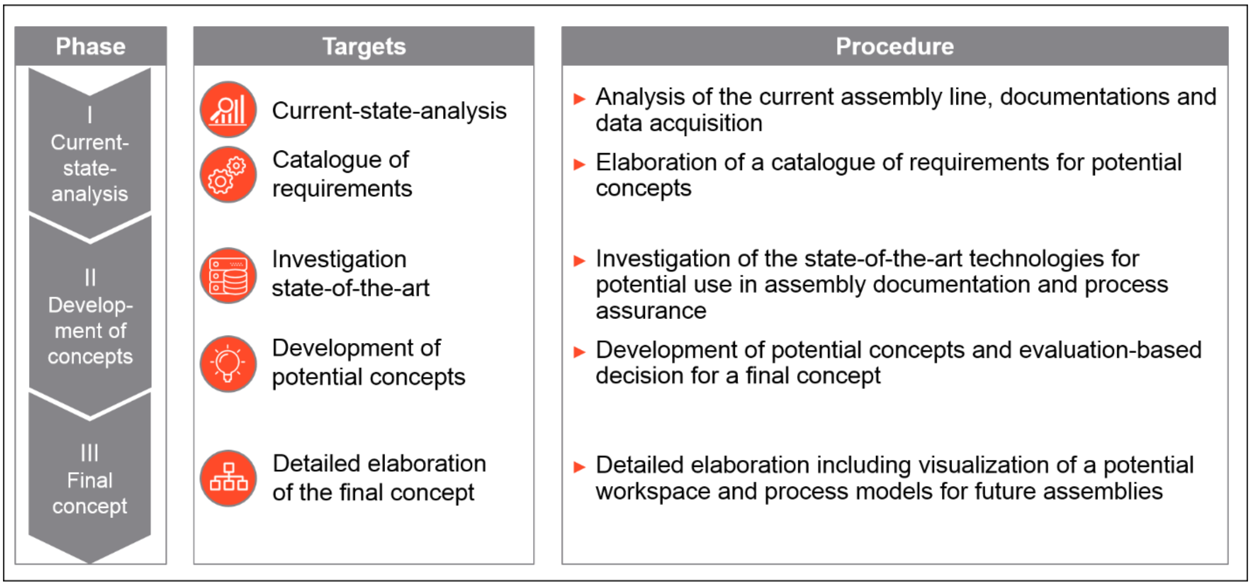

Figure 3-7: Procedure of the project

Phase I: Current-State-Analysis

In a first step, the current situation of the assembly cell at the location in Kapfenberg, Upper Styria, was surveyed. Current assembly processes, workplace designs and work instructions were captured. This was followed by analysis of the existing documentations, of the assembly process itself, as well as the derived documentations for customers.

Furthermore, the processes of departments with direct influence or connection to the assembly process were examined in order to get a complete overview of the current state.

As a result of phase I, a catalogue of requirements was derived of the observations, having regard to internal and external requirements.

Phase II: Development of concepts

Phase II started with an investigation into the current state-of-the-art in the areas of assembly documentation and process assurance. Assemblies of other Pankl Racing departments as well as research results and publications were considered.

In combination with the catalogue of requirements which were elaborated in phase I, potentially usable technologies were examined and presented in a workshop, followed by a discussion, expansion and concept derivation.

A concept catalogue, resulting from this workshop, was then evaluated on the basis of a utility value analysis, leading to the determination of a final concept.

Phase III: Final concept

This chosen concept was developed in detail during phase III, with particular attention paid to fulfilling the catalogue of requirements from phase I and to incorporating the findings from phase II.

The used technologies and assistance systems used were described in detail and their use within the assembly process illustrated in form of process models, considering expansion possibilities with further technologies.

In addition, a potential workstation was visualized, with the entire systems implemented. To ensure a maximum of flexibility within the assembly process, it was furthermore necessary to define standard modules.

Finally, a summary of the possible content data for documentations and an example for the compilation of a documentation was provided.

Project Team

When selecting the project team, great care was taken to ensure that members of the departments most relevant for the project were part of the team. For each of the two assembly cells which are currently operating parallel in Kapfenberg, one worker was selected to be part of the project team. Additionally, one employee each from design engineering and quality assurance was assigned.

Two managing directors supervised the project and were involved for important project decisions.

Finally contact persons for work scheduling, warehouse and production planning were defined, as these departments were also surveyed throughout the project.

Schedule

The project was conducted between June 2017 and February 2018, with the three main project phases taking place between August 2017 and January 2018.

Checkpoint meetings were held at the end of each project phase. Furthermore, a workshop was conducted during phase II, resulting in a concept catalogue. The decision for the final concept was made over the course of checkpoint 2, after evaluation, discussing and refining this concept catalogue. Figure 3-8 shows the detailed schedule of the project.

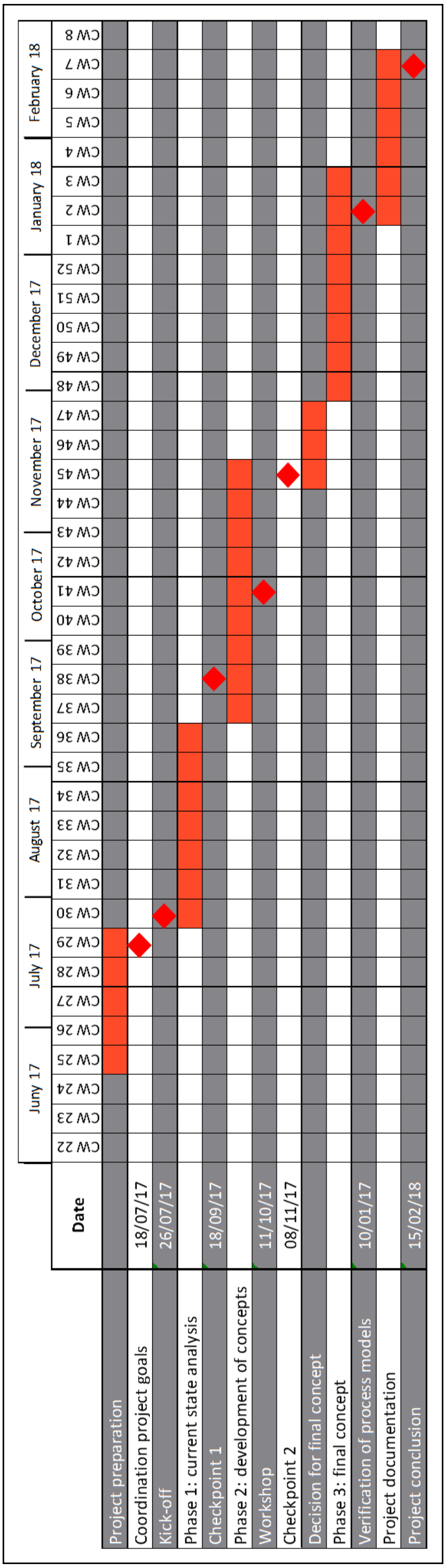

Figure 3-8: Project schedule

3.2 Current state analysis

The current state analysis looks at the assembly cells and related processes. In order to gain a good insight into all relevant processes, the two assembly cells at Pankl Drivetrain Systems in Kapfenberg were observed and analysed on site. The process steps necessary to assemble a non-integrated drive shaft were recorded and summarized, leading to a process overview and a catalogue of requirements. A summary of the analysed processes and acquired data is shown in figure 3-9:

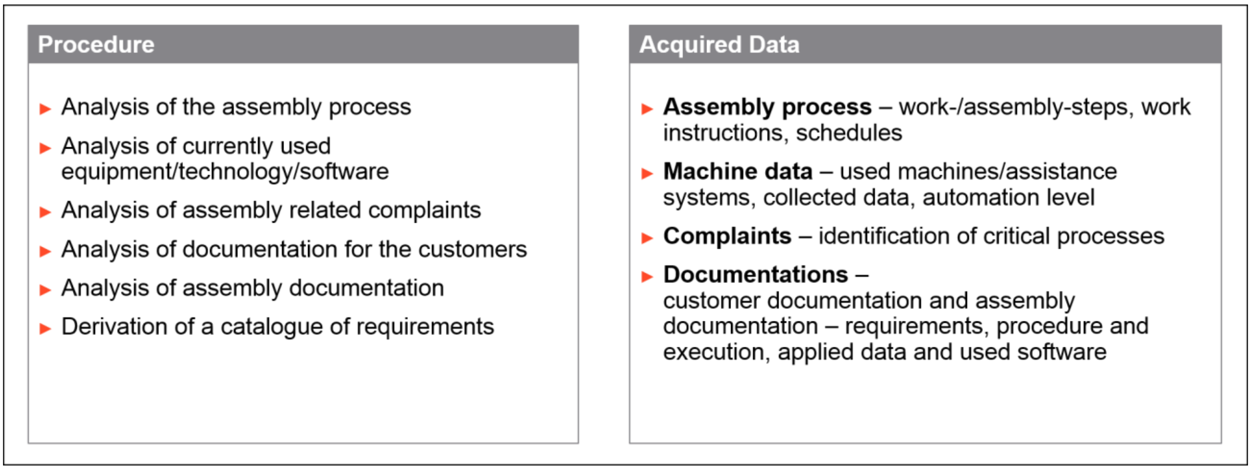

Figure 3-9: Procedure and acquired data - Phase I

3.2.1 Production volume

Pankl Drivetrain systems specializes in highly customized products, with an early order penetration point (cf. chapter 2.1.4), usually already in the design or engineering phase. This results in a low volume production, meaning that a “series production” at Pankl ranges in the area of around 100 produced products of one variant produced per year. Series productions are exceptional, typically batch sizes at Pankl range in the size of 10 to 20 products.

Additionally, the rapidly changing environmental conditions in the motorsports industry additionally results in low repetition orders of the exactly same product. Workers at Pankl therefore face the challenge of a high flexibility demand combined with a high information demand and an early abortion of the learning curve.

3.2.2 Production sequence

New customer orders are created in the Enterprise Resource Planning (ERP) – Software and the production process is started as soon as the job order is handed over to the work preparation.

In the following, an overview over the assembly related production processes and departments is given.

Production relevant identification numbers

Various numbers are used throughout the production for reasons of traceability and identification. For this project, the following are relevant:

- *order number:* includes year of production, numbering of a consecutive group and a 4-digit number, which is also located on the component
- *article number:* a unique number that is used in the ERP system. It allows the assignment of work sequences, placing of necessary orders and other production-relevant data
- *EB number:* allows the traceability for externally supplied articles or raw materials. A separate EB number is created for each purchased part and each order
- *internal operation number:* a number that is used internally for the identification within the computer aided quality (CAQ) system. It can also be found on the batch card and the picking boxes in and from the warehouse

Design engineering

The design engineering is upstream of the manufacturing and assembly process. In the design engineering department, the corresponding products are constructed according to customer’s demands and requirements. Construction drawings, which also contain work instructions for manufacturing and assembly, are prepared. As far as possible, existing construction drawings of similar products are used and adapted.

During the production process, the design engineering is involved in the initial assembly, intended to eliminate ambiguities or point out potential assembly problems.

Work preparation

The work preparation is accountable for creating a batch card, consisting of all production relevant documents and information, such as manufacturing documents, work steps, inspection plans and drawings. Additionally, the department procures the production materials in cooperation with the purchasing department.

Production planning

A detailed planning and production sequence is conducted by the production planning department. It is also responsible for the monitoring of manufacturing and assembly schedules and it records the production progress. Further production planning transfers parts from the warehouse to the assembly cells, when picking is finished.

Manufacturing/Assembly

When the batch card is handed over to manufacturing, the defined process “produce and inspect product” is triggered, as illustrated in figure 3-10. It also contains the assembly process, considered in this project, which can alternatively be triggered by a service order. Services contain the dismantling, inspection, exchange of worn-of parts and re-assembly of used drive shafts, and were not considered further in the course of this project.

Warehouse

The warehouse is responsible for providing the necessary raw materials and components. During picking, parts are placed in a container marked with an internal order number, which serves as the central identification number to call up the required components and parts in the picking software. Picking is carried out manually and is often carried out in parallel with several internal order numbers on the same picking table, thus increasing the risk of confusion.

During order picking, a label is created and printed for all components, apart from those which are individually packed and already labelled. Information such as article number, quantity and also a barcode with a charge number is stored on this label. Using this charge number, it is possible to uniquely assign an item to a delivery or production charge. The identification is item-related and not unit-related, not to be confused with a serial number. In general, all necessary parts and components are picked, with the exception of c-parts such as needles, greases, stickers, adhesives or balancing weights. This equipment is stored directly within the assembly area.

When the picking of required components is not possible due to a stock shortage, a list of missing components is attached to the batch card. An insufficient stock level is automatically detected by the software and marked on this list. Missing parts are picked up and transferred after arrival by the production planning department.

Quality assurance

Quality assurance is responsible for the creation and revision of inspection plans. It conducts end inspections on a random basis. In addition, the quality assurance department is responsible for the maintenance of the data within the CAQ-systems, the handling of complaints and the compilation of customer-specific documentations.

Applied software

For the evaluation of potential systems it is necessary to know which software is applied at Pankl in order to ensure compatibility.

As ERP-solution the software ABAS is used. Data transfer and deposit is realized with Siemens Teamcenter. The CAD files and technical drawings within the design engineering department are created with Siemens NX.

BabTec is the CAQ-software in use and SharePoint serves as a data deposit for standard work instructions. This software list only accounts for Pankl Drivetrain Systems as other departments within Pankl Racing Systems do not necessarily use the same software solutions.

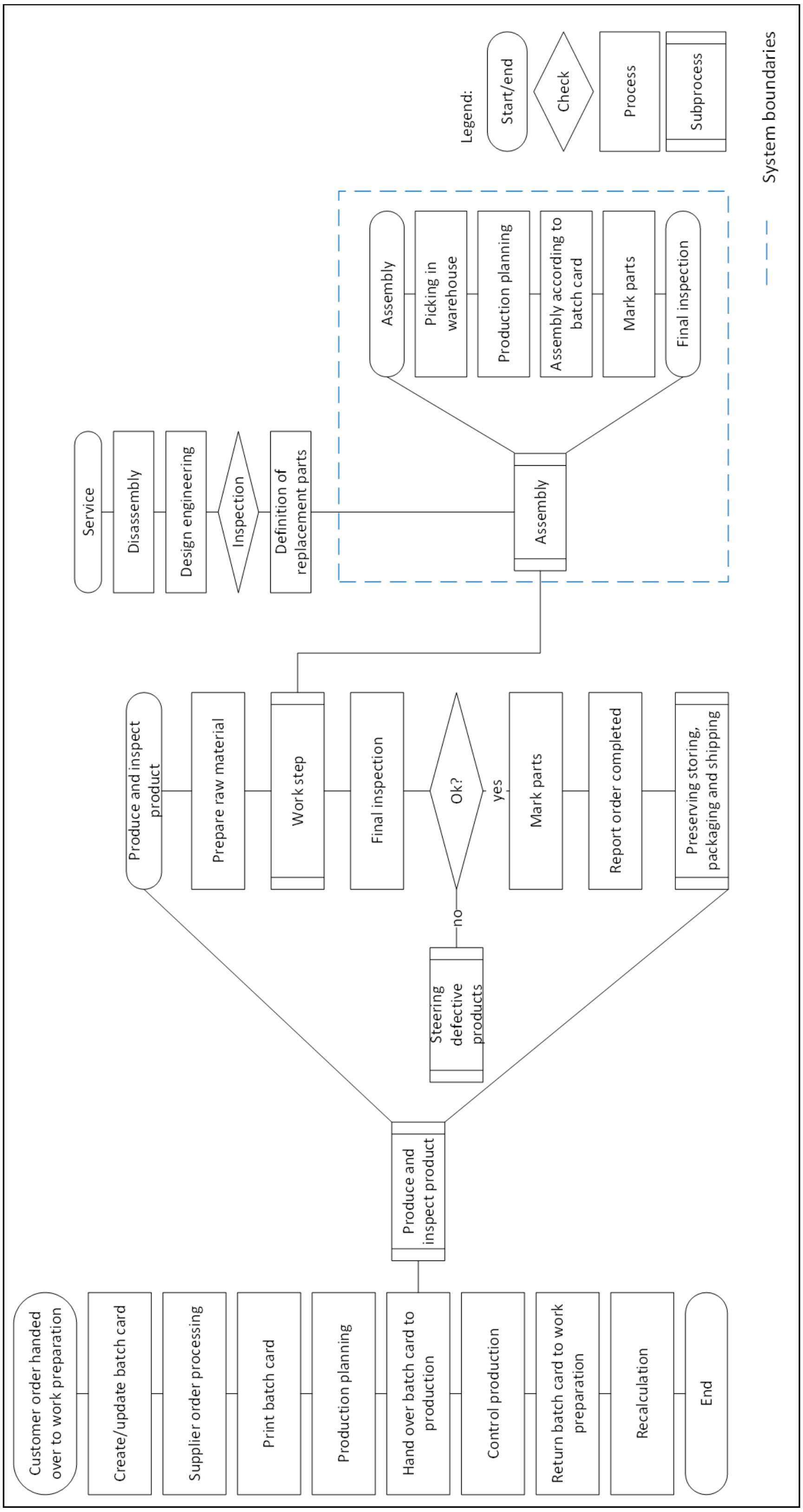

Figure 3-10: Process “Produce and inspect product”[185] [186]

[185] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017d), PB-1-013
[186] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017e), PB-1-018

3.2.3 Assembly layout

At the Kapfenberg plant, two assembly cells are operated in parallel, which should be referred to as assembly A and assembly B. Figure 3-11 shows an overview of the factory in Kapfenberg, including the assembly-relevant departments situated within the shop floor. The spatial distance of the two assembly cells is about 80m, resulting in long paths between them. The scale is to be seen as an approximate guide value for a better understanding of the proportions.

Figure 3-11: Pankl Drivetrain Systems – shop floor Kapfenberg[187]

[187] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017f)

Assembly A

Up to seven workers operate simultaneously in the assembly cell, which extends over an area of about 61 square meters.

In this department, the assembly of drive shaft assemblies and wheel carriers (drive shaft + wheel hub + upright, cf. figure 3-12) as well as service work and shaft straightening processes are carried out. Additionally, the two ovens within the assembly are used by workers of other departments for heat treatment of components.

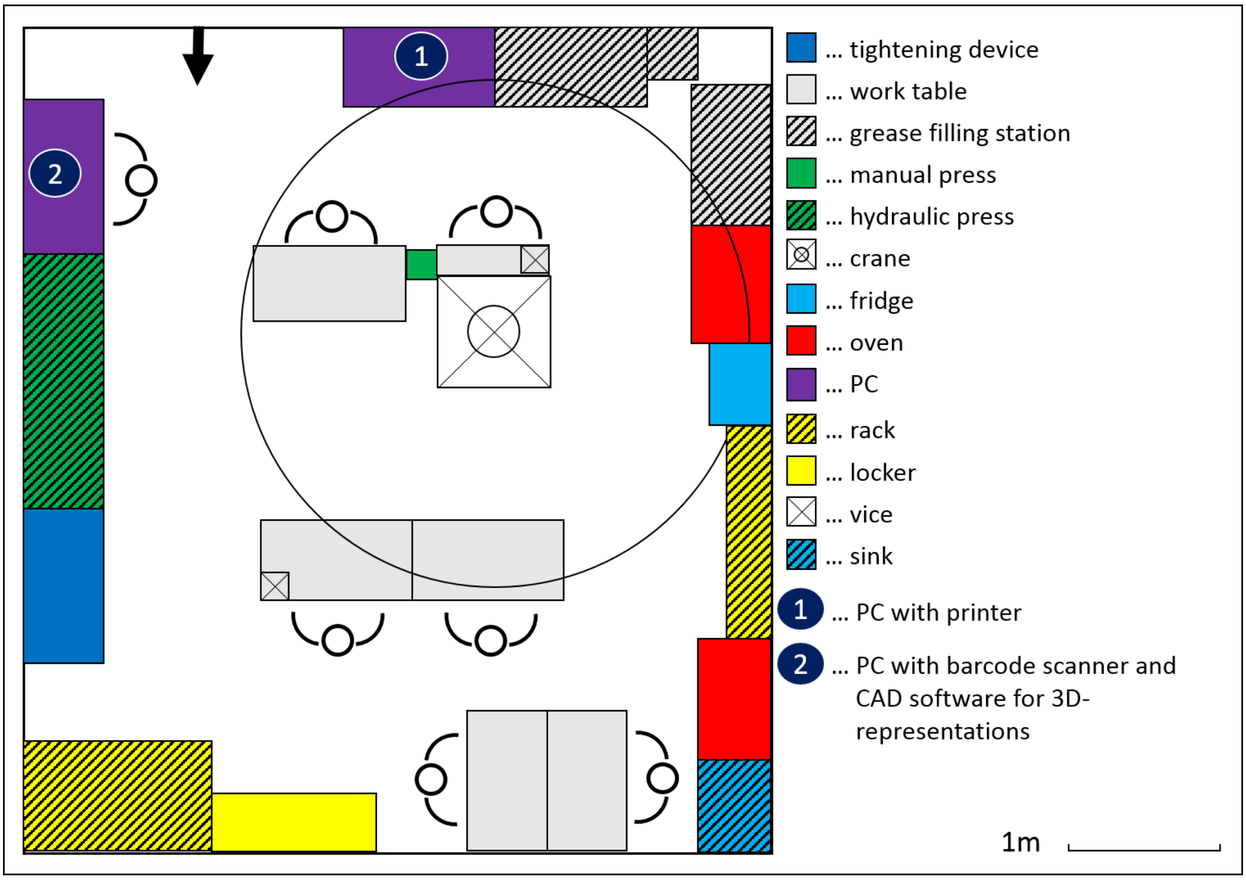

Figure 3-12: Layout assembly A

Assembly B

The assembly B extends over an area of about 90 square meters, usually with two to three workers operating. Consequently, only half as many workers operate on average in the larger assembly cell.

Typical processes carried out in this cell are drive shaft assemblies and services.

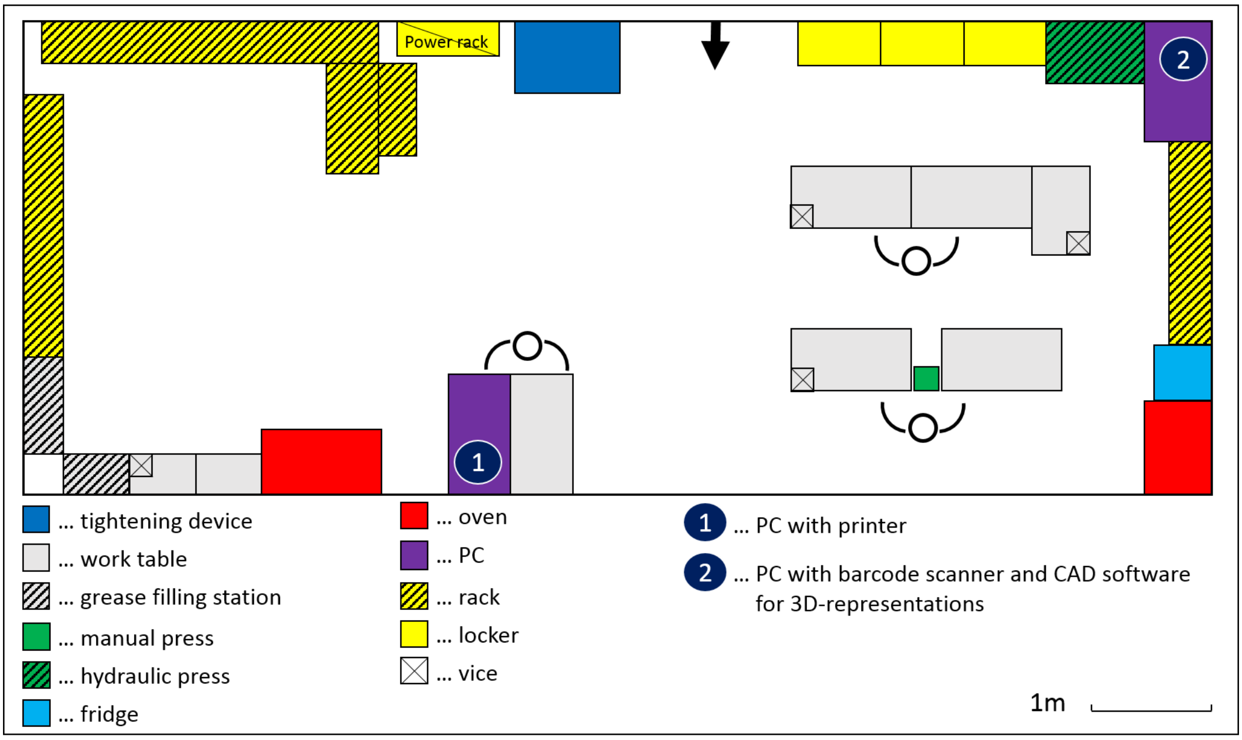

Figure 3-13: Layout assembly B

Figures 3-12 and 3-13 show layout and equipment of the two assembly cells. With the exception of a crane in assembly A, both cells have the same equipment. What becomes evident is that there is a lot more room for movement and storage in the assembly B.

