Graz University of Technology

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Design of an APP-based Data Management System in the railway industry

MASTER´S THESIS

to achieve the university degree of

Master of Science

Master's degree programme: Production Science and Management

submitted to

Graz University of Technology

Supervisor

Univ.-Prof. Dipl.-Ing. Dr.techn. Franz Haas

Institute of Production Engineering

Graz, May 2019

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Abstract

Digitalisation is not the futuristic element that it used to be. In modern companies, it already changes the way how productions work. By increasing the grade of digitalisation of their productions, it becomes easier to optimise processes and this results in increased competitiveness on the market. This master thesis shows the advantages that digitalisation of production processes in the matter of information flow, data collection and data analysation provides. In cooperation with Siemens, a global player in the railway industry, the actual processes are analysed and explained with the use of examples.

The topic of this master`s thesis was chosen during a collaboration with Siemens Mobility Graz. With a higher grade of digitalisation in the worker information, the machine operation and the incident information Siemens expects an increase of efficiency and productivity in the production. Due to the limited availability of workers, the digitalisation was neglected in the past. With this master`s thesis, first steps are made to display, analyse and execute digitalisation to catch up the backlog.

On this point the master`s thesis starts. Siemens`s goal is to digitalise three different areas with the use of applications. Those are the worker information, the outdate incident management on manual workplaces and the not available multi machine operation. In focus is the analysation and improvement of already existing processes with the use of digitalisation. The thesis explains what Worker Information Systems are, how information can be passed on to workers, which role Cloud Computing and 5G plays in the industry and the importance of a working incident management is. Another quest is to compare different Manufacturing Execution Systems and to find the best fitting software for the job. A further task is the analysation and redesign of the information flow and the worker information. Finally, the different applications start in a trail run. The programming of the different applications and software tools is provided by an expert company. As test production lines for the Worker Information System and the Call System for manual workplaces, the new cycle assembly for bogie assembly is chosen. The Multi-machine operation application is tested on the welding robots of the frame welding shop.

Kurzfassung

Digitalisierung ist in der produzierenden Industrie schon lange keine Zukunftsvision mehr. Vielmehr ist sie ein fester Bestandteil zur Optimierung von Prozessen und zur Steigerung der Wettbewerbsfähigkeit von Unternehmen. Diese Masterarbeit soll die Möglichkeiten aufzeigen, die durch die Digitalisierung von Produktionsprozessschritten im Umfang von Informationsfluss, Datensammlung und deren Datenauswertung entstehen. In Kooperation mit Siemens, einem Global Player in der Schienenfahrzeugs-Industrie, wurden die einzelnen Arbeitsschritte und Vorgänge analysiert und anhand von Fallbeispielen verdeutlicht.

Gewählt wurde das Thema der Masterarbeit während der Zusammenarbeit mit Siemens Mobility Graz. Durch die steigende Digitalisierung im Bereich Werker Information, der Maschinenbedienung und dem Störungsmanagement, erwartet sich Siemens eine Steigerung der Effizienz und Produktivität in der Produktion. Durch die beschränkte Verfügbarkeit von Mitarbeitern, die in der Vergangenheit wurde der Punkt Digitalisierung vernachlässigt. Um den Rückstand aufzuholen werden mithilfe dieser Masterarbeit erste Schritte in der Digitalisierung aufgezeigt, analysier und durchgeführt.

An diesem Punkt knüpft diese Masterarbeit an. Siemens zielt darauf aus, drei Bereiche mittles Applikationen zu digitalisieren. Dabei handelt es sich um die Werker Information, das veraltete Störungsmanagement von Montageplätzen und die nicht vorhandene mehrfach Maschinen Bedienung. Im Vordergrund der Arbeit stehen die Analyse und Verbesserung vorhandener Prozesse durch das Einsetzen von Digitalisierung. Besonderer Fokus liegt darauf, was Werker Informationssysteme sind, wie Information an Werker weitergegeben werden kann, welche Rolle Cloud-Computing und 5G in der Industrie spielen und die Wichtigkeit eines funktionierenden Störungsmanagements. Eine weitere Aufgabe ist es, verschiedene Manufacturing Execution Systeme zu vergleichen und die beste Software für den vorhanden Anwendungsfall zu finden. Ein weiterer Teil der Masterarbeit ist die Analyse und Neugestaltung der Informationsflüsse im Fall einer Störung und der Werker Information. Schlussendlich wurden die verschiedenen entwickelten Applikationen Testweise eingeführt. Das Programmieren der Applikationen und der benötigten Software wird von externen Unternehmen übernommen. Als Testlinie wurde für das Werker Informationssystem und das Rufsystem für Störungen die neue Taktmontage für Drehgestelle verwendet. Die Software für mehrfach Maschinenbedienung wird an vier Schweißrobotern getestet.