3.2.4 Assembly instructions

The workers at Pankl's assembly lines are provided with information via several instructions and documents, typically consisting of a construction drawing and the batch card.

In addition, there are some generally applicable work instructions in each assembly cell for standard processes. These standard processes are on one hand the assembly of a drive shaft with two tripod joints and no further add-on parts, named standard drive shaft and on the other hand the assembly of a tripod joint for non-integrated drive shafts, of which only two basic variants exist. All other variants differ only by size, but are assembled the same way.

Documents for standard processes contain a comprehensively step-by-step instruction of the assembly including an exploded drawing of the related component, as the example in figure 3-13 shows.

6. Montagerichtlinien

1. Einstich auf Gratfreiheit prüfen und reinigen
2. Antriebswelle, kugelförmige Wälzkörper und Anlaufscheiben entmagnetisieren
3. Anlaufscheibe innen auf Tripodenarm der Antriebswelle schieben
4. Tripodenarm mit Fett laut Zeichnung bestreichen
5. Kugelförmigen Wälzkörper mit Nummer nach außen über den Tripodenarm schieben. Wälzkörper drehen, damit die Innenfläche befettet wird
6. Anzahl der Nadeln laut Stückliste auf Tripodenarm montieren
7. Anlaufscheibe außen auf Tripodenarm schieben
8. Sicherungsring in die Nut am Tripodenarm einsetzen

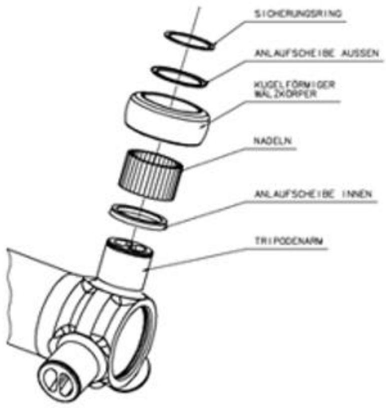

Figure 3-14: Excerpt from a standard instruction of a tripod joint assembly[188]

The construction drawing, represents the document that is most used by the workers in order to get information. It shows an explosion drawing of the whole assembly, special process steps to be performed and additional notes, directly linked to the affected component. Figure 3-15 shows an extract of such a construction drawing example.

[188] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017a)

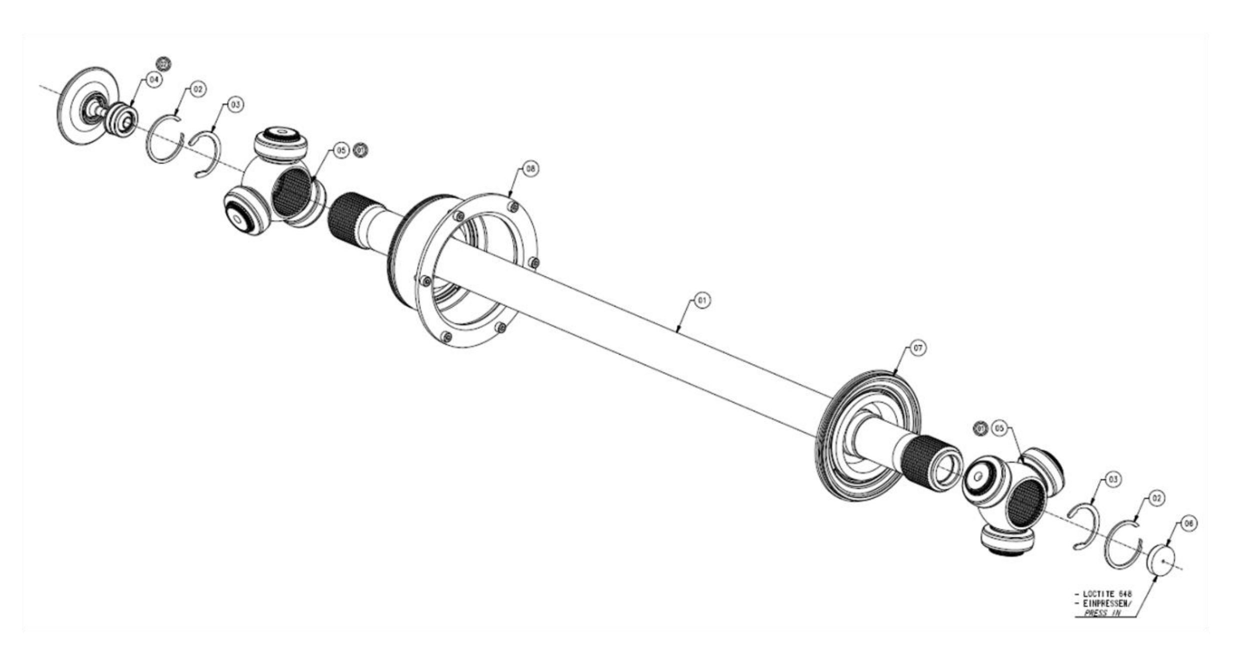

Figure 3-15: Extract of a construction drawing example[189]

The batch card, shown in figure 3-16, gives, amongst others, information on customer, order data and status, internal order number and batch size.

Furthermore it contains specific instructions for each production step, also for the assembly, meaning that there are additional instructions on top of the construction drawing which must be considered.

[189] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017c)

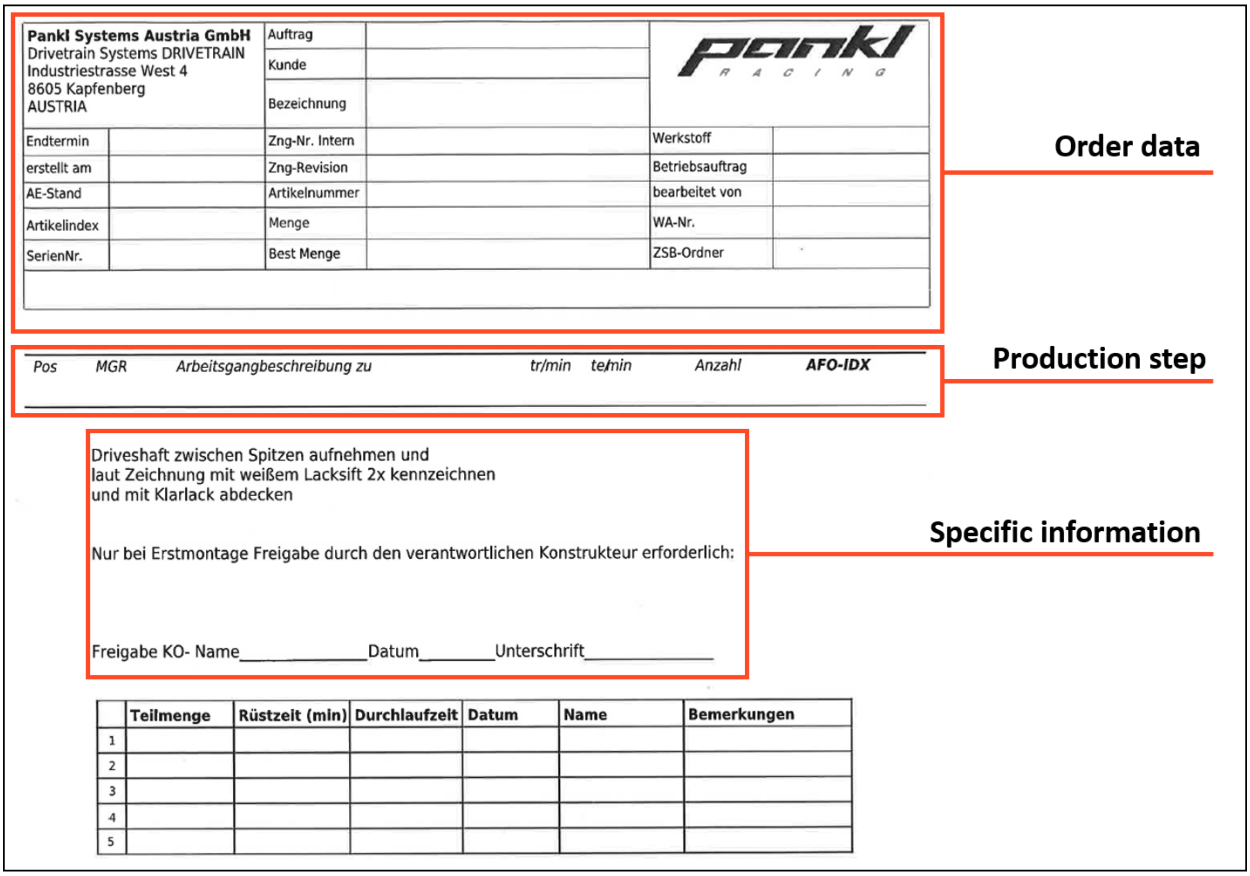

Figure 3-16. Example of a batch card[190]

The assembly instructions currently used pose several challenges to the workers:

- information is widely spread over several documents -> easy to overlook some information
- general applicable documents are located in a rack at the assembly cell, not on the work tables -> workers rarely use them
- a sequence of work steps is only defined in the two standard documents, there is no further information about it on the construction drawing or the batch card -> increased risk of wrong assembly sequence
- the construction drawing requires a lot of space, which is not available at the work desks -> the information is not displayed in the worker's field of vision
- only one PC with CAD-software for 3D-representations available per assembly cell -> up to seven workers have to share access, resulting in a rare usage

[190] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017b)

3.2.5 Assembly documentation

The aim of an assembly documentation is the traceability and comprehensibility of the assembly process.

Acquired data

Currently, the assembly documentation is only carried out manually. During the assembly, checklists should be used to record data and confirm the accomplishment of work steps.

Typically, data that is recorded is, if available, the serial number of assembled parts and the confirmation that a process step or inspection was performed according to regulations. The amount of data acquired varies and is dependent on the individual product, leading to several different checklists that are used in parallel.

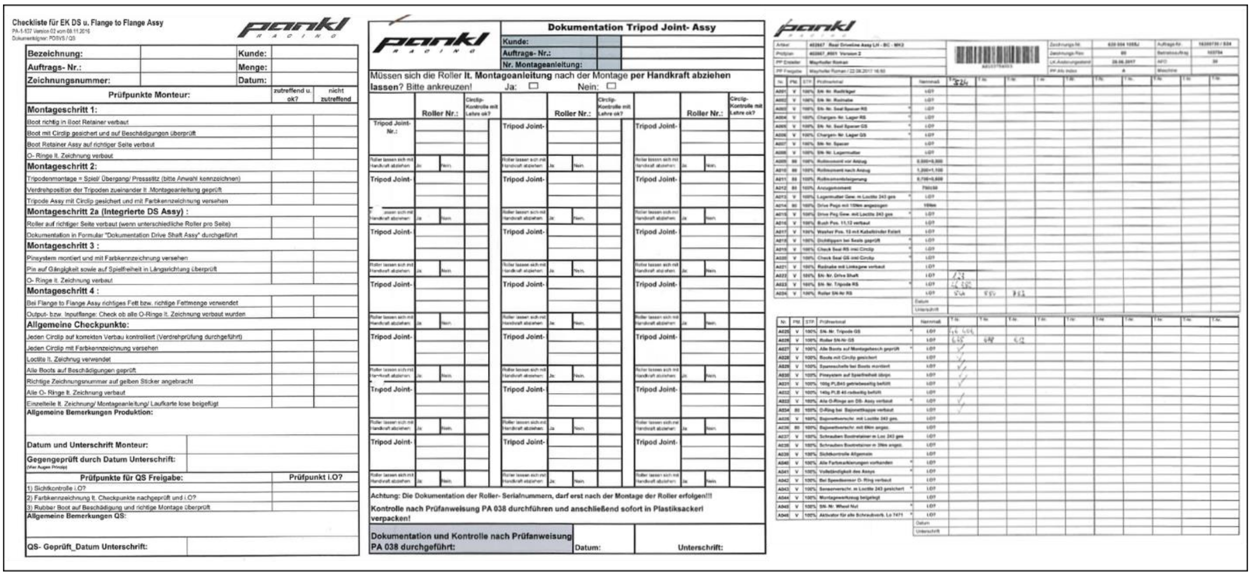

Figure 3-17: Examples of various checklists[191]

Lately, the existing documentation was expanded and a dual control principle was introduced in order to increase process assurance. For this purpose, the filled out checklist must be reviewed at the end of the assembly process by two workers and the correctness of the data confirmed by signature.

[191] Cf. Pankl Systems Austria GmbH, Drivetrain Systems (2017f)

Traceability of screw connections and built-in circlips is ensured by a color-coded system in which the assembly worker marks each assembled connection with a colored pen. Each assembly worker has an assigned color, that only he or she uses.

The existing system of data acquisition contains some risk potentials.

First, it is impossible to control the time at which the checklists are filled with data, allowing the possibility to complete them at the end of the assembly process. This makes the checklist less effective, as the worker does not pay the same attention on the correctness of the data as during the process. This includes and is valid for the dual control principle as well. Additionally it can happen, that assembled parts are not accessible anymore at the end of the process, which makes their checking impossible.

Another risk is posed through the solely manual acquisition. The checklist's data is only assured by the inspection of the worker, depending highly on their qualifications, skills and information level. As described in chapter 3.2.4, the information is widely spread and bares some challenges itself, but providing the worker with the right information is essential to ensuring that the data acquired is compliant with the quality requirements.

Customer requirements

There are currently hardly any requirements for documentations on the customer's side.

So far, only one customer demands a documentation alongside the products ordered, whereby in this case checklists are sufficient. Documentations are therefore mainly used in the event of damage and resulting customer complaints. In this case, it is essential for Pankl to be able to trace the cause of the product failure, and either prove that it is not due to faulty assembly or to initiate measures in order to prevent repetition.

To ensure this traceability over the whole product lifecycle, documentations are archived after completion of the production process and kept for a period of 15 years for high performance and five years in the area of racing.

For archiving the analogue available documentations are digitalized. This is done by scanning the filled checklists or by transferring the data manually into the CAQ-system, either way resulting in additional effort.

Documentation compilation

As mentioned in the previous chapter, there is currently only one customer demanding a documentation alongside with the ordered products. The required documents are manually collected and compiled in accordance with the customer's requirements.

Documents that are only available analogously are scanned and attached to the documentation.

Hence acquiring digital data instead of analogue hence has high potential to make this process less cumbersome.

3.2.6 Customer complaints

In order to identify potential critical processes, customer complaints that are caused by assembly faults were analysed for the years 2014 through 2017.

Complaints are handled in a separate process whereby a team, specifically assigned for this task, investigates the event of damage. It is within their responsibility to collect all relevant data, find the probable cause for failure and suggest measures to prevent similar failures in future. The investigation is summarized in an 8D-report, the 8Ds standing for[192]:

- D1: team members
- D2: description of the non-conformity
- D3: containment actions
- D4: root causes
- D5: corrective actions
- D6: corrective actions
- D7: preventive actions
- D8: final remark

[192] ibidem

In the reviewed period, there were in total six customer complaints due to assembly faults, which are summarized in table 3-1.

Date	Cause of failure
25/02/2014	Components were not assembled
05/06/2014	Components were assembled faulty
18/06/2015	Components were forgotten to pack
20/05/2016	Components were not assembled
26/07/2016	Compontens were assembled faulty, wrong investigation was conducted
04/07/2017	Required operating materials were not used correctly

Table 3-1: Customer complaints since 2014

During the observations on site, several faults and errors occurred during assembly processes, for example a wrong sequence of assembly steps or components assembled with the wrong orientation. These faults were identified and rectified over the course of the assembly, but they indicate a lack of provided information or that the worker is not capable of processing the given information in the right way. In addition, they show that there is potential for improvement regarding process assurance.

3.2.7 Assembly processes

The process steps occurring during an assembly were recorded and defined by observing the workers during their work on various drive shafts.

All recorded process steps were then gathered and processes that occurred more than once summarized, resulting in a process overview. To capture a maximum range of variants within non-integrated drive shafts, the focus was laid on the observation of preferably complex and comprehensive assemblies. Hence most observed assemblies were flange-to-flange drive shafts.

The aim was that the resulting process overview can be used as a “catalogue”, allowing the mapping of all possible drive shaft variants, by combining the collected processes in arbitrary sequence.

Because of the high number of product variants, it became necessary to make a distinction between standard process steps which occur throughout most drive shaft assemblies and variable process steps that can only be found in few product variants.

In coordination with Pankl, it was agreed to include variable process steps only to the extent that they were observed. The final concept, however, takes into account the possibility of adding further assembly steps. As new product variants are constantly designed, this is also important with regard to long-time usability.

Pre-assembly of tripod joints

The pre-assembly of tripod joints is standardized and a general sequence of process steps defined. As in the standard instruction, two variants were distinguished for the visualization of the pre-assembly, as shown in figure 3-18.

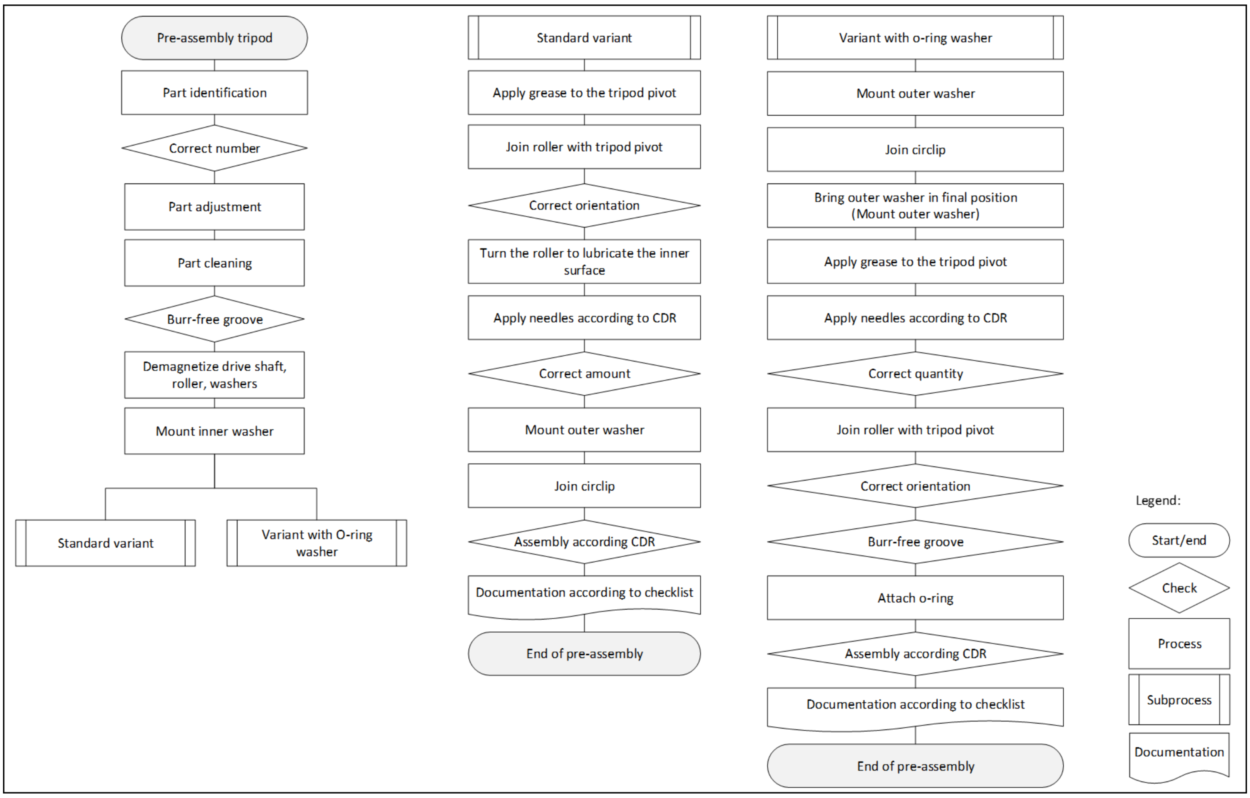

Figure 3-18: Pre-assembly tripod – process steps

Overview process steps

All process steps recorded were summarized in the overview illustrated in figure 3-19. Furthermore, the process steps were divided into following functional groups:

- preparation (P)
- circlip (C)
- joining (J)
- interim steps (I)
- use of operating materials (M)
- checking (C)
- labelling (L)
- documentation (D)

Each process step is assigned an index in the form of a letter and ascending numbers, the letter representing the associated group. A description of all process steps can be found in Appendix A. The section checking (C) is to be considered separately. It lists attributes that are intended to be checked during the assembly process. These were used in order to derive a catalogue of requirements (cf. chapter 3.2.8).

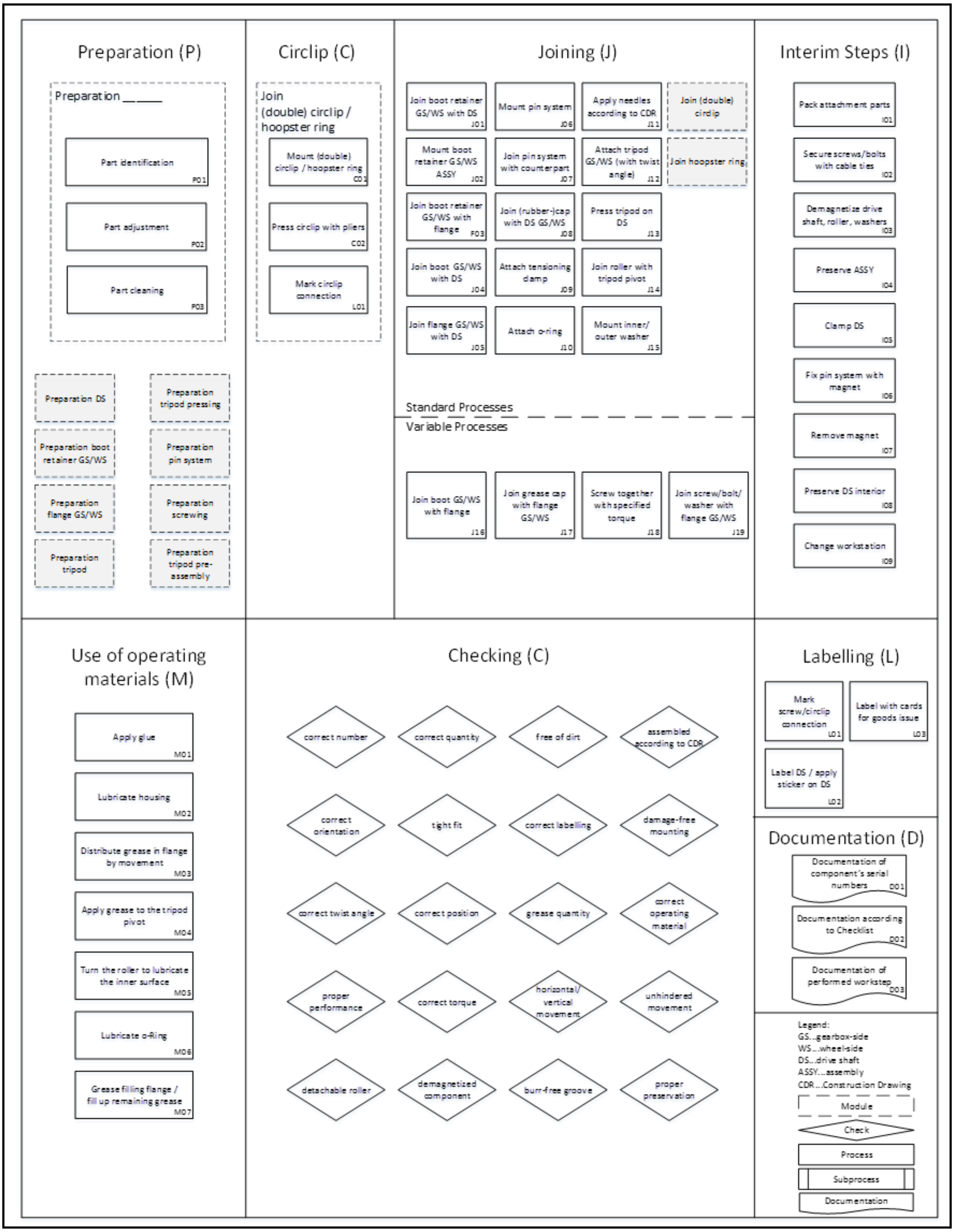

Figure 3-19: Overview process steps

3.2.8 Catalogue of requirements

Based on the overview of the process steps, it was possible to develop a catalogue of requirements. Each process step listed, has at least one attribute that can and needs to be either assured and/or documented. The only exceptions are the processes “remove magnet” (I07) and “change workstation” (I09).

For this reason, there are distinctions within the catalogue of requirements, one for process assurance and one for documentation.

They each consist of four columns:

- *ID*: the index system from the previous chapter, consisting of a letter and an ascending number, was retained for better overview and allocation
- *process step*: name for each process steps
- *attribute to check/document*: characteristic that needs to be either checked and/or documented
- *current assurance/documentation*: gives a short description about the current handling

Concepts to be developed need the ability to assure all the characteristics listed in the catalogue and additionally document them. Figure 3-20 shows an excerpt, the full catalogue can be found in Appendix B. This catalogue was verified in cooperation with the company.

Process Assurance

ID	Process step	Attribute to check	Current Assurance
P01	part identification	correct number	manual and visual comparison
		correct quantity	pre-picking in warehouse
P02	part adjustment	correct number	visual inspection
		correct quantity	visual inspection
P03	part cleaning	free of dirt	visual inspection
C01	mount (double) circlip / hoopster ring	assembled according to CDR	visual inspection
		correct orientation	visual inspection
C02	press circlip with pliers	tight fit	visual inspection, inspection with gauge
J01	join boot retainer GS/WS with drive shaft	damage-free mounting	visual inspection
		correct position	visual inspection
		correct orientation	visual inspection
J02	mount boot retainer GS/WS assembly	assembled according to CDR	visual inspection
J03	join boot retainer GS/WS with flange	correct orientation	visual inspection
		damage-free mounting	visual inspection
J04	join boot GS/WS with drive shaft	damage-free mounting	visual inspection
		correct position	visual inspection
		correct orientation	visual inspection
J05	join flange GS/WS with drive shaft	damage-free mounting	visual inspection
		correct orientation	[illegible]
		correct position	

Figure 3-20: Excerpt – catalogue of requirements

3.3 Concept Development

During phase II, concept development, the current state-of-the-art regarding assembly documentation and increase of process assurance was investigated. The focus was laid on assistance systems that deliver cognitive assistance for the worker by providing on the one hand information when needed and systems that are able to record and collect assembly data on the other. Current researches as well as, if available, technologies and systems that were already successfully applied, delivered the information base for this investigation.

Potential usable technologies were collected, summarized and presented to the project team during a workshop in the form of a morphological box which was used to derive concepts. These concepts were further elaborated and evaluated by benefit analysis. On the base of the benefit analysis, the concepts were iterated in order to get a final concept which was then to be detailed in phase III.

Procedure	Acquired Data
▸ Definition of functions that are essential to fulfill the catalogue of requirements ▸ Research state-of-the-art technology in the area of assistance systems for assembly ▸ Research for potential usable technologies ▸ Conduction of a workshop for concept development of a holistic assistance system by use of various technologies ▸ Evaluation and iteration of concepts	▸ **Technology research** – benchmarking of potential relevant technologies to assist the assembly process, increase process assurance and record data for assembly documentation

Figure 3-21: Procedure and acquired data – Phase II

3.3.1 Functions of an assembly assistance system

The catalogue of requirements (cf. chapter 3.2.8) delivered attributes that have to be tested and/or documented. Many of them are similar or equal and it was possible to derive 19 functions with the ability to fulfill the whole catalogue of requirements:

- capture quantity
- check fit
- check horizontal/vertical movement
- check integrity

- check label content
- check magnetic field
- check part surface
- check preservation
- check unhindered movement
- detect dirt
- determine grease quantity
- determine label position
- determine part orientation
- determine part position
- determine tightening torque
- document data
- identify operating materials
- identify part
- show information

These functions were used as base for the concept development. Any concept had to be capable of providing and fulfilling each of the functions listed above in order to meet all requirements.

3.3.2 Identification of applicable technologies

To ascertain applicable technologies, a research into current assembly systems and relevant research projects was carried out. As far as there was accessibility to it, benchmark systems already in use were taken into account as well, for example an assembly line at the neighboring high performance drive unit factory in Kapfenberg, built by the company Knapp AG.

The technologies were mainly investigated for the features they are able to provide, allowing a cross reference with the functions that potential concepts for the project have to provide.

Figures 3-22, 3-23 and 3-24 summarize the features offered by technologies that are currently available on the market. A distinction was made between functions for process assurance, customer documentation and process monitoring, with further subgroups for better overview.

Environment
- Measure temperature
- Measure humidity
- Measure luminous intensity
- Measure oxygen content
- Detect vibrations
- Measure breeze

Worker
- Record worker ID
- Monitor biometric data
- Know about skills
- Detect movement
- Monitor exhaustion level
- Monitor exertion level
- Monitor state of health

Material
- Identification
- Localisation
- Provision
- Sorting
- Measure material qualities
- Detect orientation
- Detect location

Machine
- Condition-monitoring
- Know work status
- Measurement of sensor data (e.g. tightening torque, angle of rotation,…)

Process
- Providing a check button
- Providing a check list
- Visual process monitoring
- Recording of work steps
- Visual quality inspection

Figure 3-22: Functions of process monitoring

Standardization
- Creation of standard operating procedures
- Modularization

Risk assessment
- Analysis of complaints
- Analysis of process errors
- Identification of critical processes
- Identification of critical components
- Elimination of critical processes

Software
- Enable communication between two systems (interfaces)
- Reading data
- Accessing data
- Comparison of actual and target values
- Information allocation

Active intervention
- Signalling (acoustic, visual, tactile)
- Controlling machines
- Performing emergency stop
- Enabling control of displayed information content

Figure 3-23: Functions of process assurance

Data acquisition
- Storing data
- Creating data backups
- Transferring data

Available Content
- Assembly step detection
- Visual data (image and video)
- Process information
- Machine data
- Product data
- Batch numbers and serial numbers of components

Input
- Providing filter with various options:
  - Customer
  - Order number
  - Product selection
  - Selection of processed data
- Creating report templates

Output
- Retrieving data
- Sorting data
- Applying selection filter
- Inserting data into report template
- Compiling an assembly documentation

Figure 3-24: Functions of assembly documentation

3.3.3 Exemplary benchmark systems

Throughout the course of the project, an investigation on benchmark systems was conducted, as some companies already provide or implement assembly assistance systems.

LEAD factory – Institute of Innovation and Industrial Management, TU Graz

The LEAD factory is a small-scale learning factory with the core focus topics on

Lean management

Energy efficiency

Agile operations

Digitization.[193]

It is an assembly line for scooters, used for research and training. Modularization allows two setup states of the factory, a non-optimized current state and an optimized and digitized lean state.

[193] Cf. Karre et al. (2018), p. 15ff.

In its current state, “workers” will find a non-optimized and non-assisted assembly line with poor work instructions. The digitized state uses several technologies to assist the worker, provide information and acquire assembly data.

The digitalized state was therefore investigated for benchmarking purposes. The following systems are either in use or planned to implement:[194]

- RFID for identification of components and workers and data acquisition
- an assembly software that allows communication between the systems, acquisition and storage of assembly data and comparison of actual and target values
- check button to record work steps
- touchscreens for context-based provision of information
- andon-lights for signaling
- human-machine-interfaces (Myo Band and Kinesic Mouse) for intuitive software control
- smart shop floor board to visualize the acquired data in a comprehensive and interactive overview

The production shown is medium to low volume production quantity (small series production) with a medium variety. There are currently three soft variants existing. (cf. chapters 2.1.5 and 2.1.6) Additional soft variants can be added with manageable effort, whereas additional hard variants would require significant adjustments.

[194] Cf. Karre et al. (2017), p. 206ff.

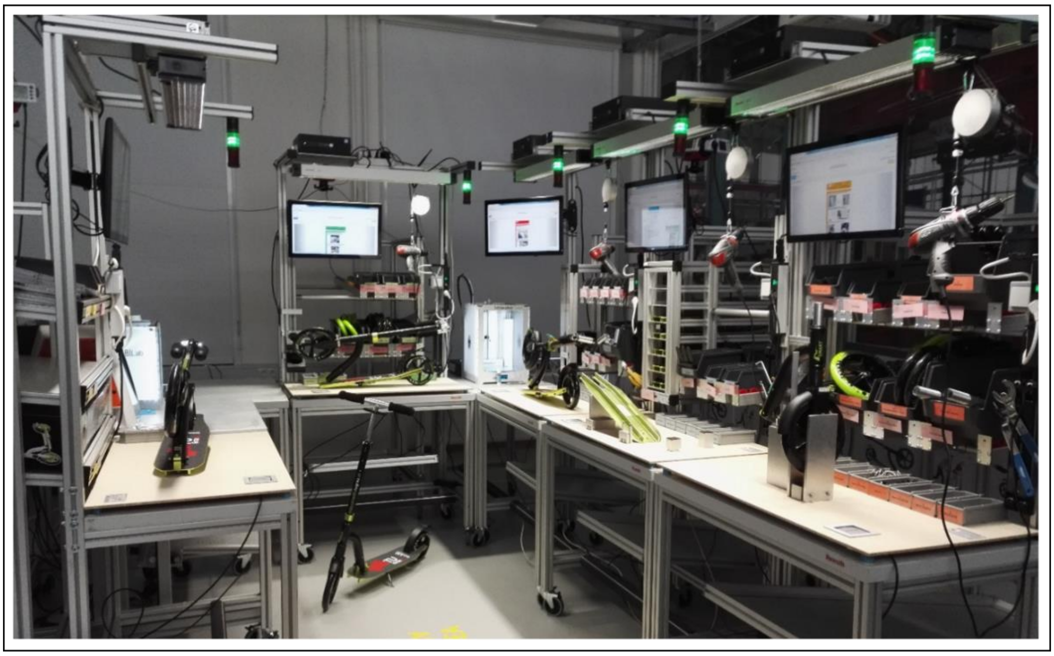

Figure 3-25: IIM LEAD Lab

Visual Assistance System – Fraunhofer IFF

The Fraunhofer Institute for Factory Operation and Automation (IFF) in Magdeburg is, amongst other topics, conducting research in the field of measurement and testing technology. They have developed a system for visual worker assistance and quality inspection for manual assembly processes, which uses augmented reality to provide workers with the information they need. Furthermore, the system is capable of conducting quality inspections for completeness and correctness after each assembly step by using optical measurement technology and industrial image processing. All necessary data is gained from the 3D-CAD models of the assembled parts.[195] The main technologies in use can be summarized as followed:

- Video camera to monitor the work desk and allow industrial image processing
- Reference system in visual sight of the video camera to allow optical measurement
- An assembly software that allows communication between the systems, acquisition and storage of assembly data and comparison of actual and target values, furthermore capable of deriving the necessary data from 3D-CAD-models
- Output device for visualising information (Touchscreen/Screen/Projector)
- Input device to control software (Touchscreen)

[195] Cf. Fraunhofer IFF Magdeburg (2018b)

The system has already been implemented successfully within a company that is specialised in engineering means of production for print processing. It is used to assist and conduct in-line quality inspections during the assembly of a clamping device for highly customized products.[196]

It was developed to increase quality assurance in complex high variant assemblies[197] and therefore delivered an excellent benchmark system for this project.

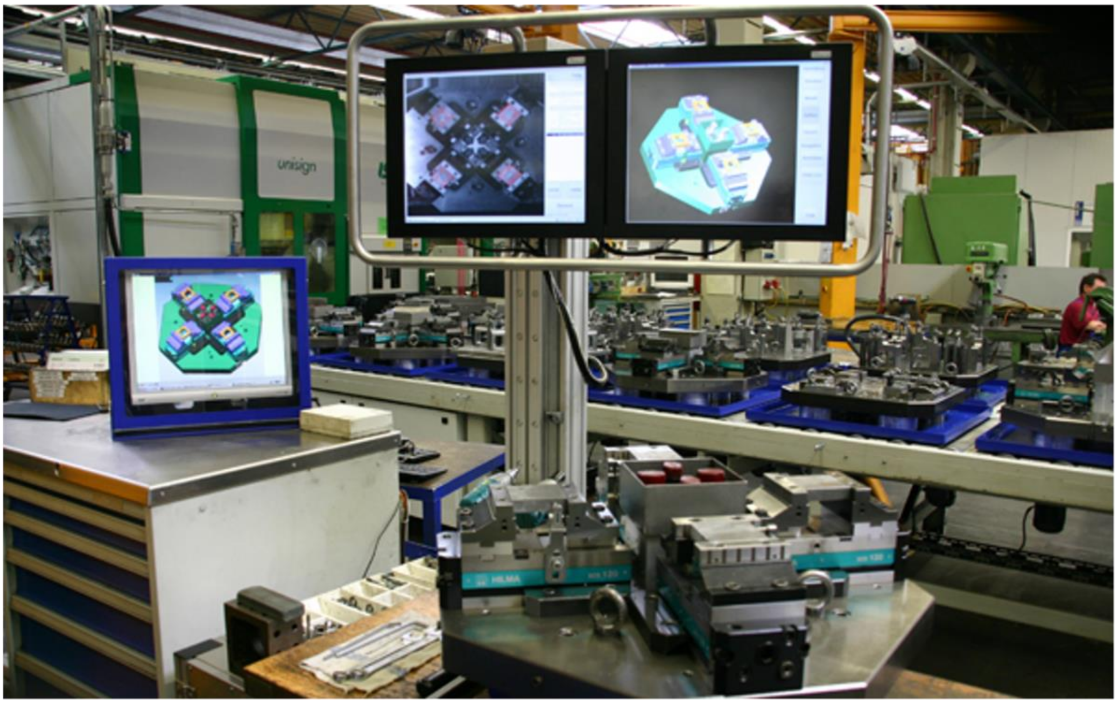

Figure 3-26: Worker-assistance-system for manual assembly[198]

High Performance Drive Unit factory – Pankl Racing Systems Kapfenberg

In 2016, Pankl built a modern production facility at the Kapfenberg location for the manufacturing of high-performance gears – the high performance drive unit factory. The company Knapp delivered a semi-automatic assembly system that uses following technologies[199]:

- fully automated warehouse system (including software) that stores, sorts and provides all necessary components at the right time, except bulk materials

[196] Cf. Sauer (2010)
[197] Cf. Fraunhofer IFF Magdeburg (2018a)
[198] Cf. Fraunhofer IFF Magdeburg (2018c)
[199] Cf. Hebezeuge Fördermittel (2018)

- 2D-scanner to identify components
- two ultraviolet video cameras to monitor the assembled product
- fixture system that is used by the cameras as a reference point and ensures correct orientation and positioning of the product
- assembly software that allows communication between the systems, acquisition and storage of assembly data
- assembly software for industrial image processing and comparison of actual and target values
- pick-to-light for signaling the currently needed component
- check button to record work steps
- two screens for context-based provision of information
- supervision software for the whole assembly

The production quantity is 160,000 units per year and only one variant is produced, hence making this system highly efficient and specialised for its purpose, but with limited flexibility and high adaptation needs in case of a variant change.

Figure 3-27: Assembly work station in Pankl's High Performance Drive Unit factory, Kapfenberg[200]

[200] Cf. Knapp AG (2017)

3.3.4 Technology overview

Figures 3-28 and 3-29 give an overview of the technologies investigated and their capabilities to fulfill the functions of the catalogue of requirements.

Technologies ↓ / Functions →	Capture quantity	Check fit	Check horizontal/vertical movement	Check integrity	Check label content	Check magnetic field	Check part surface	Check preservation	Check unhindered movement	Detect dirt
(Touch-)Screen	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
2D-Code	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Acoustic sensing	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
AR-glasses	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Automated data acquisition	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Automated label printing	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
Check button	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Checklist	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Chemical testing	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
Counting machine	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Electromagnetic waves	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Fixture	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Grease syringe with dosing function	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Induction coil	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗
Industria image processing	✓	✗	✗	✓	✓	✗	✓	✓	✗	✓
Load sensor	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗
Magnetic field meter	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗
Material supply	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Mechanical screwing	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Pre-dosing	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Printout	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Profile method	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓
Projection	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Reflexion	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗
Signal light	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Speakers	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Torque screwdriver	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Torque sensor	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Torque wrench	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Ultrasonic	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗
Use of coloured preservative	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Vibration	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
VR-glasses	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Weight measurement	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Worker	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓

✓ Capable

✗ Incapable

Figure 3-28: Technology-function map I

Functions

Technologies	Determine grease quantity	Determine label position	Determine part orientation	Determine part position	Determine tightening torque	Document data	Identify operating materials	Identify part	Show information
(Touch-)Screen	✗	✗	✗	✗	✗	✗	✗	✗	✓
2D-Code	✗	✗	✗	✗	✗	✗	✓	✓	✗
Acoustic sensing	✗	✗	✗	✗	✗	✗	✗	✗	✗
AR-glasses	✗	✗	✗	✗	✗	✗	✗	✗	✓
Automated data acquisition	✗	✗	✗	✗	✗	✓	✗	✗	✗
Automated label printing	✗	✗	✗	✗	✗	✗	✗	✗	✗
Check button	✗	✗	✗	✗	✗	✓	✗	✗	✗
Checklist	✗	✗	✗	✗	✗	✓	✗	✗	✗
Chemical testing	✗	✗	✗	✗	✗	✗	✗	✗	✗
Counting machine	✗	✗	✗	✗	✗	✗	✗	✗	✗
Electromagnetic waves	✗	✓	✓	✓	✗	✗	✓	✓	✗
Fixture	✗	✗	✗	✓	✗	✗	✗	✗	✗
Grease syringe with dosing function	✓	✗	✗	✗	✗	✗	✗	✗	✗
Induction coil	✗	✗	✗	✗	✗	✗	✗	✗	✗
Industria image processing	✗	✓	✓	✓	✗	✗	✓	✓	✗
Load sensor	✗	✗	✗	✗	✗	✗	✗	✗	✗
Magnetic field meter	✗	✗	✗	✗	✗	✗	✗	✗	✗
Material supply	✗	✗	✗	✓	✗	✗	✓	✓	✗
Mechanical screwing	✗	✗	✗	✗	✓	✗	✗	✗	✗
Pre-dosing	✓	✗	✗	✗	✗	✗	✗	✗	✗
Printout	✗	✗	✗	✗	✗	✗	✗	✗	✓
Profile method	✗	✗	✗	✗	✗	✗	✗	✓	✗
Projection	✗	✗	✗	✗	✗	✗	✗	✗	✓
Reflexion	✗	✓	✗	✓	✗	✗	✗	✗	✗
Signal light	✗	✗	✗	✗	✗	✗	✗	✗	✓
Speakers	✗	✗	✗	✗	✗	✗	✗	✗	✓
Torque screwdriver	✗	✗	✗	✗	✓	✗	✗	✗	✗
Torque sensor	✗	✗	✗	✗	✓	✗	✗	✗	✗
Torque wrench	✗	✗	✗	✗	✓	✗	✗	✗	✗
Ultrasonic	✗	✗	✗	✓	✗	✗	✗	✗	✗
Use of coloured preservative	✗	✗	✗	✗	✗	✗	✗	✗	✗
Vibration	✗	✗	✗	✗	✗	✗	✗	✗	✓
VR-glasses	✗	✗	✗	✗	✗	✗	✗	✗	✓
Weight measurement	✓	✗	✗	✗	✗	✗	✗	✗	✗
Worker	✗	✓	✓	✓	✗	✗	✓	✓	✗

✓ Capable

✗ Incapable

Figure 3-29: Technology-function map II

For each capable technology/function combination, a use-case description was created. This contains a description of the technology, advantages, disadvantages and requirements.

An example is shown in figure 3-30, the whole technology and use-case descriptions can be found in Appendix C.

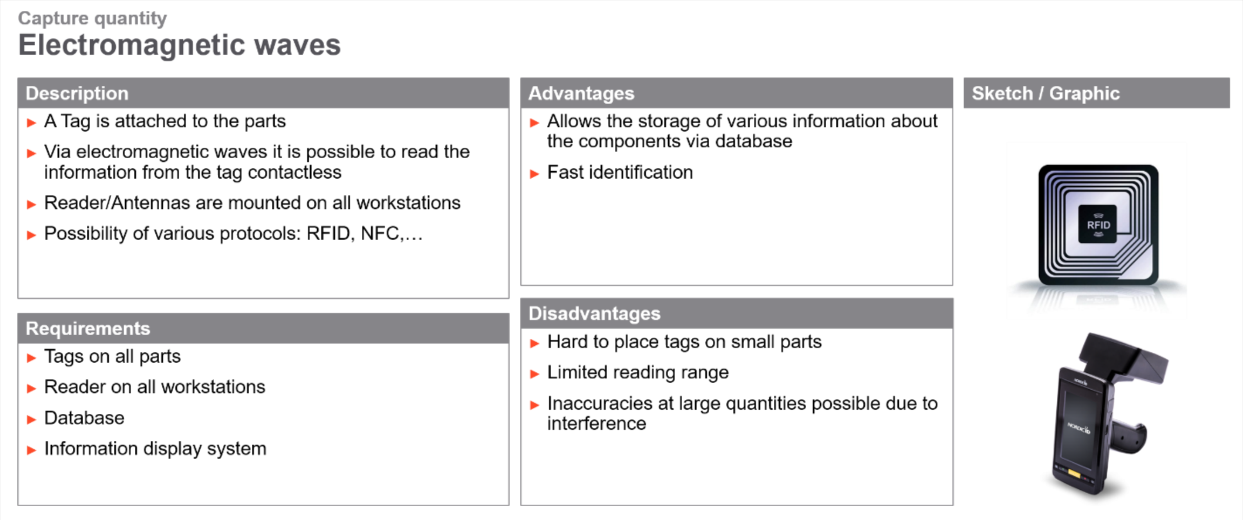

Figure 3-30: Example of a technology use case – capture quantity / electromagnetic waves

3.3.5 Concept Development Workshop

In order to derive solution concepts for the future assembly workplace at Pankl from the technology use-cases found, a workshop was held in Kapfenberg.