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AR	Augmented Reality
AV	Augmented Virtuality
BOM	Bill of Material
BPMN	Business Process Model and Notation
CIM	Computer Integrated Manufacturing
CIP	Continuous Improvement Process
EBOM	Engineering Bill of Material
EN	Engineering
ERP	Enterprise Resource Planning
HMI	Human Machine Interface
IFA	Information Flow Analysis
IIoT	Industry Internet of Things
InPs	Internet Infrastructure Providers
IoT	Internet of Things
KPI	Key Performance Indicator
MBOM	Material Bill of Material
MEC	Mobile Edge Computing
MES	Manufacturing Execution Systems
MRP	Material Resource Planning
PE	Production Engineering
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
RFID	Radio-Frequency Identification
SAE	System Architecture Evolution
SAP ME	SAP Manufacturing Execution
SGP	Siemens Graz Pauker
SIM IT UADM	Simatic IT Unified Architecture Discrete Manufacturing
STS	Siemens SGP GmbH & Co KG
VR	Virtual Reality
WIS	Worker Information System

Content

1. Introduction

The Introduction shows an overview of the creation of this thesis and gives a short insight into Siemens Mobility Graz.

1.1. Aim of thesis

The aim of the thesis is to gain a deeper insight into the production and the organization area of an international company in Austria working in bogie production. This shows the changes that are made by the industry to fulfil the market needs and to stay competitive. Now one of the big challenges is to gain higher efficiency and productivity of the production. The high demand of bogies in the next years is the reason why it makes sense supporting the production with modern tools.

One target is to understand an explain the effect that the growing digitalisation has on the industry. To explain the new computing technologies like Cloud Computing, Edge Computing and Mobile Edge Computing. To research literature about the efficiency of different information channels for transporting worker information. Furthermore, an insight is given into the world of Manufacturing Execution Systems, Worker Information Systems and Incident Management.

Another goal of this thesis is to analyse the current state of the worker information flow and the incident information flow. Out of this results, a modern and up to date information flow for these processes is developed. Beside this different MES softwares have to be benchmarked and the most suitable one for this production is determined with the use of benefit analyses. The design and prototype of the Interface to this Worker Information System placed in the production line is also part of this thesis.

Finally, the newly developed tools, that are programmed by external companies, are implemented in selected production lines at Siemens Mobility in Graz.

1.2. Methodical approach

To work on the master thesis in a structured form, the decision is made to divide it into three phases. These three phases are the data collection, a rough concept of MES and the call system. Phase three is the fine concept and implementation of the Call System and the MES system.

In the first phase of the master thesis, the scientific aspect of the thesis is treated. Technical literature is used to gain knowledge and figure out what the current scientific state is. The first step is to find and evaluate different sources to figure out if they are suitable to use as references. One of the two main topics in the second part is to work out the state of the art about call systems/ incident management and to analyse the benefits and drawbacks for the different parties in the company. Another task is to evaluate the benefits and drawbacks of a WIS that is supplied by the latest data from the MES. To find the MES that meets the requirements of the company the best a benchmark of different MES is made. Additionally, to this, this part also shows the effects and new technologies, like Cloud Computing and 5G the digitalisation brings to the industry.

In the second step, the current state is analyzed. Several meetings, guided tours and observation through the production make it possible to analyze the current state. Important information is also provided by the responsible project manager. A lot of input for further improvement is also gained by the employees. Since almost all of them have several years of experience in their field of work. State of the art technology is figured out by research, of specific articles and papers and by benchmarking visits at other companies. The correct understanding of the processes is ensured by workshops, talks to specialists in the company and a part-time job at Siemens in Graz. The team that supported the master thesis included the Siemens Production System Manager, the Production Engineering and the Production Manager. Furthermore, every workplace is analysed to get information about which data has to be saved in the MES and which information must be provided by the applications of the WIS.

In the third part of the Master´s thesis, the practical part of the thesis is treated. This part shows the designed tools and applications for the WIS, call system and the multi-machine operation. All the different applications are explained in detail and what they are capable of.

1.3. Structure of the thesis

The master thesis is divided into a theoretical and a practical part and generally deals with the topic IIoT or Industry 4.0. In the first theoretical part, an insight into the topic and the technology is given. The current state will be analyzed and compared to state of the art of technology and processes. It shows the current state in the industry and innovations which companies can implement and gain a potential improvement. The final part of the theoretical part is to analyse the system with the software and the hardware and make use of the benefit analysis. With the use of this, the concerned parties can be convinced that a change will help everyone.

In the second part of the thesis, the practical part will be discussed. Part of it is the implementation of the call system in two different production lines and to start a pilot testing. This will be documented with all the knowledge gained during this process and the opportunities for further improvements. Another part is the design of a MES based WIS in the production. At the end of the thesis, the conclusion gives a summary of the work and a future prospect.

1.4. Company overview

1.4.1. History of Siemens Mobility in Graz

In the year 1854, Johann Weitzer founded a blacksmith shop for horse hoofs and wagons where the production site is found today. Due to the high number of jobs, growth occurred quickly for the new Wagenfabrik Johann Weitzer. One of their first big assignments was to build the wagons for the construction of the Suez Channel. Soon the production increased to military carts, postal vehicles, health care and luxury wagons. Costumers from all over the world, like Australia and Russia, asked for their products. Soon the production expands to steam engines, steam boilers and agricultural vehicles. In 1870 the production facility in Graz had already a workforce of 1500 people.

In 1872 the Johann Weitzer Wagenfabrik changed into the stock company Grazer Waggon-Maschinenbau- und Stahlwerkesgesellschaft. In central Europe the plant was leading in the design and building of railway vehicles, it was also famous for the diesel engines built in Graz.

The political changes in 1914 had a small effect on the company. Way worse was the crash of the New York stock market. The reaction was that the Simmering Maschinen- und Waggonbaufabrik AG bought stocks of Grazer Waggon- und Maschinenfabriks-Aktiengesellschaft former Weitzer. With the integration of Vienna Paukerwerkes, the Simmering-Graz-Pauker (SGP) AG was founded in Graz and Vienna.

The production facility in Graz suffered from large destruction in the Second World War. In 1946 the company became state owned by Austria and was named SGP. It was one of the model companies in the state-owned Austrian industry.

At the end of the late eighties, Siemens and SGP came close to becoming a single-source supplier for railway vehicles. In 1992 Siemens AG bought 26% of SGP Verkehrstechnik GmbH. In 1994 Siemens already owned 74% and the traditional company became part of the Siemens Schienenfahrzeuggruppe. In 2001 Siemens SGP became a 100% daughter of Siemens AG and changed the name to Siemens Transportation Systems GmbH & Co KG (STS). In 2009 STS got integrated into the Mobility Division of Siemens Austria.[1]

[1] cf. Online: Siemens (2018) [State: 21.11.2018].

1.4.2. Siemens today

The Siemens Factory in Graz designs and produces, bogies, bogie components, wheelsets, pantographs and offers customer service for these components. Since 1998 about 53.000 bogies were built for different applications and delivered. Due to the highly developed value chain, 99% of all orders were fulfilled on time. In Figure 1 the different supplied fields of operation and their percentage of the production can be seen. It reaches from small metros to high-speed trains like the ICE.[2]

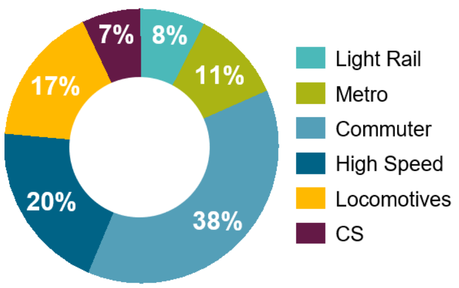

Figure 1: Customs of Siemens Mobility Graz, Source: Siemens Graz (2018).

One of the biggest challenges is the high complexity of different projects, up to 60 projects per year and with a variation of units per project, which can vary from one to sometimes more than 2000.

At Siemens Graz, 1026 workers and engineers fabricate around 3500 bogies per year. The modern production is kept up to date by investments of €120 million since 1998. Railed vehicles are used in a lot of different ways. This is the reason why there is a high complexity and variance in the design of the bogies. The maximum travel speed reaches from around 80 km/h up to 360 km/h and the distance between stops can vary between less than a kilometer up to more than 50 kilometers. Figure 2 shows the different trains produced by Siemens classified after their specifications.[3]

[2] cf. Siemens Graz (2018), P. 2ff.
[3] cf. Siemens Graz (2018), P. 2ff.

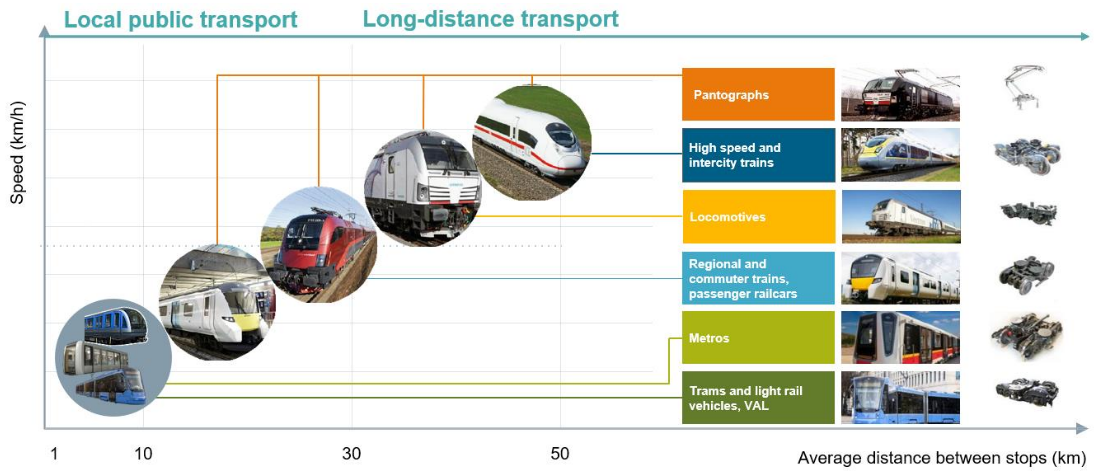

Figure 2: Types of products, Source: Siemens Graz (2018).

Another big challenge in Graz is that the property of Siemens Mobility Graz is limited in space to all sides. This affects the layout of the production site and makes it very complicated to expand.

2. Digitalisation, connection and changes in the mechanical industry

This chapter will give an overview of the current changes in the matter of digitalisation and connection. Also, it also shows the variations for modern companies.