Representatives from the design, quality assurance and assembly departments took part in this workshop in order to take into account as many different approaches and perspectives as possible and to incorporate as many experiences as possible into the concept derivation. Over the course of the workshop, the method of a morphological box (cf. chapter 2.4.1) was adapted, in order to allow usage for this project:

Firstly the problem should be defined as: “Which system of technologies fulfills our requirements in the best way?” To allow a proper evaluation, some decision criteria had to be defined as well.

For the second step, the definition of parameters, functions the system needs to provide are used as such. Thirdly, by using the elaborated technology systems as solutions found for the parameters/functions, the morphological box was created.

The morphological box created consisted of a total of 76 technology use cases apportioned among 19 functions, thus creating the enormous number of ~$6.87*10^{10}$ theoretically possible solutions. Not all of these theoretical solutions can actually be realized, but as the whole project team was familiar with the investigated field, a pre-sorting process was not necessary.

A printout version of the morphological box was used in the workshop to derive concepts, as it offered the advantage of a good overview. To ensure everybody had the same understanding of the technology use-cases, the workshop was started with an explanation of them. Over the course of this, the knowledge was gained that for four functions, the only practicable solution would be the performance through a worker. As a result, the following functions were decided to be realized with the technology worker in all concepts:

- check fit
- check horizontal/vertical movement
- check magnetic field
- check unhindered movement

After the explanation of the morphological box and the use-cases included, a concept derivation was conducted. For this purpose, each department was assigned with a color. The preferred solution for each parameter had to be marked with this color, as shown in figure 3-31. In this way, three rough concepts were derived and furthermore the current state outlined. Additionally, two further concepts were derived:

An “IIM”-concept, representing the view of the thesis’ author and a high-tech concept, which should represent the most possible advanced system relating to the state-of-the-art investigation. These rough concepts were then outlined in a level of detail that allowed a qualified evaluation.

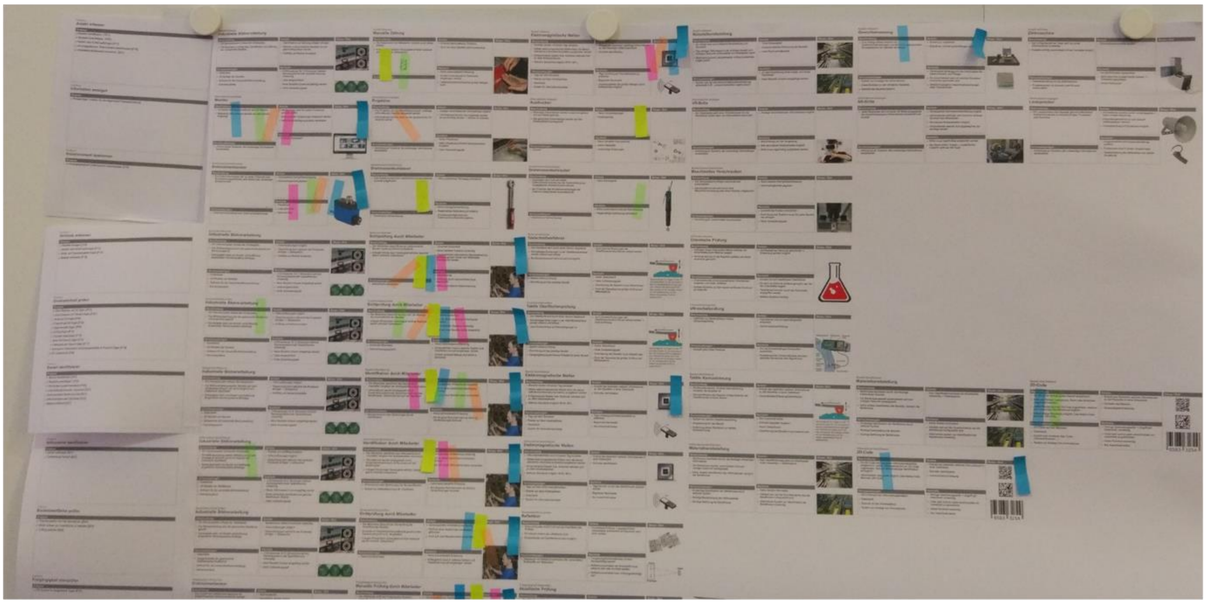

Figure 3-31: Concept derivation by using a morphological box

Figure 3-32 gives an overview over all derived concepts:

	Current State	Concept "Assembly"	Concept "Design engineering"	Concept "Quality department"	Concept "High Tech"	Concept "IIM"
Capture quantity	worker (manual counting)	electromagnetic waves	weight measurement / electromagnetic waves	worker (manual counting)	industrial image processing	weight measurement
Determine tightening torque	Torque wrench	torque sensor	torque sensor	torque sensor / torque wrench	torque sensor / torque wrench	torque sensor / torque wrench
Identify part	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	electromagnetic waves	worker (visual/manual checking) / 2D-Code
Check part surface	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing	worker (visual/manual checking)
Determine part orientation	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing	industrial image processing
Determine part position	worker (visual/manual checking)	industrial image processing	worker (visual/manual checking)	industrial image processing	industrial image processing	industrial image processing
Document data	checklist	check button / automated data acquisition	check button / automated data acquisition	check button / automated data acquisition	check button / automated data acquisition	check button/automated data acquisition
Determine grease quantity	weight measurement	grease syringe with dosing function	grease syringe with dosing function	grease syringe with dosing function	grease syringe with dosing function	grease syringe with dosing function
Identify operating materials	worker (visual/manual checking)	worker (visual/manual checking)	2D-Code	industrial image processing	industrial image processing	2D-Code
Show information	printout	projection	(touch-)screen	(touch-)screen	AR-glasses	(touch-)screen
Check preservation	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing	worker (visual/manual checking)
Determine label position	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing	industrial image processing
Check labe content	worker (visual/manual checking)	worker (visual/manual checking)	automated label printing	worker (visual/manual checking)	industrial image processing	industrial image processing
Detect dirt	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing	worker (visual/manual checking)
Check integrity	worker (visual/manual checking)	worker (visual/manual checking)	worker (visual/manual checking)	industrial image processing / Manuelle Prüfung durch MA	industrial image processing	worker (visual/manual checking)

Figure 3-32: Workshop result – derived concepts

Figure 3-33 to figure 3-38 shows potential assembly procedures for each concept. In this procedure, an axis depicts a typical driveshaft assembly with several “checkpoints”. Each checkpoint is connected to one or more functions that need to be provided by the system at this point of the assembly:

- **labelling**: determine label position; check label content
- **preparation:** identify part
- **cleaning:** detect dirt
- **mounting subassemblies:** determine part position; show information
- **glueing:** identify operating materials
- **screwing:** determine tightening torque
- **joining circlip:** check fit
- **attaching o-ring:** check integrity
- **assembling tripod:** determine part orientation, check magnetic field
- **applying needles:** capture quantity
- **mounting pin system:** check horizontal/vertical movement; check unhindered movement
- **grease filling:** check part surface; determine grease quantity
- **packing and preserving:** check preservation
- **documenting:** document data

The point “documenting” is marked with a different color on the axis as it is not part of the assembly process itself.

All technologies used in a concept are listed beneath the axis in order to show their time of usage. The use of technologies can happen either selectively for certain points within the assembly process as well as continuously over the course of the whole process or parts of it.

Additionally, there is a half transparent continuous beam over the whole process for the system worker, as he or she is involved during the whole process. Points that require special attention by the worker are extra marked.

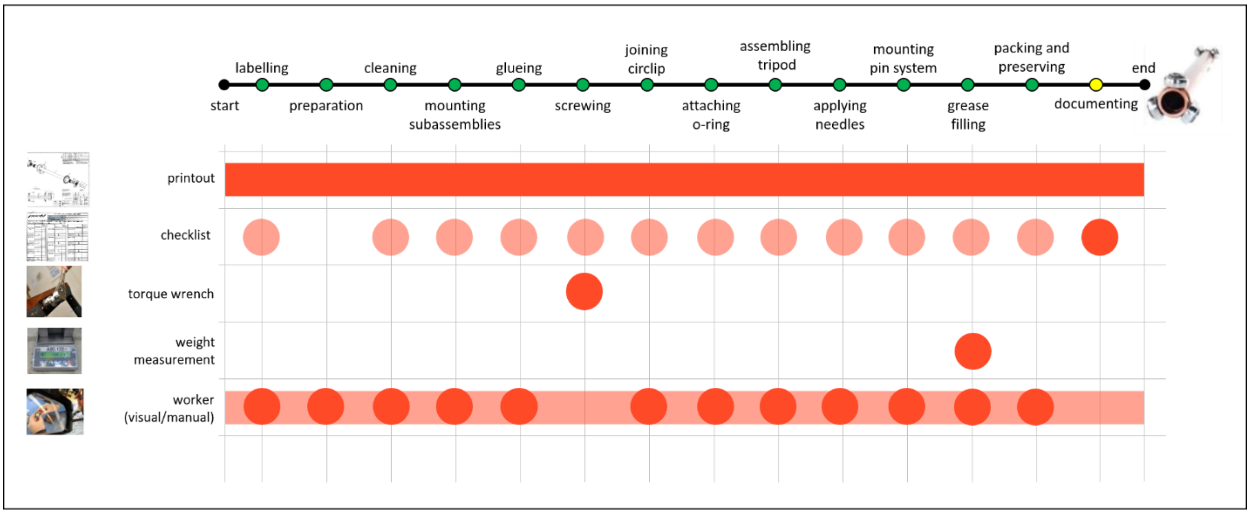

Figure 3-33: Procedure of concept “current state”

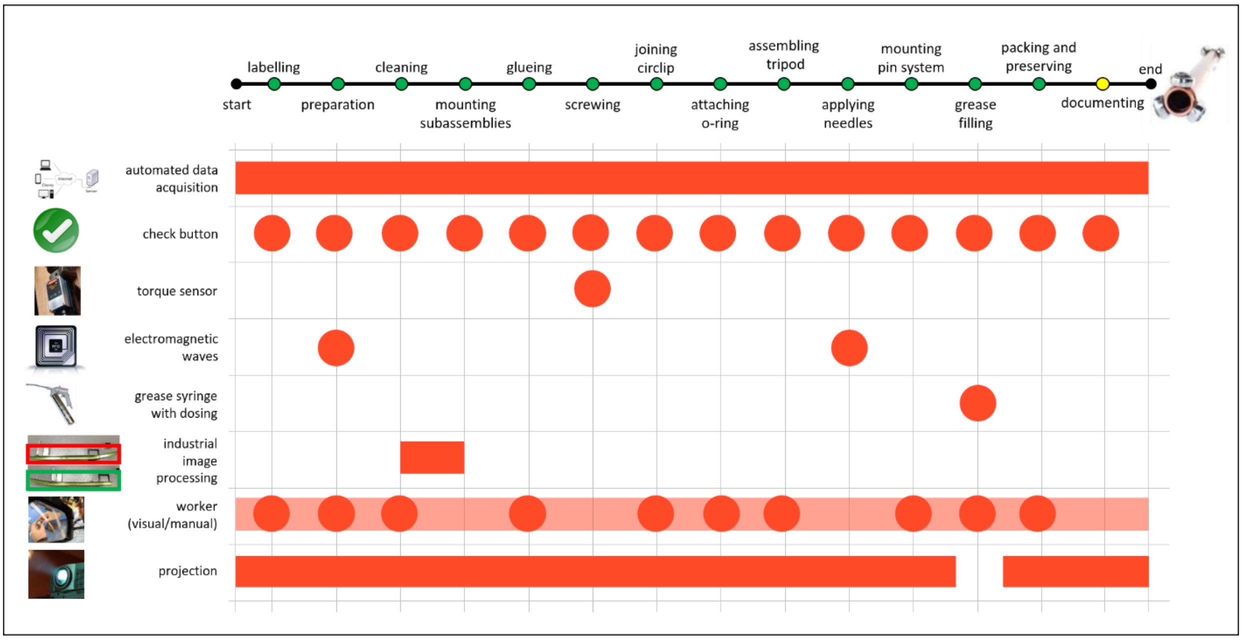

Figure 3-34: Procedure of concept “assembly”

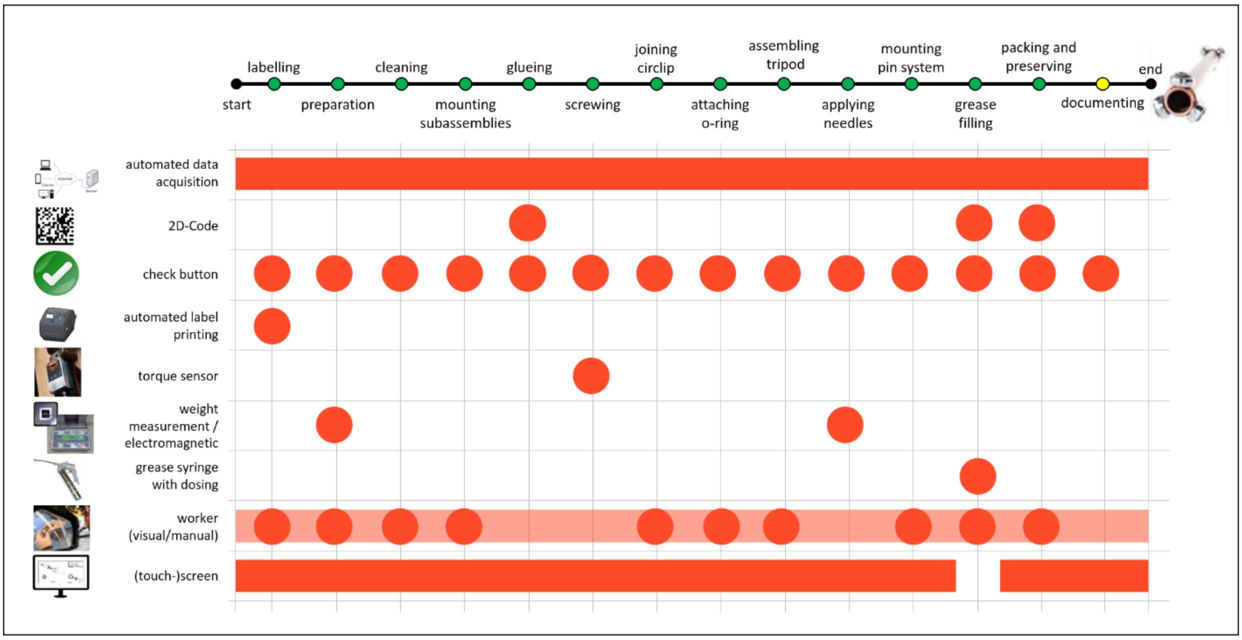

Figure 3-35: Procedure of concept “design”

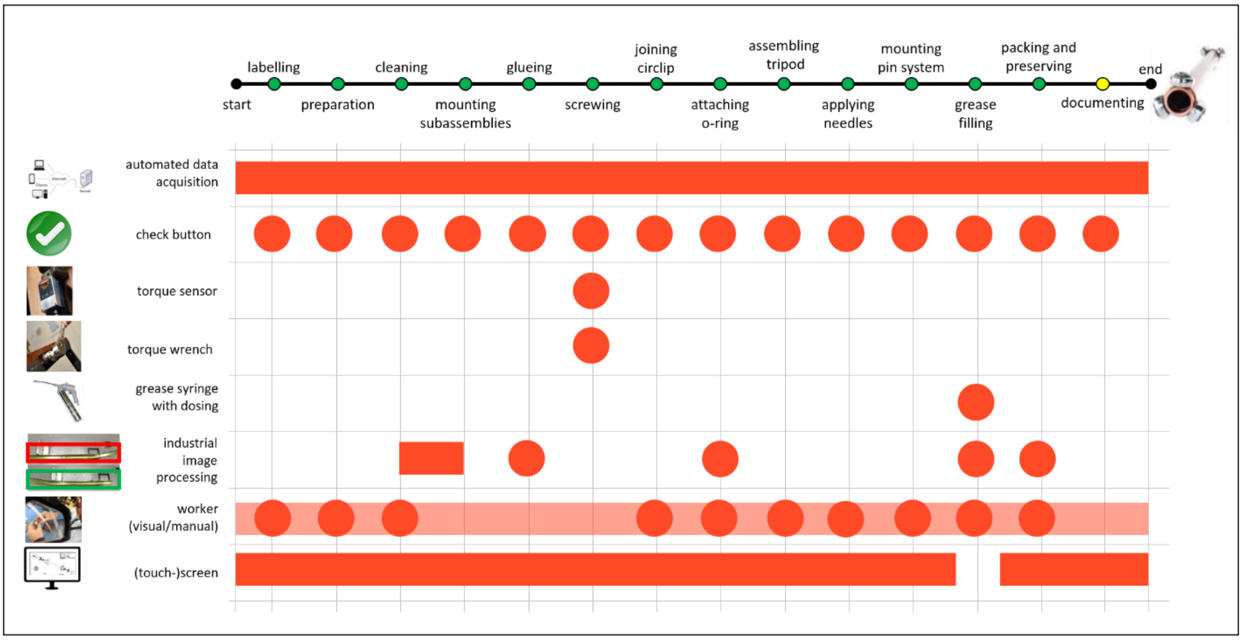

Figure 3-36: Procedure of concept “quality”

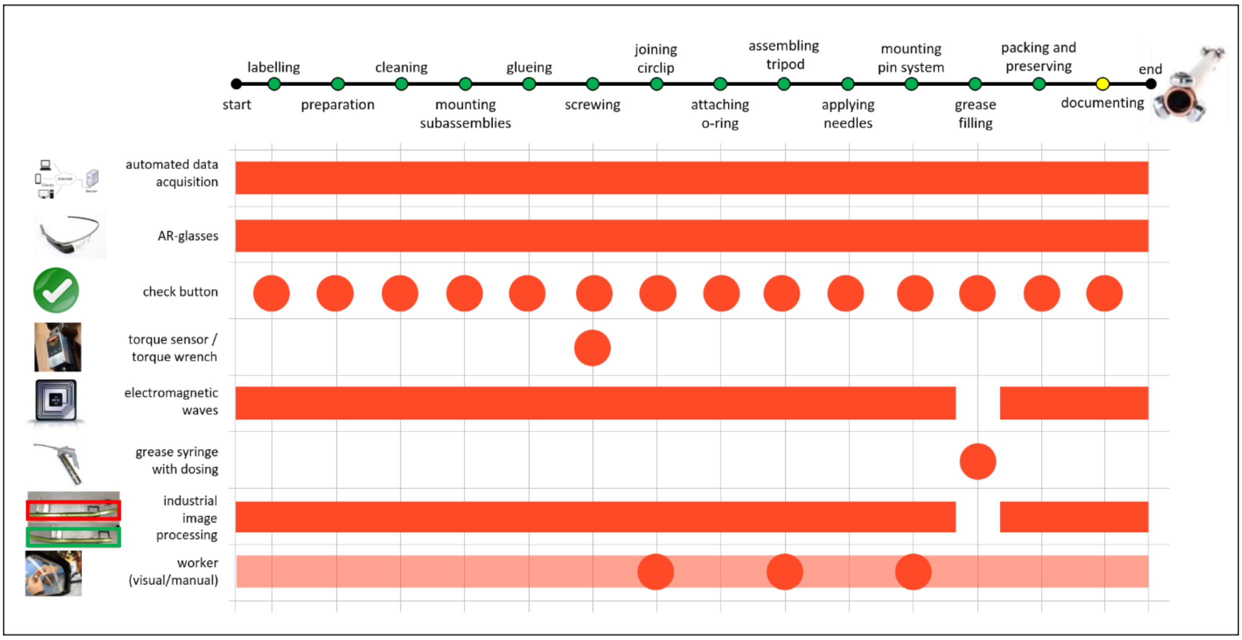

Figure 3-37: Procedure of concept “high tech”

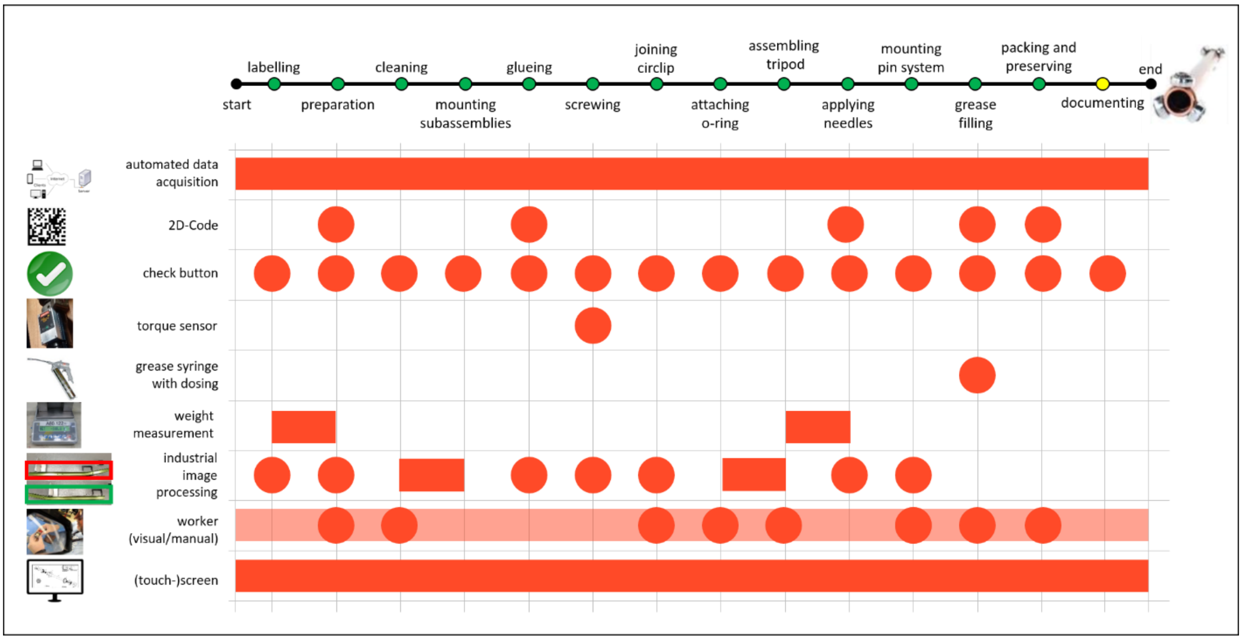

Figure 3-38: Procedure of concept “IIM”

The concepts listed above were then evaluated according to the criteria that were laid out at the workshop.

3.3.6 Concept evaluation

The concepts from the previous chapter were evaluated by conducting a benefit analysis, with each concept representing a solution alternative. (cf. chapter 2.4.3)

As the team, the working environment and the investigated problem were already defined before, the next step was to define decision criteria.

The following criteria were laid out at the concept development workshop:

- **preparation time:** this criteria evaluates how much time is required for preparation purposes, starting from the design engineering up to the start of assembly.
- **flexibility:** a high number of variants means high requirements regarding flexibility. This criteria evaluates how much effort is necessary for the introduction of new products or the change of existing product’s parameters.
- **implementation:** this criteria evaluates whether and how well the concepts can be implemented in the currently existing layouts, with the main focus on whether the concepts required significant layout changes.
- **compatibility:** evaluates the compatibility of the concepts with regard to data integration into existing software products, e.g. if collected data needs to undergo conversion processes or can be used directly.
- **time exposure:** the time required for documentation should be kept to a minimum. Therefore this criteria evaluates the estimated time required for documentation compilation.
- **mobility:** since workers often have to change work stations, this criteria evaluates mobility and hence whether it is possible to use the technologies on a mobile or stationary basis.
- **usability:** usability is a crucial factor for acceptance of the system. This criteria evaluates if the operation of the system is intuitive or requires a long training period.
- **degree of detail:** this criteria was used to assess how comprehensive the acquired data is and therefore the documentation that can be compiled. It should also take into account how assured the collected data is.

The criteria mentioned above, all of which represent “non-quantifiable” criteria, were prioritized in a next step by conducting a pairwise comparison.