2.1. Industry 4.0

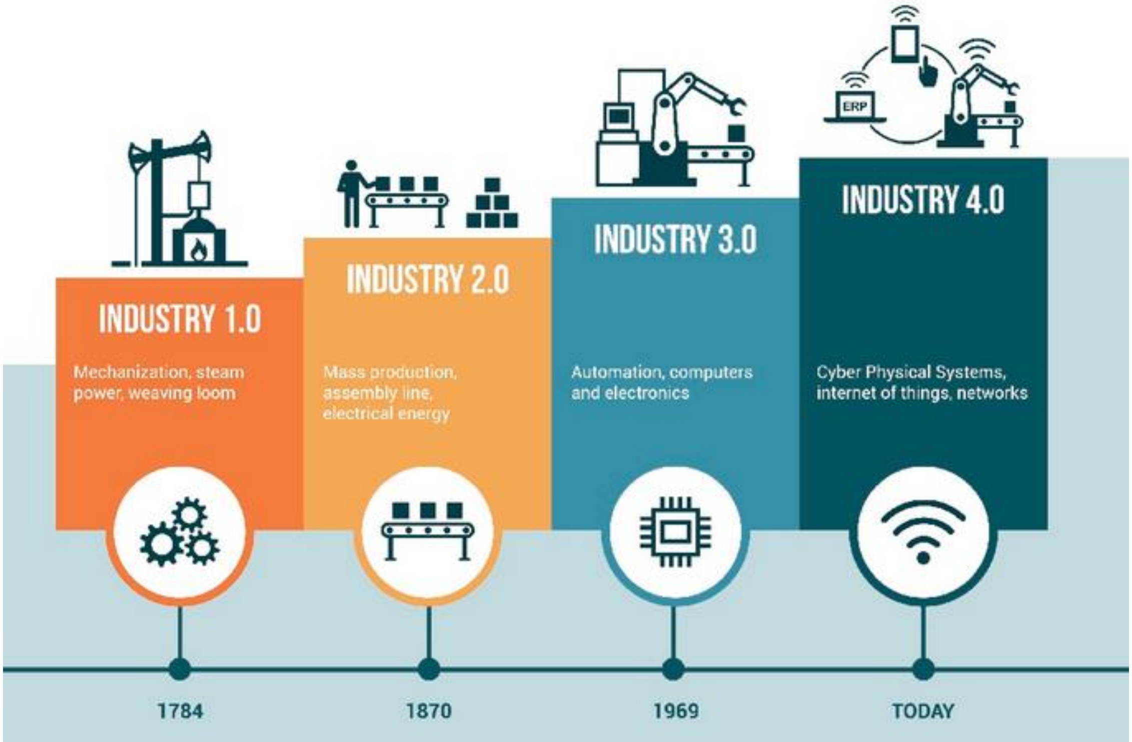

Figure 3: Timeline of the Industrial Revolutions, Source: Online: Cline (2017) [State: 21.03.2019].

Figure 3 shows a rough timeline of the different industrial revolutions. The different periods will be explained briefly below.

Industry is the name for the part in the economy that produces goods and materials that are highly mechanised and automatized. The different periods the industrial businesses went through are the so-called "Industrial Revolutions".[4]

The first Industrial Revolution was the mechanisation and took place from 1750 to 1850. Mechanisation is the development of machines that mechanise the production

[4] cf. Lasi et al. (2014), P. 261-264.

process. Some of the new inventions of this period are the steam engine, textile machines and machine tools.[5] The development of the textile machinery in England and parts of Europe was known as the start of this period[6].

The intensive use of electricity was characteristic for the second Industrial Revolution[7]. This period took place between 1870 – 1914. Inventions like the Bessemer process for steel production or the electrolytic refining process for the aluminium production formed this time.[8]

The expansion of digitalisation was the milestone that led to the third Industrial Revolution[9]. It took place from 1970 to 2000 and was characterised using electronics and computers in the manufacturing technology[10].

This is a brief insight into the industrial revolutions of the past and the actual revolution the Industry 4.0 will be explained more in depth. Industry 4.0 defines the connection of different technologies like industrial robots, machines, clouds and data in a less centralised environment than in the past. In the past, it was all about “Big Data”. Big Data is a technology to collect huge amounts of data and to use them to filter the data needed. This data can be used for different applications like predictions. The trend of Big Data is mostly over and got substituted by “Machine Learning” which is a kind of data science. Data science is the analysation of data in a quantitative way.[11]

After the research about Industry 4.0 and IIoT in several different pieces of literature the explanation in the book “Industry 4.0 chapter 3.3”[12]explains the term really well.

Industry 4.0 is about the connected company and in the book of “Industry 4.0” the authors did research about the specific keywords that are used with IIoT. To find out those keywords they used four different sources. Which are „The Second Machine Age”[13], „Produktionsarbeit der Zukunft – Industrie 4.0“[14], „Wandel von

[5] cf: Hazarika/Dixit/Davim (2019), P. 1-3.
[6] cf. Martin-Vega (2004), P. 1.3.-1.9.
[7] cf. Lasi et al. (2014), P. 231-264.
[8] cf: Hazarika/Dixit/Davim (2019), P. 3-8.
[9] cf. Lasi et al. (2014), P. 231-264.
[10] cf: Hazarika/Dixit/Davim (2019), P. 8-13.
[11] cf. Andelfinger/Till (2017), P. 1-8.
[12] cf. Andelfinger/Till (2017), P. 42-56.
[13] cf. Brynjolfsson/McAfee (2014), P. 23-88.
[14] cf. Spath (2013), P. 3-8.

Produktionsarbeit – Industrie 4.0“[15] and „Industrie 4.0 in Produktion, Automatisierung und Logistik “[16].

The keywords that Andelfinger and Till wrote in their book “Industry 4.0” are: [17]

“

- *Sensors*
- *Information and communication technology*
- *Networking*
- *Real-time ability*
- *Decentralised control*
- *Intelligent, self-controlling objects*
- *Fast and flexible reaction on customers*
- *Costumer integrated business process*
- *High variance*
- *Production automatization*
- *The relationship between human and machine*
- *Internet of things*

“

Those different keywords are sorted by Andelfinger and Till into different groups like **flexibility**, **automatisation** and **connectivity**. Customer integrated business process, fast and flexible reaction on customers and high variance are the group flexibility. Communication, digitalisation, decentralised control, real-time ability, and information technologies are the group connectivity. Self-controlling devices, sensors, production automatisation and the relationship between human and machines are the group automatisation.

[15] cf. Hirsch-Kreinsen/Weyer (2014), P. 5-13.
[16] cf. Bauernhansl/Hompel/Vogel-Heuser (2014), P. 5-33.
[17] Andelfinger/Till (2017), P. 42f.

Flexibility

Meanwhile and in the future, the companies are forced to be as flexible as possible stay competitive on the market in the future the companies must react to customer wishes quickly.[18] With this, high flexibility and high variance of products can be achieved. This results in satisfied customers because the products at the end of the productions fit the wishes. The customer-oriented business process tries to fulfil wishes of the customer after the order of the product.[19]

Automatisation

The automatisation is one major part of Industry 4.0. To accomplish self-regulating machines, they must be equipped with sensors to give them the ability to monitor the processes and to work automatically. Those are like the senses of the human being, seeing, feeling and hearing. Another challenge that comes with automatisation is the machine-human relationship. This means that the workers in the companies must accept the machines and work together with them.[20]

Connectivity

Connectivity stands for connecting several different objects to each other. It starts with machines, robots, computers and ends with the people working in the company. A very important topic is the information and communication flow between the different parties that become more digitalised. The connectivity also enables a decentralised control of objects that are connected to the network.[21]

[18] cf. Spath (2013), P. 4.
[19] cf. Andelfinger/Till (2017), P. 44.
[20] cf. Andelfinger/Till (2017), P. 44.
[21] cf. Andelfinger/Till (2017), P. 44.

2.2. Smart factory

"The smart factory is a flexible system that can self-optimise performance across a broader network, self-adapt to and learn from new conditions in real or near-real time, and autonomously run entire production processes."[22]

The smart factory is a way how companies can successfully handle the high pressure coming from the changes in the ecosystem. One of the key points is that the smart factory can adjust and learn from real-time data which makes it more responsive, proactive and predictive. This results in less downtime and other productivity challenges.[23]

The integration of equipment, machines in combination with information systems like MES and ERP in a smart factory is a cyber-physical manufacturing system that creates an agile production[24].

2.3. Automatisation Pyramid

Nowadays communication in industrial companies is mostly defined by a very hierarchical Automatisation Pyramid[25]. The goal of the Automatisation Pyramid is to reduce the complexity that is triggered by the raising automatisation in the industry by dividing it up into separate levels. This leads to an easy understandable visual presentation of the industrial production.[26] Different levels in the pyramid need different forms of communication. In the higher levels, a lot of participants have access to the network and complex computer systems are implemented. The result is a high amount of data. In comparison to that, in the lower levels, the network reach is minor because the amount of data and people that participate in the network is smaller.[27]

There are several different forms of Automatisation Pyramids, but one is explained in several different books, the model after Siepmann[28]. This is the model which is explained below.

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[22] Online: Burke et al. (2017) [State: 13.04.2019].
[23] cf. Online: Burke et al. (2017) [State: 13.04.2019].
[24] cf. Wang et al. (2016), P. 158-168.
[25] cf. Forstner/Dümmler (2014), P. 199-201.
[26] cf. Siepmann (2016), P. 47-72.
[27] cf. Heinrich/Linke/Glöckler (2017), P. n.p.
[28] cf. Meudt/Pohl/Metternich (2017), P. 1-8.

Siepmann built a model that shows the classical pyramid-like defined in the DIN EN 62264. Different from most of the other theories and the DIN EN 62264 is that Siepmann extends the pyramid with one more level, the product level.[29]

Figure 4 shows the Automatisation Pyramid after Siepmann with the level implemented by him.