The project supervisors and representatives from the assembly, quality assurance and design engineering departments as well as the author of this thesis were involved in the process of the pairwise comparison. Figure 3-39 shows the final results.

	Preparation time	Fexibility	Implementation	Compatibility	Time exposure	Mobility	Usability	Degree of detail	∑	Weighting
Preparation time		2	3	2	4	3	2	4	20	10%
Fexibility	5		7	7	4	5	2	5	35	18%
Implementation	4	0		6	1	5	0	3	19	10%
Compatibility	5	0	1		4	6	2	4	22	11%
Time exposure	3	3	6	3		3	1	5	24	12%
Mobility	4	2	2	1	4		2	3	18	9%
Usability	5	5	7	5	6	5		5	38	19%
Degree of detail	3	2	4	3	2	4	2		20	10%

Figure 3-39: Results of the pairwise comparison

As already mentioned in chapter 2.4.3 an inverse school grading was used for the valuation of criteria, with 5 being the best possible value and 1 the worst. The valuation was conducted by the same participants as the pairwise comparison, with the exception of the project supervisors. The results of the valuation and the hence calculated benefit scores of the concepts are depicted in figure 3-40.

	Weighting	Concept "IIM"	Concept "current"	Concept "assembly"	Concept "quality"	Concept "design"	Concept "high tech"
Preparation time	10%	3	4	3	3	3	2
Flexibility	18%	3	4	4	4	4	3
Implementation	10%	4	4	3	3	3	3
Compatibility	11%	3	2	3	3	3	3
Time exposure	12%	4	2	4	3	3	4
Mobility	9%	4	5	4	3	3	2
Usability	19%	4	4	3	3	3	4
Degree of detail	10%	4	2	3	4	3	5
Benefit score	∑	3,54	3,52	3,39	3,31	3,34	3,15

Figure 3-40: Benefit scores

It should be noted that there were some considerable differences in the beginning of the valuation by the departments. As it turned out, this was due to a still low degree of detail of the concepts, leaving room for different interpretations. A discussion provided for common understanding and levelling, resulting in the concept “IIM” having the highest benefit score. It has high scores for all criteria except preparation time, flexibility and compatibility, where it still performed averagely. The current concept scored particularly well due to its familiarity, high flexibility and excellent mobility. However, the low level of detail with regard to the documentation was also noted. Having the highest score in this criteria, the concept “high tech” still was evaluated as being non-preferable due to its high preparation time, low flexibility and low mobility.

3.3.7 Decision

Due to its benefit score, the “IIM” concept was to be detailed further. However, as the scores of the two concepts “IIM” and “current” were similar, the decision was made to refine the concept IIM further in order to reduce the preparation time and increase the flexibility.

The adaptations made led to the final concept to be selected. The final concept’s documentation scope can be defined as required, depending on the application of the implemented technologies.

The following adaptations were made:

In order to reduce preparation time and effort, industrial image processing technology was removed and replaced by giving the workers more responsibility. For the function of checking label content, the worker should be supported by the technology “automated label printing”. Furthermore, the technology “grease syringe with dosing” was replaced by “weight measurement”, as in the course of a rough cost estimate, the costs for this technology turned out to be too high. Lastly, because of doubts regarding the real-world usability due to weight tolerances, the worker was foreseen for the function capture quantity.

In addition, the concept should be expandable with additional technologies. As a concrete example of this a camera for taking photographs after work step confirmations and checkpoints has therefore already been taken into account in the final concept.

3.4 Final Concept

In phase III, the previously selected final concept was elaborated in detail, taking into account the results of phase II. Applied technologies were summarized and potential solution systems proposed. Furthermore, a modularization of the product drive shaft was conducted and a visualization of a possible workstation design provided. Lastly, process models were developed in order to depict the potential assisted assembly process, taking into account the preparation processes.

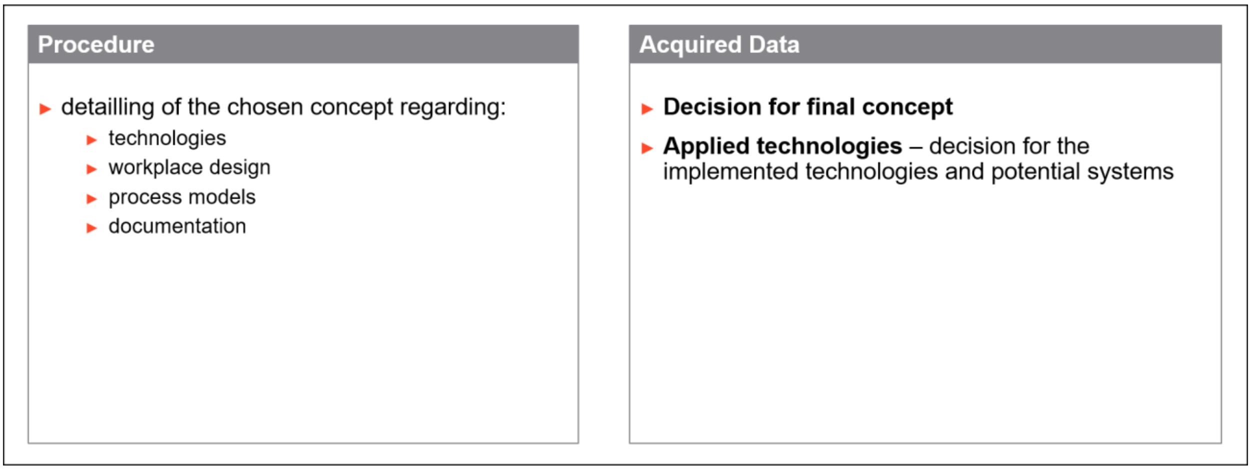

Figure 3-41: Procedure and acquired data – Phase III

3.4.1 Technology Overview

In order to better describe their application within the final concept, three technology designations were adapted:

- automated data collection = assembly software
- 2D-code = 2D-code scanner
- (touch-)screen = touchscreen

In addition to the selected technologies, a camera was considered as an example of an extension. By adding a camera, the possibilities for assembly documentation are significantly increased, due to the ability of collecting pictures during the assembly process. The recording of videos would be an additionally provided function, but because of objections regarding data security and acceptance, this possibility is not considered further. As a camera only acts passively for documentation purposes, it is not to be confused with the previously proposed technology of industrial image processing.

In the following chapter, descriptions of the applied technologies are provided and potential solution systems introduced.

Assembly software

The assembly software represents the “control center” of the final concept. It is responsible for data acquisition, storing and processing. All cognitive processes are performed by the software, such as decision-making based on comparison of target and actual values. Providing the right information for the assembly process based on situation is also carried out by the software. Additionally, hardware that fulfills the system’s requirements is needed.

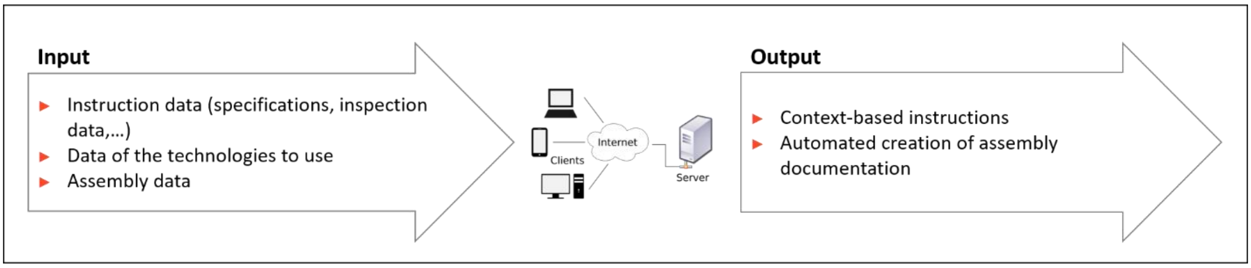

Figure 3-42: Input/output – assembly software

Potential solution system:

Already applied ERP-software ABAS. This solution would be limited to functions which ABAS can provide, therefore the combination with add-on assembly software could be meaningful. ABAS would then be used to provide and store data.

2D-code scanner

Parts and components should be identified via 2D-code, resulting in the need for a 2D-code scanner. It must to provide reliable and fast (<1s) registration of barcodes and data matrix codes. Furthermore, it should be portable and of small size/weight in order to be handy for the worker.

Figure 3-43: Input/output - 2D Code scanner

Potential solution systems:

Industrial-suited 2D-handscanners, e.g. Datalogic PowerScan PBT9500[201] that provide additional Bluetooth support and visual/acoustic read confirmation.

Automated label printing

The automated label printing is used to prevent false label content due to input errors, by automatically printing the label with the information stored in the system. Therefore the label printer needs the ability to interact with the assembly software, hence an interface for PC-connection.

Figure 3-44: Input/output – automated label printing

Potential solution system:

All label printers with interface for PC-connection may be used-

Check button

A check button is needed to confirm the proper performance of work steps for documentation. It is important that the check button is easily seen and an unintended initiation is obviated. Furthermore the underlying software has to ensure that a bypass of the check button is not possible.

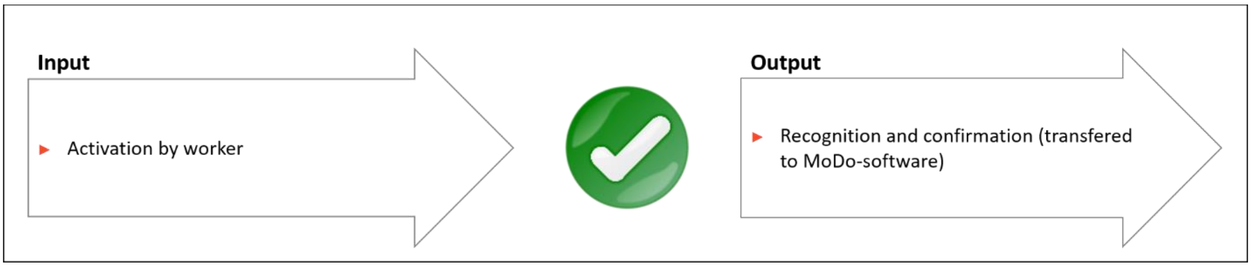

Figure 3-45: Input/output – check button

[201] Cf. Datalogic (2018)

Potential solution system:

Analogue or digital execution possible. Since information is provided via touchscreen, the digital solution is preferable, with the check button implemented in the assembly software.

Torque sensor

Throughout the screwing process, the application of the claimed torque must be checked. The torque sensor needs to provide an accuracy of ± 1Nm and give feedback when the correct tightening torque is reached. Optionally, the torque data should be transferred directly between software and torque sensor in order to prevent input errors.

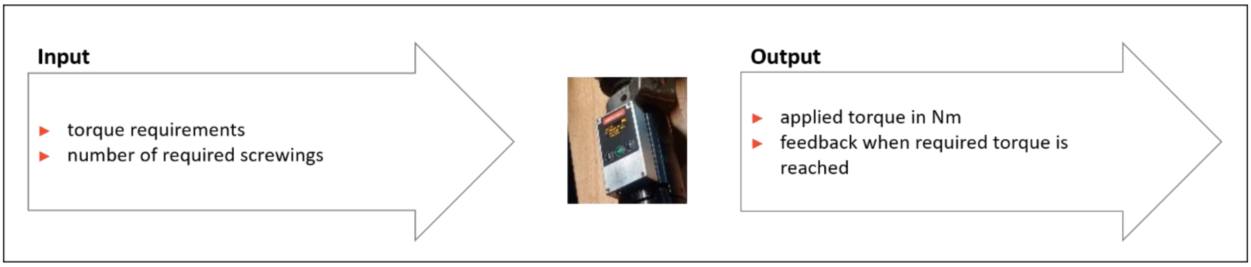

Figure 3-46: Input/output – torque sensor

Potential solution system:

Digital torque wrench with included sensor, e.g. Gedore E-Torc Q[202], which additionally provides communication via radio and direct connection to CAQ software systems.

Alternatively, a common torque sensor in combination with the preferred tightening tool could be used.

Weight measurement

The correct amount of grease should be checked by weight measurement. Therefore a continuous measurement of the weighed part is therefore necessary and an accuracy of ± 1g for a measuring range of up to 20kg is required. Optionally, the weight measurement system should have an integrated fixture for the drive shafts.

[202] Cf. GEDORE (2018)

Figure 3-47: Input/output – weight measurement

Potential solution system:

Table scale with the required specifications, e.g. Gram SBZ-20K, which additionally provides an interface for direct data transfer.[203]

Worker

The worker still plays a key role within the assembly process, as he conducts all physical work and many required inspections. It is therefore proposed, besides providing meaningful and context-based information, to train the workers on a regular basis.

Figure 3-48: Input/output – worker

Touchscreen

Representing the central human-machine-interface and the main input/output system for the worker, the touchscreen must provide good readability under a variety of environmental light and high viewing angles. Due to the space available, the touchscreen should measure between 20-30 inches and be robust enough for application on the shop floor. Optionally, the touchscreen could be an all-in-one PC, so no additional hardware is necessary for the assembly software.

[203] Cf. Waagenet (2018)

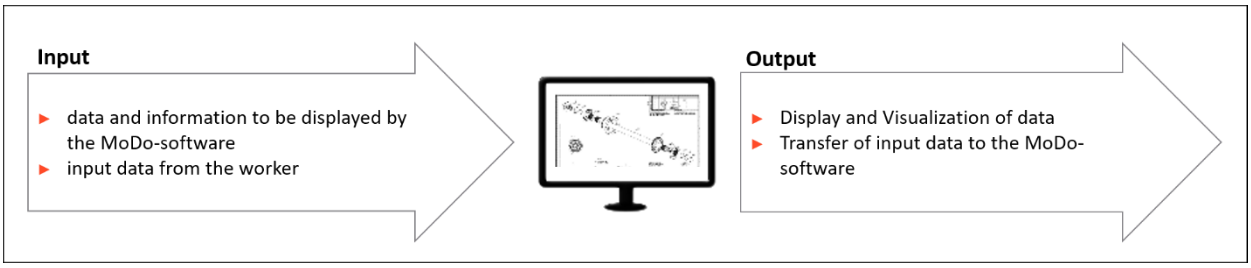

Figure 3-49: Input/output – touchscreen

Potential solution system:

20”-30” touchscreens with multitouch capability

Camera

To support and extend the documentation, photos of the assembly should be taken at checkpoints, allowing a subsequent check of work steps if necessary. The camera should therefore provide at least high definition resolution and autofocus function. It should be compact and easy to install, and a communication with the assembly software needs to be possible.

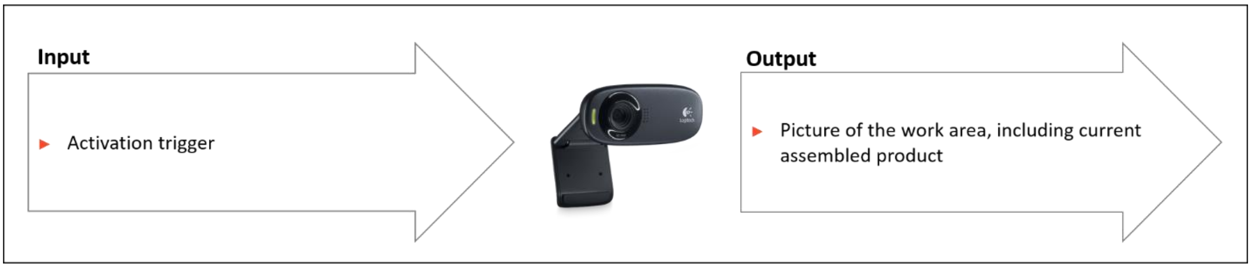

Figure 3-50: Input/output – camera

Potential solution system:

High definition webcam, e.g. Logitech C920 HD Pro[204], which provides an additional universal mount.

The following figure shows a possible procedure of an assembly in the final concept. The time and type of technology application are proposed for a standard drive shaft assembly,

[204] Cf. Logitech (2018)

but are by default considered to be determined in the course of the preparation process, consisting of both design and initial assembly.

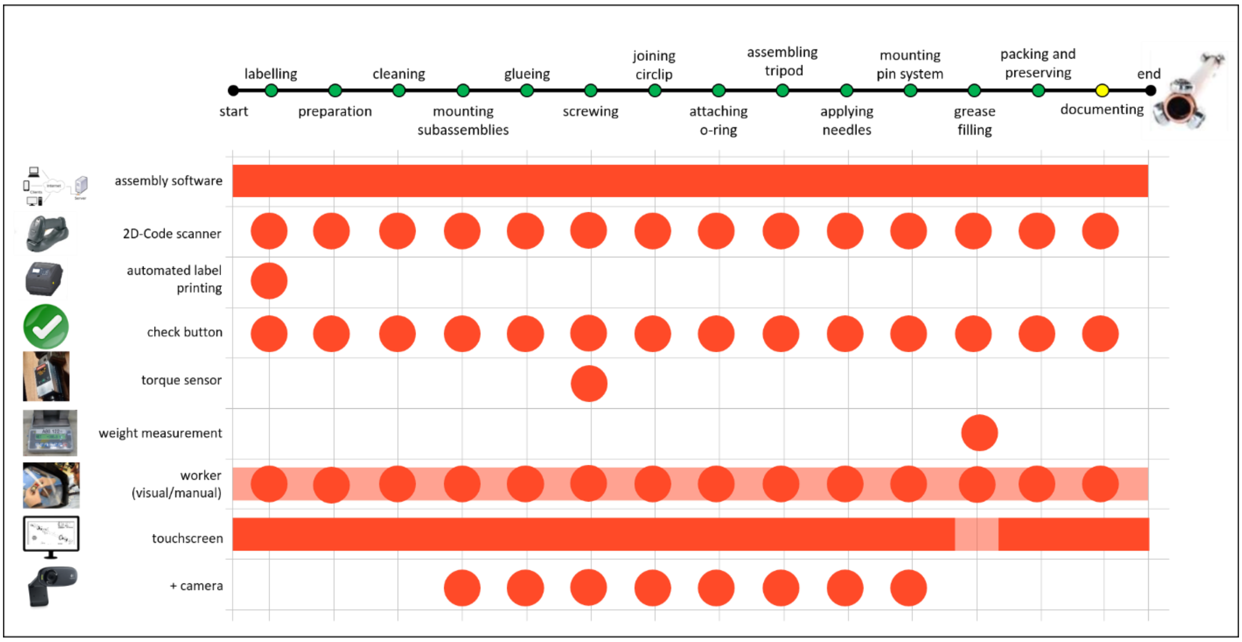

Figure 3-51: Procedure of the final concept - example

3.4.2 Visualization

Figure 3-53 shows a layout proposal for a potential workstation of the final concept. Most of the systems are mounted on a column in the corner of the table, which minimizes the impact on the working environment.

The placement of the technology column is freely selectable and variable. This is necessary because long levers (>2m) are used for dismantling processes and therefore there is a corresponding space requirement.

Alternatively, the structure could be suspended from the ceiling to leave the working area directly above (~1m) the table surface completely undisturbed.

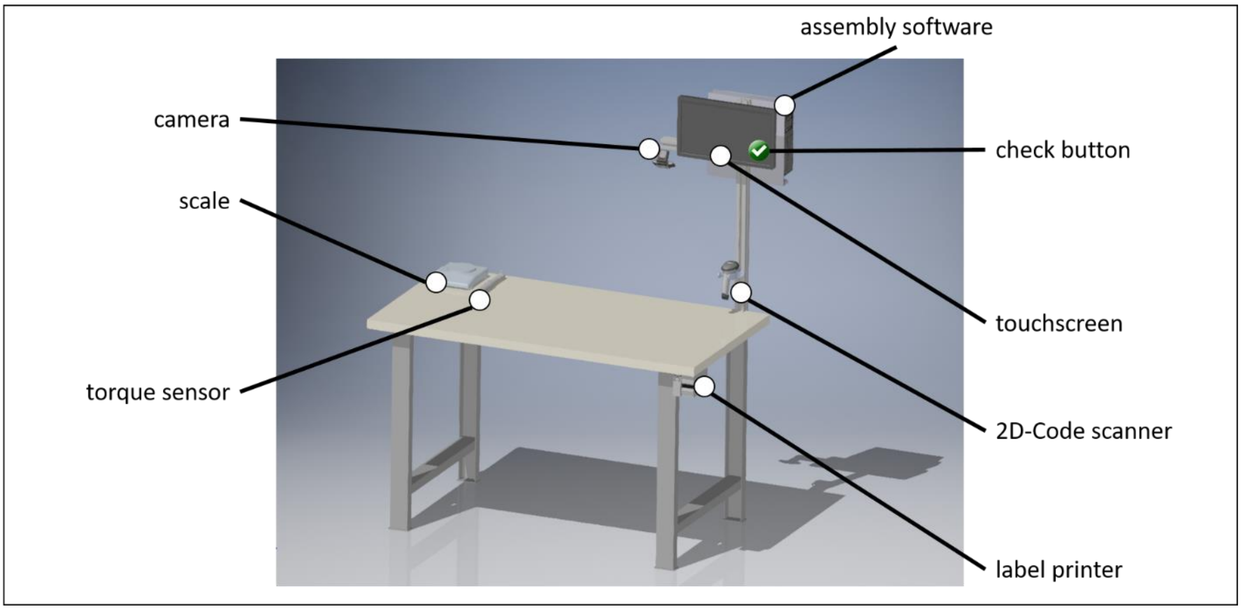

Figure 3-52: Visualization of a potential workstation - final concept

3.4.3 Modularization

For the product drive shaft, standard modules were defined. These standard modules represent checkpoints within the assembly process which allow an interruption or pause, or to continue with another product. Within the modules' assembly, no interruption of any type is planned. A module consists of at least one part or component and must be assigned to one side of the drive shaft. Modules can have additional inspection procedures, which are carried out and documented in addition to part's or component's inspections when the end of the module is reached.

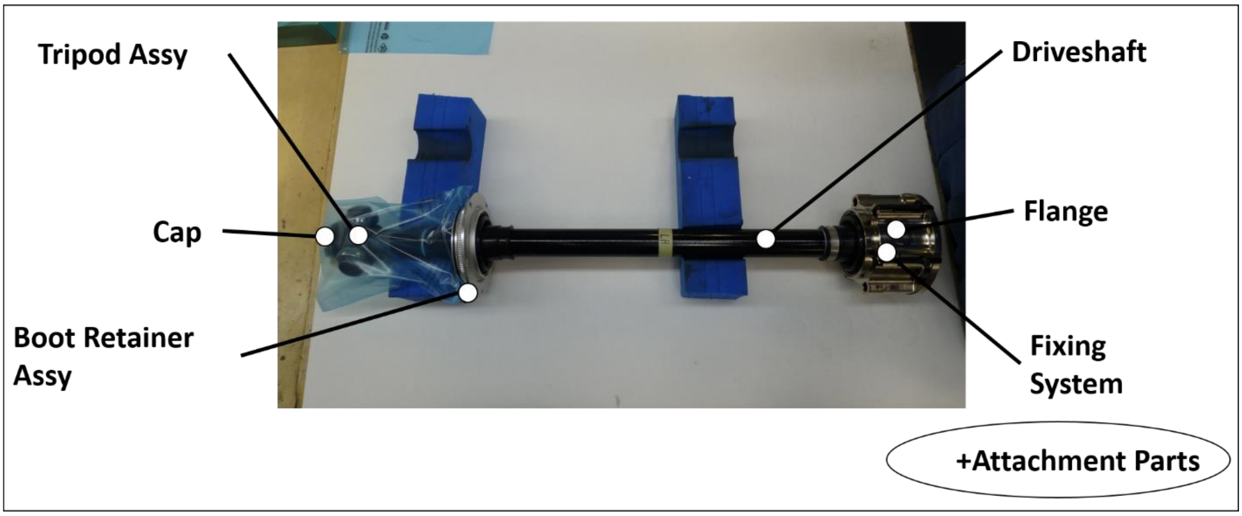

Figure 3-53: Standard modules of a drive shaft

3.4.4 Process Models

By using BPMN (cf. chapter 2.4.2), process models that depict how the processes of the final concept work, were developed. Two main processes were differentiated.