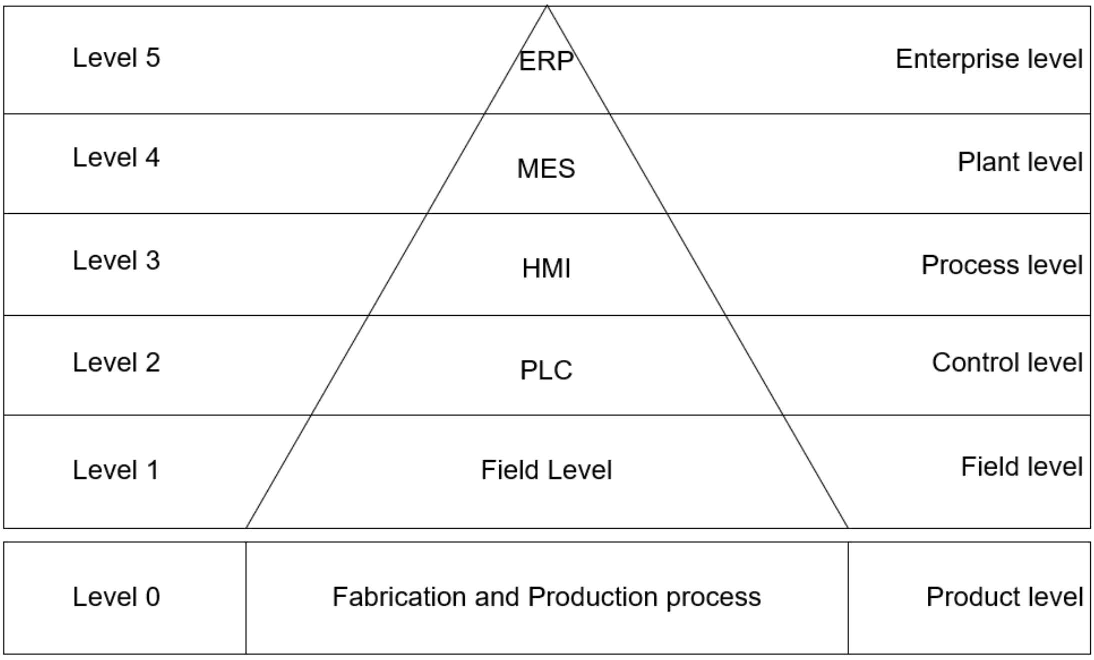

Figure 4: Automatization Pyramid after Siepmann, Source: Meudt/Pohl/Metternich (2017), P. 6.

The different levels are: [30]

- **Level 0 (Product level):** This level is about the production and assembly process. Because in the modern production process the use of Radio Frequency Identification (RFID) or other intelligent products that are providing information to the parts.
- **Level 1 (Field level):** Field level can also be called shop floor and contains the different production departments. Several actors and sensors like temperature sensors, light barriers and electric controllers are part of it. In this level input and output signals are used to get production relevant data.

[29] cf. Meudt/Pohl/Metternich (2017), P. 1-8.
[30] cf. Meudt/Pohl/Metternich (2017), P. 6.

- **Level 2 (Control level):** The control level uses Programmable Logic Controller PLC's to process result data out of the provided sensor data and gives this information back to the control level. This is the reason why this level is a major player in decentralised machine operation.
- **Level 3 (Process level):** The process level or in other words command leve,l serves as operating or monitoring system in the human-machine interface.
- **Level 4 (Plant level):** The MES is the connecting part between the shop floor and the enterprise level. It is mostly used for production fine planning, data collection, data transfer and is connected to an Enterprise Resource Planning (ERP) system to pass on and get information.
- **Level 5 (Enterprise level):** The ERP system also called the top floor contains the production rough planning and the ordering process of the industrial production.

In the classical Automatisation Pyramid, there are almost no interfaces between the different layers. In the future, this will change because of the development of more connected productions. This results in several connections in the horizontal and vertical direction in the Automatisation Pyramid. In the future, more devices, machines or systems in one company will send data across several levels. With an intelligent connection in a company, all devices and services can communicate directly to each other.[31]

This is the reason why a strict separation of the levels is not possible anymore and the fixed structure of the classical Automatisation Pyramid will lose value[32].

[31] cf. Hoppe (2017), P. 119-144.
[32] cf. Kleinemeier (2014), P. 571-579.

2.4. Big Data

Whenever the topic is Industry 4.0 the companies show interest in Big Data[33]. Moore's law, that says that the power and memory of computer semiconductors double every 18 months, and the following decline of costs for memory is one reason why Big Data is an interesting topic because of the increase of data that can be processed.[34]

Big data is the word for the mass of data, whether structured or unstructured, that is collected by organisations in their daily business[35].

The literature shows different definitions for big Data on different aspects:

- **Data:** "*Big Data refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyse*"[36]
- **Process:** "*Collecting, storing and processing massive amounts of data for the purpose of converting it into useful information*"[37]
- **Technology:** "*Big Data technologies as a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data by enabling high-velocity capture, discovery, and/or analysis*"[38].

Not all data is the same and has several different characteristics, an overview of the different data characteristics shows Figure 5. Data can be different in matters of volume (amount of data that must be processed), speed (is the time data needs to respond), variety (are the different formats of data), veracity and the value of the different data.

[33] cf. Jäger et al. (2016), P. 116-121.
[34] cf. Schaller (1997), P. 52.
[35] cf. Online: Keith D. (2018) [State: 13.04.2019].
[36] Online: Manyika et al. [State: 12.04.2019].
[37] Pittman/Atwater (2016), P. n.p.
[38] Online: Gantz/Reinsel (2012) [State: 12.04.2019].