Preparation process:

Consisting of the entities design, initial assembly and software, the process starts after completion of the design drawing. According to the current state, this process is adapted, so that component notes are noted in an extra column of the parts list.

Product modules and component affiliation are defined by the designer, as well as inspection procedures. Over the course of an initial assembly, the sequence of modules and, if required, components is determined. Hence the sequence of work steps is also defined. In addition, the display contents showed during assembly are determined, in particular the explosion drawing sections and images shown. The acquired data is collected and linked to the product by the assembly software. If the same product is produced or assembled again in the future, the preparation process is not necessary, as the necessary data is already available.

Main assembly:

Consisting of the entities software and documentation, the main assembly represents processes performed at the assembly workstation throughout the entire assembly of the drive shafts. To start the process, the product to be mounted and the desired drive shaft side must be selected. The next module is then called up and the work steps and any necessary checks are carried out. After completion of a module, the installer has three options: starting the next module on the desired drive shaft side, assembling another drive shaft or completing the assembly process.

At Pankl's explicit request, these options were taken into account in order to meet the current assembly process, without the need to adapt it.

The documentation software is executed in the background throughout the entire assembly. It collects information from the technology systems installed at the workplace and provides the worker with information on the current task. This information typically consists of sections of the design drawing and notes on the corresponding components, which were determined during the preparation process.

At the same time, the software carries out any necessary tests by controlling the technology systems (for example, the camera triggers) and comparing target and actual values. The data collected is transmitted and stored throughout the entire assembly process. After the process is finished, the data is available for the automated creation of assembly documentation.

The entire process models in BPMN notation are to be found in Appendix E.

3.4.5 Assembly Documentation

With the final concept, all data for the documentation is collected automatically during the assembly process. This does not only lead to a discharge and saves time for the worker, much more data can also be acquired and recorded during the assembly process. Additionally the automated data acquisition prevents input errors and increases correctness of data, by acquiring it already within the process instead of the end (compare chapter 3.2.5 – acquired data). Customized documentation is now possible via customer profiles and selection filters, depending on customer requirements.

Required data is automatically retrieved, collected and filled into a template document, whilst applying the selected filters. A mock-up of the documentation compilation can be found in Appendix D.

Table 3-2 gives a comparison between data which is currently collected and data that can be collected by using the developed assembly concept.

Currently collected data	Potential data in the developed concept
manually, by using checklists: • serial number of defined parts • grease filling (weight) • application of operational material • performance of defined assembly steps • manual inspection results	automatically, by assembly software: • serial number / batch number of all parts (including packed ones) • grease filling (weight and specification) • application of operational material (weight and specification) • proper performance of all assembly steps • inspection results and data (automatic and manual) • applied torque for screwing connections • pictures of defined work steps • extension through additional technology possible at all times

Table 3-2: Comparison of data acquisition possibilities

4 Conclusion

The current trend for individualization poses new challenges to companies in industrialized countries. Due to the still high proportion of human work share, assemblies are particularly affected by the early customer integration and the thus resulting high variant variety. Increased uncertainty, an early abortion of the learning curve and high complexity lead to a high information demand and an overburdening of the human worker. Moreover, quality and productivity, representing essential survival factors for companies in high-wage countries, suffer from these conditions.

Digital assistance systems and modern information communications technology can provide a possible solution to support the worker by taking over cognitive processes and providing context-based information when needed.

Existing information technology infrastructure is used to provide all required data and keep additional effort as low as possible, while cyber-physical-systems allow recognition of environmental conditions and changes. Their ability to acquire exponentially more data in a shorter amount of time allows them to react almost instantly to the worker’s needs, hence increasing speed and efficiency of manual work steps. Additionally the integration of cyber-physical-systems delivers feedback on faulty performances, consequently increasing quality. The acquired data can be used further for documentation purposes, allowing full traceability of the production process of a product.

Especially for companies in a highly competitive field, this could provide a cutting-edge advantage over competitors, by attracting customers in need of highly customized products combined with extraordinarily high requirements on quality.

An example where both criteria apply is the field of racing, which this master’s thesis focused on over the course of a cooperation with a supplier for high-performance and racing parts. It was shown that existing assembly structures are not in competition with implementation of modern assistance systems, as they can be adapted accordingly, postulated that key factors such as detail level, technologies to be used and degree of support are adapted to the purpose and targeted individuals.

In the future, with increasing capacity of information assistance systems and innovative human-machine-interfaces, new possibilities for assistance will be generated and will therefore advance the fourth industrial revolution.

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List of Abbreviations

ASSY	Assembly
AV	Work Preparation Department
BPMN	Business Process Modelling Notation
CAQ	Computer Aided Quality
CDR	Construction Drawing
CPS	Cyber-physical-systems
DIN	Deutsches Institut für Normung
ERP	Enterprise Resource Planning
e.g.	For Example
F2F	Flange-to-Flange
GS	Gearbox Side
HMI	Human-Machine-Interface
ICT	Information and Communications Technology
IFF	Fraunhofer Institute for Factory Operation and Automation
IIM	Institute of Innovation and Industrial Management
IOT	Internet Of Things
KO	Engineering Department
KWLT	Desired Customer Delivery Date (Kunden-Wunschliefertermin)
LH	Left Handed
LAMS	Lightweight Assistive Manufacturing Solutions
MES	Manufacturing Execution System
NC	Non Conformance
OPP	Order Penetration Point
Pankl	Pankl Racing Systems AG
PDSYS	Pankl Drivetrain Systems
PLC	Programmable Logic Controller
PPL	Production Planning Department

QS	Quality Management Department
RFID	Radio-Frequency Identification
RH	Right Handed
SCADA	Supervisory Control And Data Acquisition
VDI	Verein Deutscher Ingenieure
WS	Wheel Side

Appendix A: Process descriptions

ID	Process step	Description
P01	part identification	identifying part or component and comparing with number on the construction drawing
P02	part adjustment	sorting parts or components, needed for the next work step, on the table
P03	part cleaning	cleaning components with cleaning fluid and compressed air or cleaning cloth
C01	mount (double) circlip / hoopster ring	mounting (double) circlip or hoopster ring according to design drawing
C02	press circlip with pliers	pressing the circlip in several places with pliers (only applies to inner circlips)
J01	join boot retainer GS/WS with drive shaft	adding boot retainer gearbox side / wheel side to drive shaft
J02	mount boot retainer GS/WS assembly	mounting boot retainer gearbox side / wheel side assembly according to the connstruction drawing
J03	join boot retainer GS/WS with flange	adding boot retainer gearbox side / wheel side to flange
J04	join boot GS/WS with drive shaft	adding boot retainer gearbox side / wheel side to drive shaft (using silicone spray and application tool)
J05	join flange GS/WS with drive shaft	adding flange gearbox side / wheel side to drive shaft
J06	mount pin system	assembling pin system, making sure that the housing parts have identical numbers
J07	join pin system with counterpart	adding assembled pin system into the counterpart
J08	join (rubber-)cap with drive shaft GS/WS	adding the (rubber-)cap on the drive shaft gearbox side / wheel side
J09	attach tensioning clamp	joining the tensioning clamp according to the construction drawing
J10	attach o-ring	joining o-ring according to design drawing
J11	apply needles according to CDR	applying needles (according to needle type and quantity given on the construction drawing)
J12	attach tripod GS/WS (with twist angle)	attaching tripod joint gearbox side / wheel side, taking into account the required twist angle between the joints
J13	press tripod on drive shaft	pressing on the tripod joint with the appropriate stamp using the hand press; measuring pressure with load cell, if required
J14	join roller with tripod pivot	attaching roller on to tripod pivots (according to standard instructions)
J15	mount inner/outer washer	adding inner/outer washer to tripod pivot, depending on the variant

J16	join boot GS/WS with flange	adding boot gearbox side / wheel side with flange
J17	join grease cap with flange GS/WS	adding grease cap on flang gearbox side / wheel side
J18	screw together with specified torque	screwing components together with specified torque by using a manual torque wrench
J19	join screw/bolt/washer with flange GS/WS	inserting screws/bolts/washers into flange gearbox side/wheel side, paying attention to orientation
I01	pack attachment parts	packing and enclosing components that are not assembled but have to be delivered additionally
I02	secure screws/bolts with cable ties	securing screws/bolts with cable ties, using cable tie pliers for tightening
I03	demagnetize drive shaft/roller/washers	demagnetizing drive shaft/roller/washers
I04	preserve assembly	preserving assembly according to Pankl specifications (see standard documents on SharePoint)
I05	clamp drive shaft	clamping drive shaft without damage
I06	fix pin system with magnet	fixing pin system with a magnet
I07	remove magnet	removing fixing magnet
I08	preserve drive shaft interior	preserving the inside of the drive shaft according to specifications (see standard documents)
I09	change workstation	changing workstation (e.g. changing to manual press/grease filling/assembly table)
M01	apply glue	applying glue according to specifications on the construction drawing
M02	lubricate housing	lubricating housing with grease (grease specification according to construction drawing)
M03	distribute grease in flange by movement	distributing grease in flange by movement, checking unhindered movement parallel
M04	apply grease to the tripod pivot	applying grease to tripod pivots (specifications according to construction drawing)
M05	turn the roller to lubricate the inner surface	turning the roller to lubricate the inner surface with surrounding grease
M06	lubricate o-ring	lubricate o-ring with grease
M07	grease filling flange/fill up remaining grease	grease filling of flange (specification and quantity according to construction drawing) / filling up the remaining grease after pre-filling
L01	mark screw/circlip connection	marking screw and circlip connections with the assigned worker colour
L02	label drive shift/apply sticker on drive shaft	attaching labels or stickers according to construction drawing (position and content)
L03	label with cards for goods issue	marking the assembly with cards for goods issue

D01	documentation of component's serial numbers	documenting the serial numbers of the assembled components
D02	documentation according to checklist	documenting selected work steps and checkings according to checklist
D03	documentation of performed workstep	documenting the proper performance of a work step

Table A-1: Process descriptions

Appendix B: Catalogue of requirements

Process Assurance

ID	Process step	Attribute to check	Current Assurance
P01	part identification	correct number	manual and visual comparison
		correct quantity	pre-picking in warehouse
P02	part adjustment	correct number	visual inspection
		correct quantity	visual inspection
P03	part cleaning	free of dirt	visual inspection
C01	mount (double) circlip / hoopster ring	assembled according to CDR	visual inspection
		correct orientation	visual inspection
C02	press circlip with pliers	tight fit	visual inspection, inspection with gauge
J01	join boot retainer GS/WS with drive shaft	damage-free mounting	visual inspection
		correct position	visual inspection
		correct orientation	visual inspection
J02	mount boot retainer GS/WS assembly	assembled according to CDR	visual inspection
J03	join boot retainer GS/WS with flange	correct orientation	visual inspection
		damage-free mounting	visual inspection
J04	join boot GS/WS with drive shaft	damage-free mounting	visual inspection
		correct position	visual inspection
		correct orientation	visual inspection
J05	join flange GS/WS with drive shaft	damage-free mounting	visual inspection
		correct orientation	visual inspection
		correct position	visual inspection
J06	mount pin system	correct number	visual inspection
		correct orientation	visual inspection
J07	join pin system with counterpart	horizontal/vertical movement	manual inspection
		unhindered movement	manual inspection
J08	join (rubber-)cap with drive shaft GS/WS	correct orientation	construction measures
		correct position	visual inspection
J09	attach tensioning clamp	damage-free mounting	visual inspection
		correct position	visual inspection
J10	attach o-ring	assembled according to CDR	visual inspection
		damage-free mounting	visual inspection

J11	apply needles according to CDR	correct quantity	inspection with broach, inspection with gauge
		free of dirt	inspection with gauge
J12	attach tripod GS/WS (with twist angle)	correct twist angle	visual inspection
		correct orientation	construction measures
		correct position	visual inspection
J13	press tripod on drive shaft	damage-free mounting	visual inspection
J14	join roller with tripod pivot	detachable roller	manual inspection
		correct orientation	visual inspection
		burr-free groove	visual inspection
		correct position	visual inspection
J15	mount inner/outer washer	assembled according to CDR	visual inspection
		correct orientation	visual inspection
		free of dirt	visual inspection
J16	join boot GS/WS with flange	correct orientation	visual inspection
		damage-free mounting	visual inspection
J17	join grease cap with flange GS/WS	assembled according to CDR	visual inspection
		damage-free mounting	visual inspection
J18	screw together with specified torque	correct orientation	visual inspection
		correct torque	usage of a manual torque wrench
		correct quantity	visual inspection
J19	join screw/bolt/washer with flange GS/WS	correct orientation	visual inspection
		damage-free mounting	visual inspection
I01	pack attachment parts	correct quantity	pre-picking in the warehouse
		correct number	visual inspection
I02	secure screws/bolts with cable ties	tight fit	usage of a special plier to tighten
I03	demagnetize drive shaft/roller/washers	demagnetized component	no inspection
I04	preserve assembly	proper preservation	visual inspection
I05	clamp drive shaft	damage-free mounting	usage of rubber or textile puffer elements
I06	fix pin system with magnet	tight fit	visual inspection
I08	preserve drive shaft interior	proper preservation	visual inspection
M01	apply glue	correct operating material	visual inspection
M02	lubricate housing	grease quantity	visual inspection
M03	distribute grease in flange by movement	unhindered movement	manual inspection
M04	apply grease to the tripod pivot	grease quantity	visual inspection
M05	turn the roller to lubricate the inner surface	grease quantity	visual inspection

M06	lubricate o-ring	grease quantity	visual inspection
M07	grease filling flange/fill up remaining grease	grease quantity	weighing with scale
		correct operating material	visual inspection
L01	mark screw/circlip connection	correct labelling	visual inspection
L02	label drive shift/apply sticker on drive shaft	correct labelling	visual inspection
		correct position	visual inspection
L03	label with cards for goods issue	correct labelling	visual inspection

Documentation

ID	Process step	Attribute to document	Current documentation
D01	documentation of component's serial numbers	serial number	inspection report, checklist
D02	documentation according to checklist	proper performance	checklist
D03	documentation work step	proper performance	manual checking of some steps per checklist
P01	part identification	serial number and quantity	manual recording of some parts per checklist
P02	part adjustment	serial number and quantity	no documentation
P03	part cleaning	dirt-free	no documentation
C01	mount (double) circlip / hoopster ring	proper assembly	checklist
		orientation	no documentation
C02	press circlip with pliers	tight fit	checklist
J01	join boot retainer GS/WS with drive shaft	damage-free	checklist
		position	checklist
		orientation	no documentation
J02	mount boot retainer GS/WS assembly	proper assembly	checklist
J03	join boot retainer GS/WS with flange	orientation	no documentation
		damage-free	checklist
J04	join boot GS/WS with drive shaft	damage-free	checklist
		position	checklist
		orientation	no documentation
J05	join flange GS/WS with drive shaft	damage-free	no documentation
		orientation	no documentation
		position	no documentation
J06	mount pin system	serial number	no documentation
		orientation	no documentation
J07	join pin system with counterpart	movement within tolerance	checklist
J08	join (rubber-)cap with drive shaft GS/WS	orientation	no documentation
		position	no documentation
J09	attach tensioning clamp	damage-free	checklist
		position	checklist
J10	attach o-ring	proper assembly	checklist (for more than one o-ring at a time)

		damage-free	no documentation
J11	apply needles according to CDR	quantity	checklist
		dirt-free	(checklist)
J12	attach tripod GS/WS (with twist angle)	twist angle between tripods	checklist
		orientation	no documentation
		position	no documentation
J13	press tripod on drive shaft	damage-free	no documentation
		applied pressure	customer specific - through load cell
J14	join roller with tripod pivot	roller movement within tolerance	checklist
		orientation	no documentation
		burr-free groove	no documentation
		position	checklist
J15	mount inner/outer washer	proper assembly	checklist
		orientation	no documentation
		dirt-free	no documentation
J16	join boot GS/WS with flange	orientation	no documentation
		damage-free	checklist
J17	join grease cap with flange GS/WS	orientation	no documentation
		position	no documentation
J18	screw together with specified torque	orientation	no documentation
		applied torque	no documentation
		quantity	no documentation
J19	join screw/bolt/washer with flange GS/WS	orientation	no documentation
		damage-free	no documentation
I01	pack attachment parts	quantity	checklist
		serial numbers	checklist
I02	secure screws/bolts with cable ties	tight fit	no documentation
I03	demagnetize drive shaft/roller/washers	status magnetization	no documentation
I04	preserve assembly	proper preservation	no documentation
I05	clamp drive shaft	damage-free	no documentation
I06	fix pin system with magnet	tight fit	no documentation
I08	preserve drive shaft interior	proper preservation	no documentation
M01	apply glue	glue specification	checklist
M02	lubricate housing	proper performance	no documentation
M03	distribute grease in flange by movement	unhindered movement	no documentation
M04	apply grease to the tripod pivot	proper performance	no documentation
M05	turn the roller to lubricate the inner surface	proper performance	no documentation
M06	lubricate o-ring	proper performance	no documentation
M07	grease filling flange/fill up remaining grease	grease quantity	checklist
		grease specification	checklist
D01	mark screw/circlip connection	correct labelling	checklist

D02	label drive shift/apply sticker on drive shaft	correct labelling and label position	checklist
D03	label with cards for goods issue	correct labelling	no documentation

Table B-1: Catalogue of requirements

Appendix C: Technology descriptions

Overview:

Function
Capture quantity

Processes

- part identification [P01]
- part adjustment [P02]
- apply needes according to CRD [J11]
- screw together with specified torque [J18]
- pack attachment parts [I01]

Capture quantity
Electromagnetic waves

Description

- A Tag is attached to the parts
- Via electromagnetic waves it is possible to read the information from the tag contactless
- Reader/Antennas are mounted on all workstations
- Possibility of various protocols: RFID, NFC,…

Requirements

- Tags on all parts
- Reader on all workstations
- Database
- Information display system

Advantages

- Allows the storage of various information about the components via database
- Fast identification

Disadvantages

- Hard to place tags on small parts
- Limited reading range
- Inaccuracies at large quantities possible due to interference

Sketch / Graphic

Capture quantity
Weight measurement

Description

- Based on the weight changes and the previously stored individual weights of the components, a scale records the number of components in the system

Requirements

- Information display system
- Weight data for the individual components
- Identity of the component known

Advantages

- Simple installing
- Allows fast tracking of high quantities

Disadvantages

- Accuracy depends on the accuracy of the weight data and scale
- It must be known which components are currently being used
- Sensitive to weight deviations or foreign bodies

Sketch / Graphic

Capture quantity

Counting machine

Description

- The correct number of parts is prepared by a counting machine
- Output is automated with the correct number

Requirements

- Parts supply for the counting machine
- Input system for selecting components or process

Advantages

- Automated correct number

Disadvantages

- Can only be used for small parts
- Counting machines must be filled -> preparation effort
- High space requirement

Sketch / Graphic

Capture quantity

Worker (manual counting)

Description

- The quantity is captured manually by the employee by counting
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

Advantages

- Requires no other systems
- Can also be used immediately on new components

Disadvantages

- Keine automatisierte Erfassung
- Anzahl muss manuell in Datenbank eingetragen werden
- Fehlerwahrscheinlichkeit bei großen Mengen hoch

Sketch / Graphic

Capture quantity

Material supply

Description

- Components are provided automatically
- The right number of the right parts are automatically available at the workplace at the right time
- Realisation by, for example, a fully automated storage system

Requirements

- System that ensures the required material supply (e.g.: fully automated storage system)

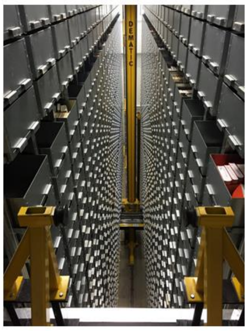
Advantages

- High accuracy
- Fully automated recording of components
- High traceability

Disadvantages

- High costs and high space requirements, depending on the design
- New components must be maintained

Sketch / Graphic



Capture quantity

Industrial image processing

Description

- A camera system records the workplace
- The existing components are identified and counted by image comparison and processing

Requirements

- Data base
- 3D models of the components
- Software for industrial image processing
- Camera systems

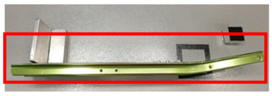
Advantages

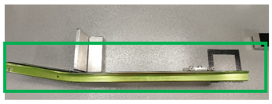
- Simultaneous identification and counting
- Several different components can be detected simultaneously
- Versatile and flexible in use

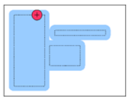
Disadvantages

- 2-dimensional, for 3rd dimension several camera systems or special cameras necessary
- Locally restricted
- New components must be maintained
- High preparation time

Sketch / Graphic







Function

Check fit

Processes

- press circlip with pliers [C02]
- join pin system with counterpart [J07]
- join roller with tripod pivot [J14]
- secure screws/bolts with cable ties [I02]
- fix pin system with magnet [I06]

Check fit

Worker (manual inspection)

Description

- The worker manually checks the seat of the system by moving the system and sensing any resistance.
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- Documentation system

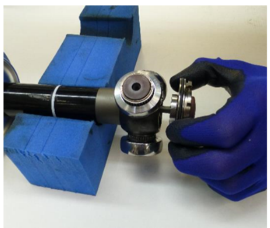
Advantages

- No additional systems required
- No preparatory work necessary

Disadvantages

- No characteristic recording
- Testing not 100% reproducible
- No automated documentation
- No clear definition of "firm fit" (no specific values)

Sketch / Graphic



Check fit

Load sensor

Description
- The employee uses a load cell as an aid to test the seat with a certain, predefined force.

Advantages
- Characteristic recording possible
- reproducibility
- Clear definition for a firm fit

Sketch / Graphic

Requirements
- Documentation system

Disadvantages
- No automated documentation

Function

Check horizontal/vertical movement

Processes
- join pin system with counterpart [J07]
- distribute grease in flange by movement [M03]

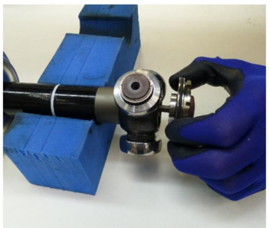
Check horizontal/vertical movement

Worker (manual inspection)

Description
- The worker manually checks the game of the system by moving the system and feeling any resistance.
- 4-eye principle can increase accuracy means, however, increased time expenditure

Advantages
- No additional systems required
- No preparatory work necessary

Sketch / Graphic



Requirements
- Documentation system
- Trained staff

Disadvantages
- No characteristic recording
- Testing not 100% reproducible
- No automated documentation
- No clear definition of how much play can be tolerated

Check horizontal/vertical movement

Load sensor

Description	Advantages	Sketch / Graphic
► The worker uses a load sensor as an aid and performs predefined movements on the test part. ► The forces applied are recorded and evaluated ► This makes it possible to conclude that there is no unwanted movement	► Characteristic recording possible ► Clear specification of measurement values	
Requirements	**Disadvantages**	
► Documentation system ► Defined motion or test sequence	► No automated documentation	

Function

Check integrity

Processes

- join boot retainer GS/WS with DS [J01]
- join boot retainer GS/WS with flange [J03]
- join boot GS/WS with DS [J04]
- join flange GS/WS with DS [J05]
- attach tensioning clamp [J09]
- attach o-ring [J10]
- press tripod on DS [J13]
- join boot GS/WS with flange [J16]
- join grease cap with flange GS/WS [J17]
- join screw/bolt/washer with flange GS/WS [J19]
- clamp DS [I05]

Check integrity

Ultrasonic inspection

Description	Advantages	Sketch / Graphic
► Detection of material defects using ultrasonic inspection	► Minor errors and irregularities can be detected ► Non-destructive testing	
Requirements	**Disadvantages**	
► Specially trained staff	► Can only be used with conductive materials ► Evaluation of the ultrasonic image requires special knowledge or algorithms	

Check integrity

Worker (visual inspection)

Description

- The worker checks the integrity of the components before and after assembly
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- Trained staff
- Data collection system

Advantages

- Universally applicable
- Not tied to a specific workplace
- No further systems necessary
- Can also be used immediately on new components

Disadvantages

- No automated recording
- Intactness must be entered manually in another system (e.g. checklist)
- Defects that are difficult to see are easy to overlook

Sketch / Graphic

Check integrity

Industrial image processing

Description

- A camera system records the workplace
- The desired component is checked for integrity by image processing
- Accuracy strongly dependent on number and resolution of used camera systems

Requirements

- Data base
- 3D models of the components
- Software for industrial image processing
- Camera systems

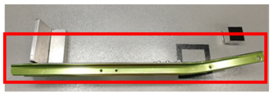
Advantages

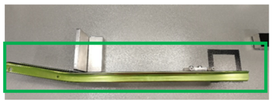
- High resolutions possible
- Checking can take place during the process -> time-saving
- Versatile and flexible in use

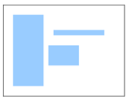
Disadvantages

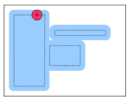
- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- Locally restricted
- High preparation effort

Sketch / Graphic









Check integrity

Profil method

Description

- The surface is scanned with profil method by using a sensor
- Minor changes in the surface structure are detected and recorded
- Allows conclusions to be drawn about damage

Requirements

- Stable holding device
- Device for the respective component
- Defined/programmed test path for each component

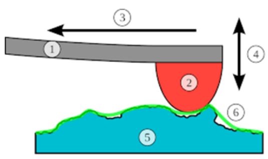
Advantages

- Even the smallest changes in the surface structure can be recorded -> high resolution

Disadvantages

- High time expenditure
- High preparation time
- Component orientation must be known
- The shape of the probe tip has a great influence on the measurement result

Sketch / Graphic



Function

Check label content

Processes

- Label DS / apply sticker on DS [L02]
- Labe with cards for goods issue [L03]
- Mark screw/circlip connection [L01]

Check label content

Industrial image processing

Description

- A camera system records the workplace
- In the captured image, the system checks whether the marking/labelling matches the specifications.

Requirements

- Data base
- Software for industrial image processing
- Camera systems
- Comparative pictures
- Display system

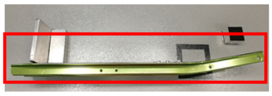
Advantages

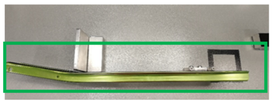
- Automatic acquisition
- Automated documentation

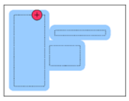
Disadvantages

- 2-dimensional, for 3rd dimension several Camera systems or special camera necessary
- Locally restricted
- Requires comparison images
- High preparation time

Sketch / Graphic







Check label content

Worker (visual inspection)

Description

- The worker visually checks the marking and compares it with the specifications.
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- Provision of specifications
- Document data system

Advantages

- No comparison images required
- Universally applicable
- High flexibility

Disadvantages

- Time consuming
- Errors not excluded

Sketch / Graphic

Check label content

Automated label printing

Description
- Label printer for automatic printing of the correct inscription

Requirements
- Provision of the required lettering
- Data transmission and control system

Advantages
- Manual transmission errors during input are excluded
- Time saving for employees

Disadvantages
- Requires additional system

Sketch / Graphic

Function

Check magnetic field

Processes
- Demagnetize drive shaft, roller, washers [I03]

Check magnetic field

Magnetic field meter

Description
- A magnetic field meter is used to check whether demagnetization was successful

Requirements
- Component has to be demagnetized before testing

Advantages
- High accuracy, detects even low residual magnetism

Disadvantages
- Additional device at the workplace -> Space requirement

Sketch / Graphic

Check magnetic field

Induction coil

Description
- The component is moved through an induction coil and generates a voltage in case of residual magnetism

Requirements
- Voltmeter

Advantages
- Quick
- Easy to use

Disadvantages
- Limited size of the test part
- Low sensitivity
- Additional device at the workplace

Sketch / Graphic

Function

Check part surface

Processes
- Apply grease to the tripod pivot [M04]
- Apply grease to the tripod pivot [M05]
- Lubricate o-ring [M06]

Check part surface

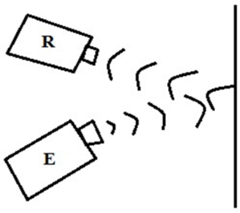
Reflexion

Description
- A light source radiates light onto the surface of the test part
- A sensor detects the reflected light
- Conclusions on surface structure possible

Requirements
- Database with reflection behaviour of the materials used

Advantages
- Contactless testing -> any existing lubricating film on components is not damaged

Disadvantages
- Ambient light conditions must be taken into account
- Reflection behaviour of the materials must be known or determined
- Reflection behaviour can be direction-dependent

Sketch / Graphic


Check part surface

Worker (visual inspection)

Description
- The worker visually inspects the surface of the components
- Check whether the surface condition corresponds to the desired condition (e.g.: greased)
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements
- Trained staff

Advantages
- No special preparation necessary
- Not tied to a specific workplace
- Can also be used immediately on new components

Disadvantages
- No automated recording
- Test result must be entered manually in another system (e.g. checklist)

Sketch / Graphic

Check part surface

Industrial image processing

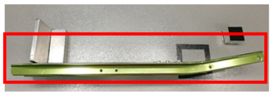
Description
- A camera system records the workplace
- The desired surface is checked by image processing
- Accuracy strongly dependent on number and resolution of used camera systems

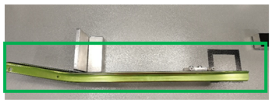
Requirements
- Data base
- Comparison images of the desired surface finish
- Software for industrial image processing
- Camera systems

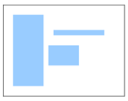
Advantages
- System can cover further functions
- High resolutions possible
- Checking can take place during the process -> time-saving

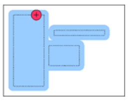
Disadvantages
- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- High preparation time

Sketch / Graphic









Function

Check preservation

Processes
- Preserve ASSY [I04]
- Preserve DS interior [I08]

Check preservation

Verwendung von farbigem Konservierungsmittel

Description

- The colour of the preservative used is clearly different from that of the component materials
- When applied, it increases the visibility of the preservation

Requirements

- Additional system for visual inspection

Advantages

- Facilitates visual inspection

Disadvantages

- Optical change of the component

Sketch / Graphic

Check preservation

Worker (visual inspection)

Description

- The worker visually checks the preservation and pays special attention to defined critical areas
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- Trained staff
- Additional data acquisition system

Advantages

- Universally applicable
- High flexibility

Disadvantages

- Time consuming
- Errors not excluded

Sketch / Graphic

Check preservation

Industrial image processing

Description

- Workstation is captured by a camera system
- The camera images are compared with comparative images
- The system checks whether the component corresponds to the target state

Requirements

- Preservation must look clearly different from the base material
- Software for industrial image processing
- Camera systems
- Display system

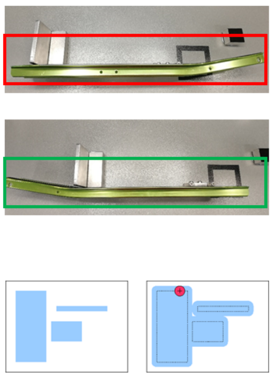
Advantages

- Automatic acquisition
- Automated documentation
- Contactless testing

Disadvantages

- Locally restricted
- Requires comparison images
- Must be trained -> high preparation times

Sketch / Graphic



Check preservation

Ultrasonic layer thickness measurement

Description
- The layer thickness of the preservation is measured with ultrasound
- Automatic check whether layer thickness is sufficient or corresponds to the target value

Requirements
- Display system
- Database with target values regarding layer thickness and place of preservation

Advantages
- Automatic acquisition
- Automated documentation

Disadvantages
- Does not check if the correct preservative has been used

Sketch / Graphic

Function

Check unhindered movement

Processes
- join pin system with counterpart [J07]

Check unhindered movement

Worker (manual inspection)

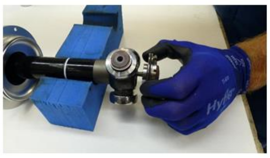
Description
- The worker manually checks the release of the system by moving the system and feeling any resistance.
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements
- Documentation system

Advantages
- No additional systems required
- No preparatory work necessary

Disadvantages
- No characteristic recording
- Testing not 100% reproducible
- No automated documentation

Sketch / Graphic



Check unhindered movement

Torque sensor

Description

- The system is moved by means of an apparatus with connected torque sensor
- The force measuring sensor measures the force required for the defined movement
- The data obtained are analysed for irregularities and increased resistances

Requirements

- Measurement equipment
- Universal holding device

Advantages

- Reproducible
- Parameters are recorded

Disadvantages

- Space requirement
- Locally bound
- Energy supply needed

Sketch / Graphic

Check unhindered movement

Acoustic testing

Description

- Friction noises during the movement of the test part are detected and evaluated by an employee via microphone
- The friction noises indicates the freedom of movement of the system

Requirements

- Requires another system (or employee) to perform the movement of the test part
- Low-noise or noiseless environment
- Information display system

Advantages

- Parameters are recorded
- Employees are supported in the examination
- Enables more precise checking

Disadvantages

- Does not work without another system or worker
- Use of different materials and lubricants must be taken into account

Sketch / Graphic

Function

Detect dirt

Processes

- Part cleaning [P03]
- apply needes according to CRD [J11]
- join roller with tripod pivot [J14]
- mount inner/outer washer [J15]

Detect dirt

Worker (visual inspection)

Description

- The worker visually inspects the component to be inspected for dirt residues
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- Data acquisition system

Advantages

- Universally applicable
- No further systems necessary
- If necessary, post-processing (cleaning) can be carried out directly by the worker

Disadvantages

- Time consuming
- Resolution limited by the human eye
- No automatic data acquisition

Sketch / Graphic

Detect dirt

Industrial image processing

Description

- A camera system records the workplace
- The desired component is checked for dirt by image processing
- Accuracy strongly dependent on number and resolution of used camera systems

Requirements

- Data base
- 3D models of the components
- Software for industrial image processing
- Camera systems

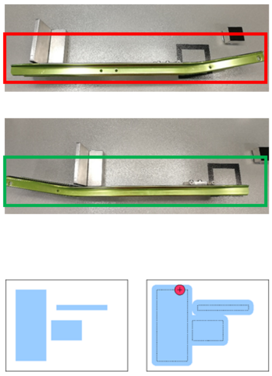
Advantages

- High resolutions possible
- Checking can take place during the process -> time-saving
- Versatile and flexible in use

Disadvantages

- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- Locally restricted
- High preparation time

Sketch / Graphic



Detect dirt

Profile method

Description

- The surface is scanned by a sensor
- Minor changes in the surface structure are detected and recorded
- It is possible to draw conclusions about dirt

Requirements

- Stable holding device
- Device for the respective component

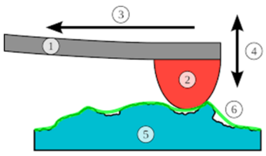
Advantages

- Even the smallest changes in the surface structure can be recorded

Disadvantages

- High time expenditure
- High preparation time
- Component orientation must be known
- The shape of the probe tip has a great influence on the measurement result

Sketch / Graphic



Detect dirt

Chemical testing

Description
- Application of a chemical agent which reacts with non-metallic material
- Dirt is discoloured by the reaction and made easily recognizable

Advantages
- Visibility of dirt is increased -> easier detection

Sketch / Graphic

Requirements
- Chemicals that react with non-metallic surfaces and discolour them
- Further systems to detect the better visible dirt

Disadvantages
- Use only on metallic surfaces
- Only dirt that reacts with the chemical is made visible
- Surfaces could be attacked by the chemical
- Further systems required

Function

Determine grease quantity

Processes
- lubricate housing [M02]
- grease filling flange/fill up remaining grease [M07]

Determine grease quantity

Grease syringe with dosing function

Description
- The grease is applied by syringe with built-in dosing function
- The syringe receives data about the desired amount of grease and delivers this exactly dosed

Advantages
- No additional measurements required
- Exact dosing possible

Sketch / Graphic

Requirements
- Input system for grease quantity
- Additional information about grease specification

Disadvantages
- Own grease syringe required for each grease specification

Determine grease quantity

Weight measurement

Description
- The amount of grease is determined by measurements on a scale
- Either the grease container or the component can be measured to determine the induced amount of grease

Advantages
- Simple system
- Only one scale required for all grease specifications

Sketch / Graphic

Requirements
- Calibrated balance

Disadvantages
- Time consuming
- Relatively inaccurate

Determine grease quantity

Vordosierung

Description
- The exact amount of fat required is provided by pre-dosing

Advantages
- No measurement at the workplace necessary

Sketch / Graphic

Requirements
- Pre-dosing must be carried out correctly else-> further system necessary

Disadvantages
- Losses or misapplication are not taken into account

Function

Determine label position

Processes
- Label DS / apply sticker on DS [L02]

Determine label position

Worker (visual inspection)

Description
- The worker determines the position of the label visually

Requirements
- Additional data acquisition system

Advantages
- No special preparation necessary
- Not tied to a specific workplace
- Can also be used immediately on new components

Disadvantages
- No automated recording
- No automated documentation

Sketch / Graphic

Determine label position

Industrial image processing

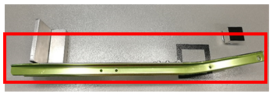
Description
- A camera system records the workplace
- The position of the label is determined automatically by image processing

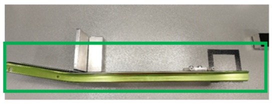
Requirements
- Database with detailed information on labels and label positions
- Comparative pictures
- Software for industrial image processing
- Camera systems
- Display system

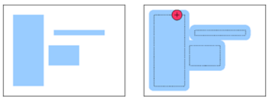
Advantages
- High resolutions possible
- Checking can take place during the process -> time-saving
- Can detect several components at the same time

Disadvantages
- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New labels and components must be trained -> high preparation effort

Sketch / Graphic







Determine label position

Electromagnetic waves

Description
- Labels are tagged with
- The position of the label can be determined by electromagnetic waves
- Appropriate readers or antennas are located at all workstations
- Several standards possible: RFID, NFC,...

Requirements
- Tag on every label
- Reader on all workstations
- Data base
- Display system

Advantages
- Versatile in use
- Can capture multiple labels at the same time

Disadvantages
- Difficult to place tags on small parts
- Limited accuracy
- Limited range

Sketch / Graphic

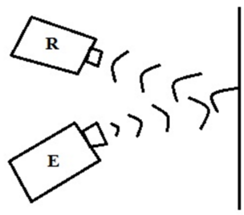
Determine label position

Reflexion

Description
- A light source radiates light onto the workplace
- Reflectors are attached to the labels
- A sensor detects the reflected light from the reflectors and thus determines the label position

Advantages
- Can capture multiple labels at the same time

Sketch / Graphic



Requirements
- Tag on every label
- Reader on all workstations
- Data base
- Display system
- Reflector must be placed in the middle of the label

Disadvantages
- Ambient light conditions must be taken into account
- Only detects label position, but does not return any identification
- Reflectors difficult to install on small labels

Function

Determine part orientation

Processes
- mount (double) circlip / hoopster ring [C01]
- join boot retainer GS/WS with DS [J01]
- join boot retainer GS/WS with flange [J03]
- join boot GS/WS with DS [J04]
- join flange GS/WS with DS [J05]
- mount pin system [J06]
- join (rubber-)cap with DS GS/WS [J08]
- attach tripod GS/WS (with twist angle) [J12]
- join roller with tripod pivot [J14]
- mount inner/outer washer [J15]
- join boot GS/WS with flange [J16]
- screw together with specified torque [J18]
- join screw/bolt/washer with flange GS/WS [J19]

Determine part orientation

Worker (visual inspection)

Description
- The worker visually determines the orientation of the component

Advantages
- No special preparation necessary
- Not tied to a specific workplace
- Can also be used immediately on new components

Sketch / Graphic

Requirements
- Information about desired orientation
- Data acquisition system

Disadvantages
- No automated recording
- No automated documentation

Determine part orientation

Industrial image processing

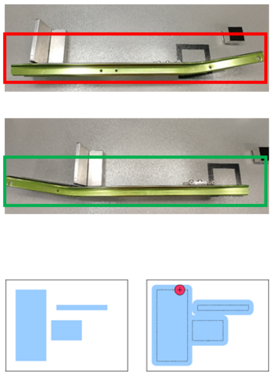
Description
- A camera system records the workplace
- The orientation of the component is determined automatically by image processing
- Accuracy strongly dependent on number and resolution of used camera systems

Requirements
- Data base with 3D models of components
- Software for industrial image processing
- Camera systems
- System for displaying incorrect orientations

Advantages
- System can cover further functions
- High resolutions possible
- Checking can take place during the process -> time-saving

Disadvantages
- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- High preparation time

Sketch / Graphic



Determine part orientation

Electromagnetic waves

Description
- Components are tagged with
- The orientation of the component can be determined by means of electromagnetic waves
- Appropriate readers or antennas are located at all workstations
- Several standards possible: RFID, NFC,...

Requirements
- At least 2 tags on all components
- Reader on all workstations
- Data base
- Information display system

Advantages
- Allows further information on the components to be stored in a database
- Quick identification
- Versatile in use

Disadvantages
- Difficult to place tags on small parts
- 1 tag not enough to know orientation
- Limited range

Sketch / Graphic

Determine part orientation

Material supply

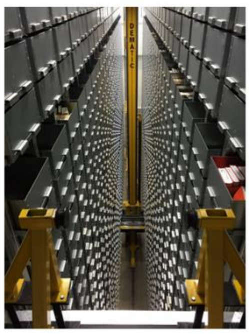
Description
- The required components are provided in containers with recesses
- The recesses are designed in such a way that the components automatically take the correct orientation (e.g. using PokaYoke).

Requirements
- Containers with recesses especially for each component

Advantages
- Correct material supply prevents errors right from the start

Disadvantages
- Correct orientation of the containers not sufficiently ensured
- Specific recesses necessary -> new container for each new part

Sketch / Graphic



Function

Determine part position

Processes

- join roller with tripod pivot [J14]
- mount inner/outer washer [J15]
- mount (double) circlip / hoopster ring [C01]
- join boot retainer GS/WS with DS [J01]
- mount boot retainer GS/WS ASSY [J02]
- join boot GS/WS with DS [J04]
- join flange GS/WS with DS [J05]
- join (rubber-)cap with DS GS/WS [J08]
- attach tensioning clamp [J09]
- attach o-ring [J10]
- attach tripod GS/WS (with twist angle) [J12]
- join grease cap with flange GS/WS [J17]

Determine part position

Fixture

Description

- Holding devices for the components define the position on the work surface

Advantages

- Facilitates assembly processes

Sketch / Graphic

Requirements

- Universally applicable holding device
- Fixed point for holding device for position determination

Disadvantages

- Static
- Only the position of the clamped component can be determined.

Determine part position

Worker (visual inspection)

Description

- The worker determines the position of the component visually

Advantages

- No special preparation necessary
- Not tied to a specific workplace
- Can also be used immediately on new components
- Quick

Sketch / Graphic

Requirements

- Additional data acquisition system

Disadvantages

- No automated recording
- No automated documentation

Determine part position

Industrial image processing

Description

- A camera system records the workplace
- The position of the component is determined automatically by image processing
- Accuracy strongly dependent on number and resolution of used camera systems

Requirements

- Database with 3D models of components
- Software for industrial image processing
- camera systems
- Display system

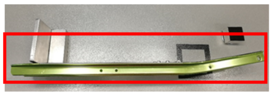
Advantages

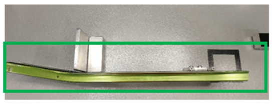
- System can cover further functions
- High resolutions possible
- Checking can take place during the process -> time-saving
- Can detect several components at the same time

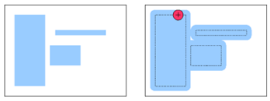
Disadvantages

- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- High preparation time

Sketch / Graphic







Determine part position

Electromagnetic waves

Description

- Components are tagged with
- The position of the component can be determined by electromagnetic waves
- Appropriate readers or antennas are located at all workstations
- Several standards possible: RFID, NFC,...

Requirements

- At least one day on all components
- Reader on all workstations
- data base
- Display system

Advantages

- Allows further information on the components to be stored in a database
- Versatile in use
- Can detect several components at the same time

Disadvantages

- Difficult to place tag on small parts
- Limited accuracy
- Limited range

Sketch / Graphic

Determine part position

Reflexion

Description

- A light source radiates light onto the workplace
- Reflectors are attached to the components
- A sensor detects the reflected light from the reflectors and thus determines the position of the component

Requirements

- Link to component identification system
- Reflector position at the centre of the component
- Display system

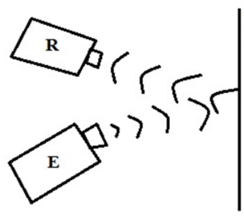
Advantages

- Can detect several components at the same time

Disadvantages

- Ambient light conditions must be taken into account
- Only detects component position, but does not provide any identification
- Reflectors difficult to install on small components
- Only 2-dimensional acquisition possible

Sketch / Graphic



Determine part position

Ultrasonic location

Description

- An ultrasound device continuously scans the working surface
- Components and persons can be detected without contact

Requirements

- Display system

Advantages

- Non-contact
- Independent of environmental influences
- Simultaneous detection of several components and persons possible

Disadvantages

- Depending on the area to be examined, several sensors are required

Sketch / Graphic

Function

Determine tightening torque

Processes

- screw together with specified torque [J18]

Determine tightening torque

Torque screwdriver

Description

- Tightening is done manually using a torque screwdriver which allows the presetting of the specified tightening torque.
- When the torque is reached, the torque screwdriver locks automatically.

Requirements

- Checklist for data acquisition

Advantages

- High accuracy

Disadvantages

- No automatic characteristic recording
- Regular calibration required

Sketch / Graphic

Determine tightening torque

Torque wrench

Description
- The torque is applied manually using a torque wrench

Requirements
- Checklist for data acquisition

Advantages
- No additional tools required

Disadvantages
- No characteristic recording
- Regular calibration required
- Possibility to adjust the torque wrench inaccurately

Sketch / Graphic

Determine tightening torque

Torque sensor

Description
- A torque sensor connected to a wrench or screwdriver records the tightening torque used.

Requirements
- Torque wrench or torque screwdriver

Advantages
- Automatic parameter acquisition
- Traceability given

Disadvantages
- Space requirement
- Energy supply needed

Sketch / Graphic

Determine tightening torque

Mechanical screwing

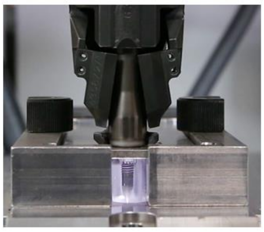
Description
- The screwing takes place mechanically and automatically
- The torque is applied by a machine/device or a robot

Requirements
- Device for mechanical screwing

Advantages
- Automatic parameter acquisition
- Traceability given

Disadvantages
- Additional system required
- The system must be set up anew for each component
- High preparation time

Sketch / Graphic



Function
Document data

Processes
- pard identification [P01]
- part adjustment [P02]
- mount pin system [J06]
- documentation of performed work step [D03]

Document data
Check button

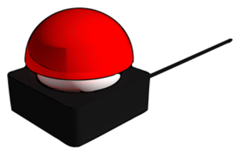
Description
- By pressing a check button the current process/test is acknowledged

Requirements
- Information display systems

Advantages
- Simple system
- Enables the specification of process sequences

Disadvantages
- Limited variety of information -> 2 operating states

Sketch / Graphic



Document data
Checklist

Description
- Processes and parameters are recorded using checklists
- The checklists provide the employee with an indication of which processes have to be completed/checked

Requirements
- Checklists for the Processes
- Trained staff

Advantages
- Depending on the scope, a lot of information can be recorded
- High flexibility
- Easy to adapt

Disadvantages
- Manual transfer to a database required

Sketch / Graphic

Document data

Automated data acquisition

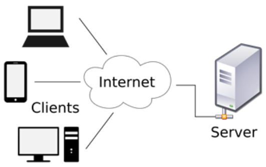
Description

- Data is automatically transferred and stored over a network
- A server manages the database or its entries

Advantages

- Automated documentation process
- No transmission errors
- Time-saving

Sketch / Graphic



Requirements

- Systems which are able to record and digitally transmit parameters

Disadvantages

- Data must always be read from the system
- Resource costs for the required hardware
- High energy costs

Function

Identify operating materials

Processes

- Apply glue [M01]
- grease filling flange/fill up remaining grease [M07]

Identify operating materials

Electromagnetic waves

Description

- Auxiliary material container is tagged
- The information on it can be read out contactlessly by means of electromagnetic waves
- Appropriate readers or antennas are located at all workstations
- Several standards possible: RFID, NFC,...