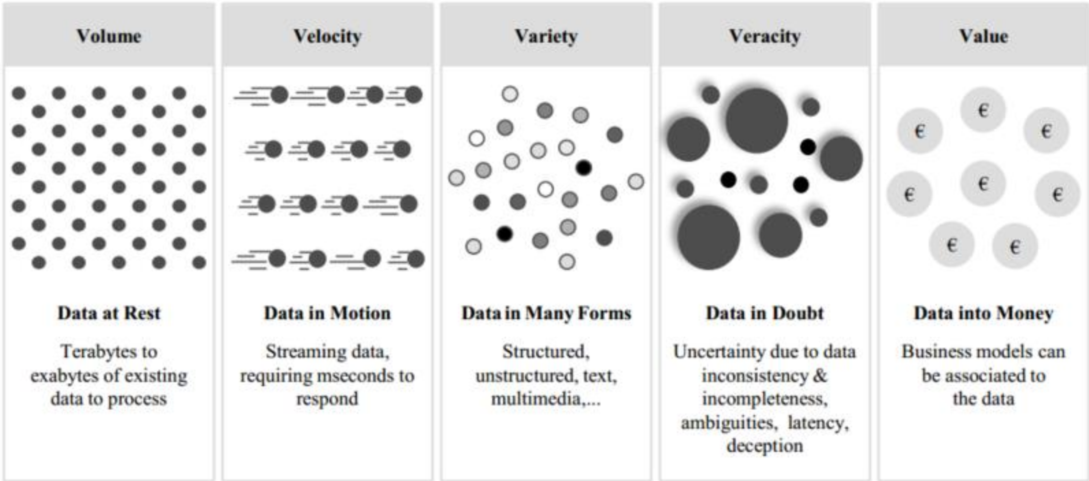

Figure 5: Characteristics of data, Source: Online: BDV PPP & BDVA (2019) [State: 12.04.2019].

Smart data

"We don't need Big Data – we need SMART Data!"[39]

The application of analytical skills and tools creates Smart Data. This enables business intelligence and real-time process operation[40]. Smart data can be divided into two different types: [41]

- Smart data is processed Big data that is turned into indicatable information.
- Smart data that is directly sourced from smart sensors on the machines, this is very common with the Industrial Internet of Things.

Small Data

"Small is beautiful in a Big Data world"[42]. Small data can be explained by looking on the different variances of data in Figure 5 and taking less variance, less volume and so on and lay the focus on the key parameters.[43]

[39] Marr (2015), P. n.p.
[40] cf. Iafrate (2014), P. 25-34.
[41] cf. Online: Keith D. (2018) [State: 13.04.2019].
[42] Marr (2015), P. n.p.
[43] cf. Online: Gregory Thompson [State: 13.04.2019].

2.5. 5G and IIoT

After 3G and 4G networks, the time has started for the next generation of network, the 5G. The 5 G focuses not only on an increase of data speed like 3G and 4G did but also on the efficiency of the network.[44] [45]

The diversity of applications covered by 5G is one of the main differences between the others. The high connectivity of 5G will have an impact in several different sectors reaching from wearables to industrial applications. It will enable industrial companies to step ahead into the direction of a fully automated and flexible production system. Therefore, 5G also is a part of the Industry 4.0 or in other words for IIot. Future companies will gain with the change of Industry 4.0, greater automatisation, higher productivity and higher flexibility to withstand the challenges of the market.[46] [47]

Figure 6 shows the implementation of 5G in the industry.

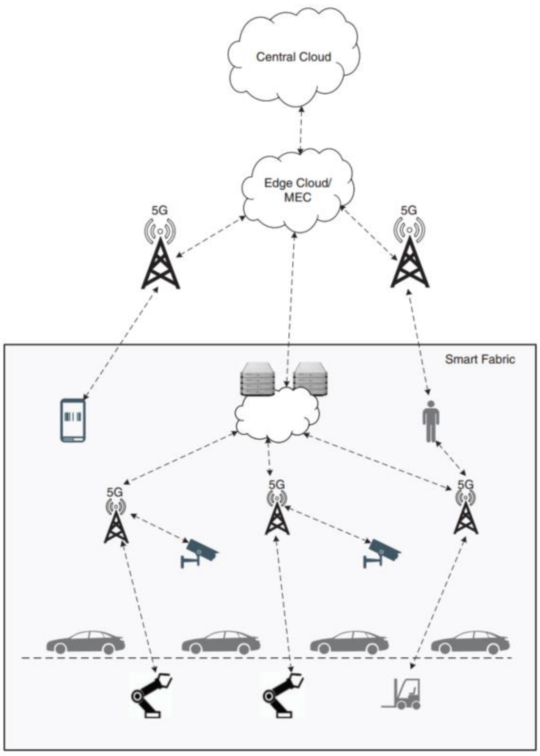

Figure 6: 5G for Industry 4.0, Source: Chandramouli/Liebhart/Pirskanen (2019), P. 25.

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[44] cf. Bangerter et al. (2014), P. 90-96.
[45] cf: Varghese/Tandur (2014), P. 634-638.
[46] cf. Chandramouli/Liebhart/Pirskanen (2019), P. 1-2.
[47] cf: Varghese/Tandur (2014), P. 634-638.