Advantages

- Allows further information to be stored in a database
- Quick identification

Sketch / Graphic

Requirements

- Tags on all auxiliary material containers
- Reader on all workstations
- Data base
- Information display system

Disadvantages

- Tags can only be placed on the containers
- Limited range
- Machine readable only

Identify operating materials

2D-Code

Description

- A 2D-code is applied to each auxiliary material container. A 2D-code is assigned to each auxiliary material, enabling unique identification
- Different standards possible: Data Matrix Code, Barcode, QR-Code,...

Requirements

- 2D codes on the auxiliary material containers
- Data base
- Scanner at the workstations
- Information display system

Advantages

- Allows further information to be stored in a database
- Quick identification
- Automated collection

Disadvantages

- Low memory capacity -> access to database required
- Code must not get too dirty to guarantee readability
- High contrast necessary
- Machine readable only

Sketch / Graphic

Identify operating materials

Worker (identification)

Description

- The employee identifies the auxiliary material by manually comparing the information provided
- Information is provided by:Design drawing, ID numbers on the containers
- 4-eye principle can increase accuracy means, however, increased time expenditure

Requirements

- ID numbers or drawings for identification
- System for data acquisition (e.g. checklist)

Advantages

- No special preparation necessary
- Not tied to a specific workplace
- Can also be applied immediately to new auxiliary material

Disadvantages

- No automated recording
- Longer numbers can easily be confused

Sketch / Graphic

Identify operating materials

Material supply

Description

- Containers contain the auxiliary material required for installation
- Containers are automated and provided at the right time
- No direct identification of the auxiliary material, but of the containers

Requirements

- Clear identification of the containers by another system
- Correct provision of auxiliary material
- Correct filling of the containers

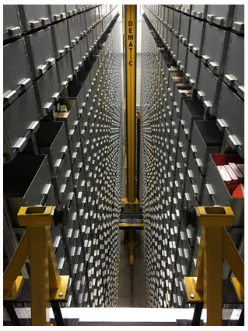
Advantages

- No more identification process at the workplace -> time saving

Disadvantages

- No direct information
- Relying on the basic assumption that the containers are correctly filled
- Alternative system for identification of containers necessary

Sketch / Graphic



Identify operating materials

Industrial image processing

Description

- A camera system records the workplace
- Image processing detects containers on the workstation and identifies them by matching them with the database
- Accuracy strongly dependent on number and resolution of used camera systems

Requirements

- Data base
- 3D models of containers
- Software for industrial image processing
- Camera systems

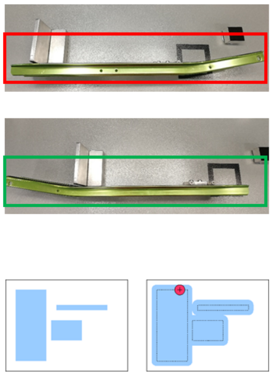
Advantages

- Flexible and versatile in use
- High resolutions possible
- Checking can take place during the running process -> time-saving

Disadvantages

- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New auxiliary material must be entered
- No unambiguous identification possible with identical containers
- High preparation time

Sketch / Graphic



Function

Identify part

Processes

- part identification [P01]
- part adjustment [P02]
- mount pin system [J06]
- pack attachment parts [I01]
- documentation of component's serial numbers [D01]
- documentation according to checklist [D02]

Identify part

Electromagnetic waves

Description

- Components are tagged
- The information on it can be read out contactlessly by means of electromagnetic waves
- Appropriate readers or antennas are located at all workstations
- Several standards possible: RFID, NFC,...

Requirements

- Tags on all components
- Reader on all workstations
- Data base
- Information display system

Advantages

- Allows further information on the components to be stored in a database
- Quick identification

Disadvantages

- Difficult to place tags on small parts
- Limited range
- Machine readable only

Sketch / Graphic

Identify part

2D-Code

Description
- A 2D code is applied to each component
- Can be applied by sticker, laser engraving, etching or the like
- A 2D code is assigned to each part, enabling unique identification
- Different standards possible: Data Matrix Code, Barcode, QR-Code,...

Requirements
- 2D codes on the components
- Data base
- Code reading system (camera/scanner/...)
- Information display system

Advantages
- Allows further information on the components to be stored in a database
- Quick identification
- Automated collection

Disadvantages
- Low memory capacity -> access to database required
- Code must not get too dirty to guarantee readability
- High contrast necessary
- Machine readable only (except barcode)

Sketch / Graphic

6583 3254

Identify part

Worker (identification)

Description
- The employee identifies the component by manually comparing the information provided
- Information is provided by: design drawing, part numbers on the containers, serial numbers on the components

Requirements
- Part numbers or drawings for identification

Advantages
- No special preparation necessary
- Not tied to a specific workplace
- Can also be used immediately on new components

Disadvantages
- No automated recording
- Longer numbers can easily be confused

Sketch / Graphic

Identify part

Profile method

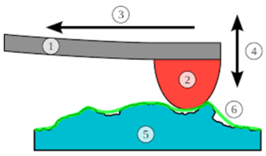
Description
- The components are provided with a marking that can be felt
- The identification of the component by scanning the surface with a sensor using profile method

Requirements
- Tactile surface inspection system
- Clamping for the component
- Introduction of a standard for tactile marking

Advantages
- Allows further information on the components to be stored in a database
- Automated capture/identification

Disadvantages
- Machine readable only
- Requires special systems
- High time expenditure
- Component orientation must be known

Sketch / Graphic



Identify part

Material supply

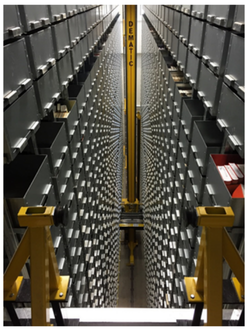
Description

- Vessels contain the components required for assembly
- Containers are automated and provided at the right time
- No direct identification of components, but of containers

Advantages

- No identification process at the workplace necessary -> time saving

Sketch / Graphic



Requirements

- Clear identification of the containers by another system
- Correct provision of components
- Correct filling of the containers

Disadvantages

- No direct information
- Relying on the basic assumption that the containers are correctly filled
- Alternative system for identification of containers necessary

Identify part

Industrial image processing

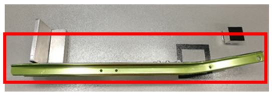
Description

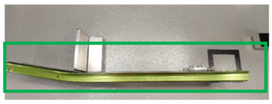
- A camera system records the workplace
- Image processing recognizes components on the workstation and identifies them by matching them with the database
- Accuracy strongly dependent on number and resolution of used camera systems

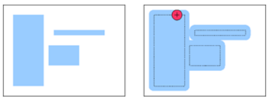
Advantages

- High resolutions possible
- Checking can take place during the process -> time-saving
- Versatile and flexible in use

Sketch / Graphic







Requirements

- Data base
- 3D models of the components
- Software for industrial image processing
- Camera systems

Disadvantages

- 2-dimensional, for 3rd dimension several camera systems or special camera necessary
- New components must be maintained
- High preparation time

Function

Show information

Processes

- Necessary function, required in order to assure/enable other functions and increase process assurance

Show information

Signal light

Description

- Signal lights provide information about a problem that has occurred
- If irregularities or errors in the process are detected, this is indicated by a light signal and is thus easily and quickly recognizable for all workers
- Different colors allow the visualization of different types of problems

Requirements

- Connection to other process monitoring systems that provide the necessary information

Advantages

- Quick visualization of problems
- Clear signal through the use of different colours
- Can also be used in noisy environments
- Low space requirement
- No impairment of other workers

Disadvantages

- Limited information due to limited operating states

Sketch / Graphic

Show information

Vibration

Description

- A device that the worker carries with him emits a vibration alarm in case of a problem
- Can be worn in the form of a bracelet, for example

Requirements

- Connection to other process monitoring systems that provide the necessary information
- Stable wireless connection

Advantages

- Wireless transmission
- Every worker can be specifically alerted
- No impairment of other workers
- Low space requirement
- Can also be used in noisy environments

Disadvantages

- Regular charging required
- Alarm can easily be "overheard"
- Workers have to carry an additional device with them
- Limited operating states -> limited information

Sketch / Graphic

Show information

(Touch-)Screen

Description

- There is a screen on each workstation
- Relevant information is displayed on the screen

Requirements

- Connection to other process monitoring systems that provide the necessary information

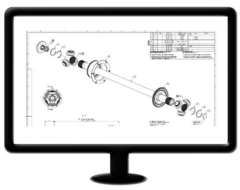
Advantages

- Screens can also be used for other functions
- Can be used in noisy environments
- No impairment of other workers

Disadvantages

- Increased space requirements

Sketch / Graphic



Show information

Printout

Description

- Relevant information is summarized and printed on paper
- The printed information is made available on the workstations

Requirements

- Printer

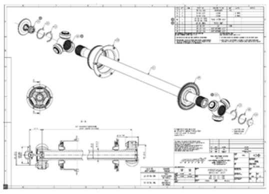
Advantages

- No requirements
- Cost-effective

Disadvantages

- No current information
- No flexibility
- No interaction possible
- Elaborate changes

Sketch / Graphic



Show information

Projection

Description

- A wide range of information can be displayed interactively by projection onto the work surface
- Information can be projected directly to the desired location

Requirements

- Connection to systems that provide the necessary information

Advantages

- Display of various information possible
- Information can be displayed where it is needed -> easier to comprehend

Disadvantages

- High space requirement
- Bright environment requires powerful projector
- High preparation time

Sketch / Graphic

Show information

VR-glasses

Description

- At the workplace a VR-glasses is available which the employee can use to retrieve information.

Requirements

- Connection to systems that provide the necessary information

Advantages

- Display of various information possible

Disadvantages

- Isolation from the environment
- Simultaneous continuation of work is not possible
- Glasses must be charged regularly

Sketch / Graphic

Show information

AR-glasses

Description

- Each worker is equipped with AR glasses that provide and display situational information

Requirements

- Connection to systems that provide the necessary information

Advantages

- Comprehensive information display possible
- Information is always in the direct field of vision of the employee
- Simultaneous work possible
- Information is displayed where it is needed

Disadvantages

- Glasses must be charged regularly
- When worn permanently -> additional weight acts on the head

Sketch / Graphic

Show information

Speakers

Description

- A loudspeaker or headset provides the worker with audio information on work steps, processes or components

Requirements

- Connection to systems that provide the necessary information

Advantages

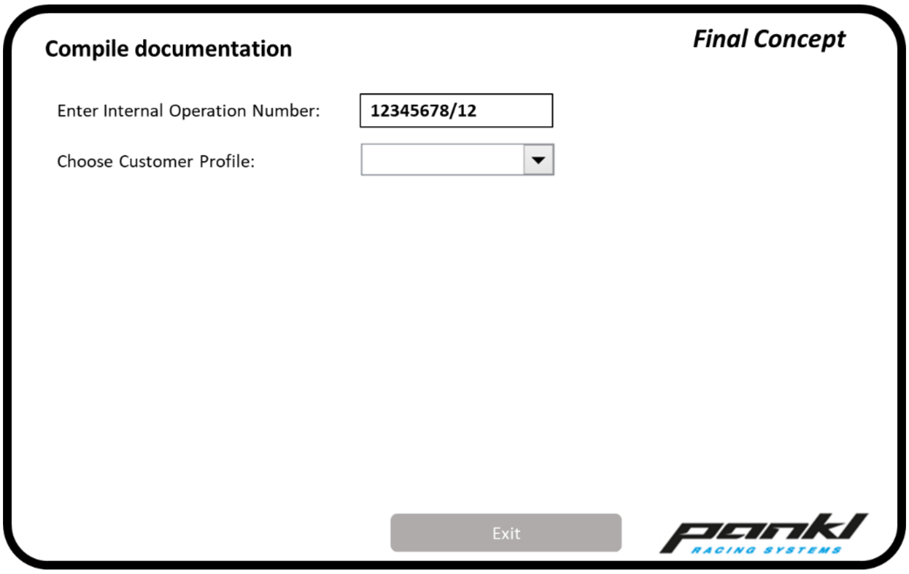
- Information is reproduced audibly-> no visual distraction
- Information can be displayed as required
- Radio connection with supervisor possible

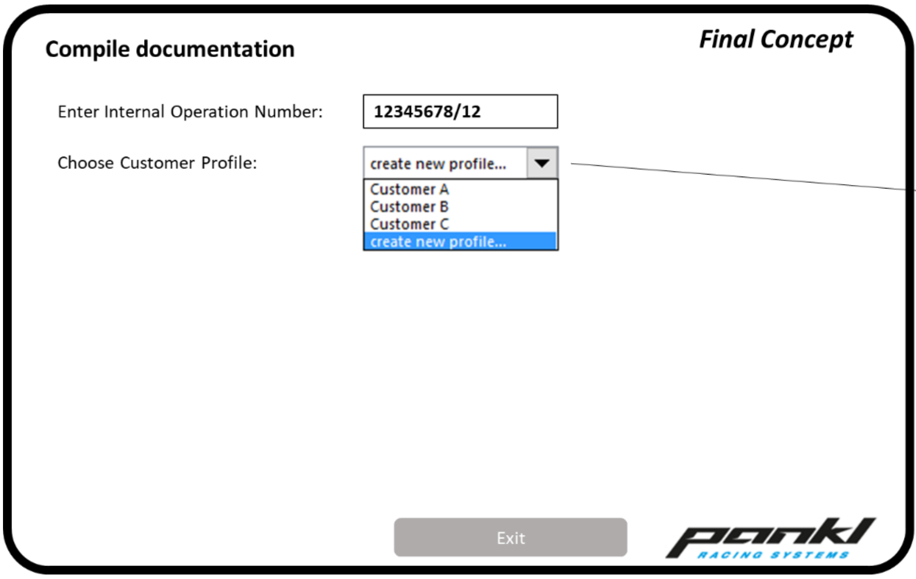
Disadvantages

- Restricted information display (auditory)
- Does not work well in noisy environments
- Partial separation of the worker from his environment

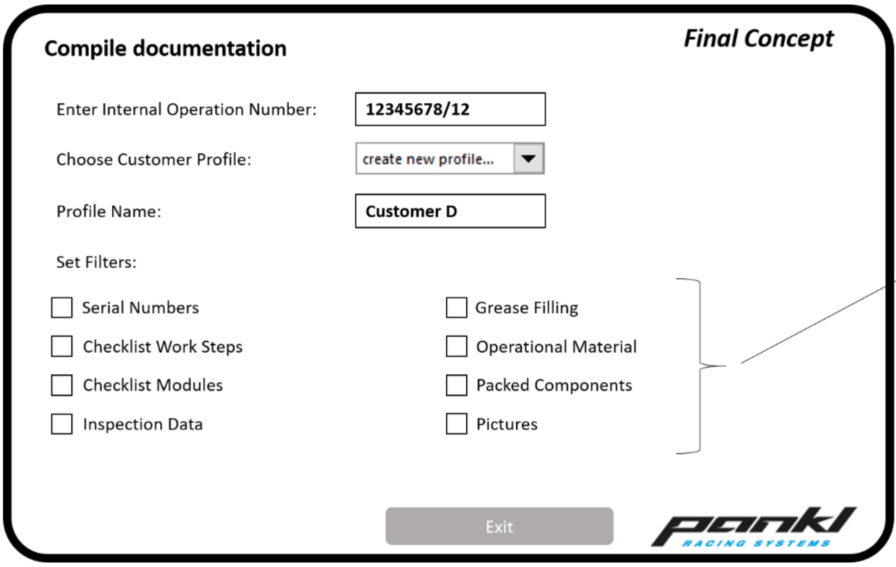
Sketch / Graphic

Appendix D: Documentation – compilation example

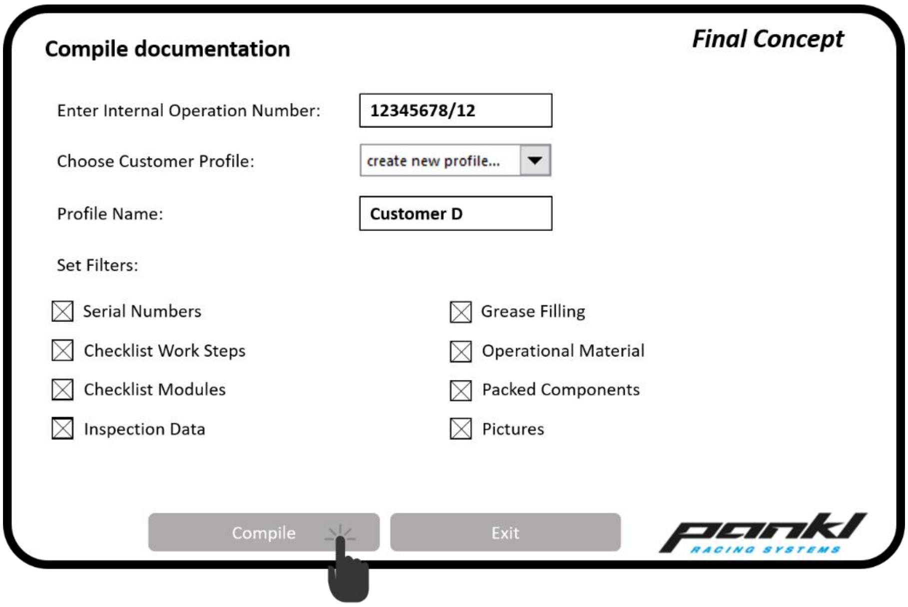




Choose customer profiles with pre-defined filters



Filters to define the detail level of the documentation – non chosen data is not implemented into the compiled documentation



Assembly Documentation
for Internal Operation Number 12345678/12

pankl RACING SYSTEMS

Serial Numbers

Checklist Work Steps

Checklist Modules

Inspection Data

Grease Filling

Operational Material

Packed Components

Pictures

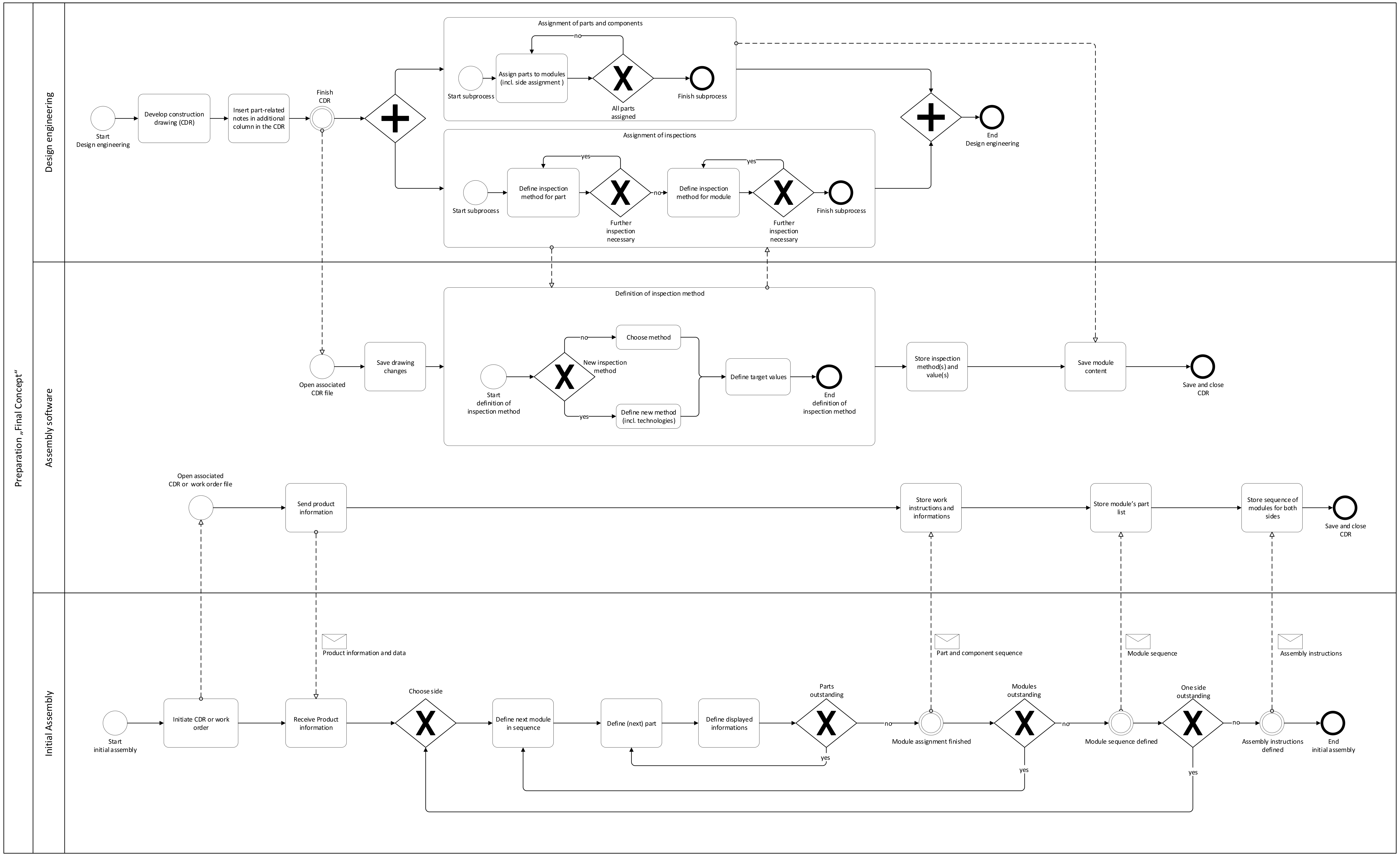
Pankl Drivetrain Systems GmbH & Co KG
A member of Pankl Racing Systems

Page 1 of 1

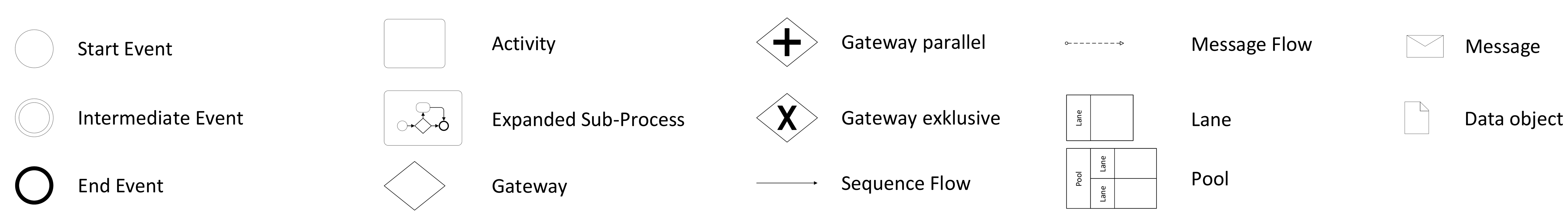
Appendix E: Process models

Process model

Final concept - preparation process



Legend



Process model

Final concept – assembly process

Legend