Today's industry uses about 90%, wires to transfer data from one place to the other. Those wired data transfers have benefits and drawbacks. The benefits are the high performance and reliability. The system with wires brings a not negligible downside. Modern companies that want to compete on the world market need to be very flexible to adapt on changing markets and production demands, this is a problem with a wired network in the production, because it cannot offer the needed flexibility. This is the place where 5G wireless technology comes into action. It offers high speeds, low latency and very high reliability, that is not possible with wireless networks jet. This makes 5G to the perfect substitution for wired connections. Up to 5 times lower costs, makes 5G, a very interesting tool for the industrial companies. The thought that it is expensive to replace an already existing wired system with wireless technology is not true, the payback time is short. A crucial part of companies is the functional safety of the system because any kind of accidents could have severe results. Another threat is the fear of attacks from outside. This is the reason why now most industrial networks are completely isolated from the internet. Therefore, the 5G network must be able to transport data between the different participants in a fast, secure and reliable way.[48]

[48] cf. Chandramouli/Liebhart/Pirskanen (2019), P. 24-26.

2.6. Modern computing technologies

In this chapter the different forms, cloud computing, edge computing and mobile edge computing are explained and the benefits and drawbacks of the different systems are evaluated.

2.6.1. Cloud Computing

Cloud Computing is one of the big and important changes recently. This network application provides users with a completely different IT service and delivery mode.[49]

In Figure 7 the basic system of cloud computing can be seen.

Figure 7: Cloud Computing, Source: Online: JustScience (2018) [State: 06/01/2019].

There are several advantages that come with the usage of Cloud Computing:

1. The provider of the cloud service owns and manages the hardware, storage, and networking. He is also responsible for providing the electricity needed. The user of the cloud service does not need to make a huge investment to build up and maintain the whole system by himself.[50]
2. The system and the capacity the user needs are flexible. If he needs more or less computing resources it is easy to change[51] [52].

[49] cf. Yang/Lin (2015), P. 219-232.
[50] cf. Kim (2009), P. 1-8.
[51] cf. Kim (2009), P. 1-8.
[52] cf. Marston et al. (2011), P. 176-189.

3. The costs for the cloud service are generally cheaper than maintaining a computing resource that is most of the time not even completely needed. This is also a benefit for smaller companies that need to do compute-intense analytics that is only available to big businesses due to costs[53] [54].
4. The operator can use the cloud service all times with access to the internet[55] [56].

To find out all the influence factors of cloud computing a SWOT analysis can be done. A SWOT analyse purpose is to identify the strengths, weaknesses, opportunities and threats on a system or environment. With an internal validation, the strength and weaknesses are found. The opportunities and threats are identified by an external appraisal. The internal validation contains all aspects of the company like personnel, facilities, location, service and production. The external appraisal looks at the political, economic, social, competitive and technological situation. On the bases of the SWOT analyses, different variations exist like the TOWS matrix. This matrix pairs the different factors of the SWOT analyses with the idea to find strategical solutions.[57]

Strength(S): Most of the strength is already shown above and will not be repeated here, the focus is on the other three points.

Weaknesses(W): There are several points of weakness that work along with the introduction of Cloud Computing. One of them is the loss of physical control of the data that is added to the cloud. In the past providers have not been able to guarantee the location of the company's information. They could not tell on which servers and location their data is stored.

Large companies with mission-critical applications have the troubles that Cloud Computing providers cannot guarantee the high quality and availability needed. For example, Amazon Web Devices Service Level Agreement commits to an uptime target on 99.99%[58]. That means downtime of 52.60 minutes per year.[59]

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[53] cf. Kim (2009), P. 1-8.
[54] cf. Marston et al. (2011), P. 176-189.
[55] cf. Kim (2009), P. 1-8.
[56] cf. Marston et al. (2011), P. 176-189.
[57] cf. Dyson (2004), P. 631-640.
[58] cf. Online: AWS Amazon (2019) [State: 06.01.2019].
[59] cf. Marston et al. (2011), P. 176-189.

Opportunities(O): A significant opportunity is the potential to help developing countries to use modern computing technology without making a huge investment first. Also, small and medium-sized companies profit from Cloud Computing. They can use high-end applications like ERP software without high investments in data storage and computing.[60]

Threats(T): One of the biggest threats of cloud computing is that the in-house IT departments will present it as a threat to the company's IT culture, or they are scared about their job security. Therefore, larger cooperation's have not adopted cloud computing as fast as small ones.

Maybe the biggest threat with cloud computing is data security and data privacy. The regulation for data privacy and data access are based on different law in every country. Therefore, organisations exist that define requirements on a local, national and international level.[61]

2.6.2. Edge Computing

Cloud Computing in the existing form is powered by strategically built data centres with limited but large aggregated resource capacities.[62]

The expansion of various forms of internet applications and bandwidth-hungry applications increases the need to place servers closer to the edge (customer). This makes it possible that user applications get responsive performance. Since the IIOT age devices need quick answers into their analytic computation requests.[63]

In Figure 8 the principle of Edge Computing can be seen. It shows the base layer with the sensors and controllers that communicate with the edge devices. Those devises make a real time data processing. This process filters out of the complete date the important ones and sends them to the cloud. This results in a lower bandwidth consumption.

[60] cf. Marston et al. (2011), P. 176-189.
[61] cf. Marston et al. (2011), P. 176-189.
[62] cf. Coady et al. (2015), P. 38-43.
[63] cf. Olaniyan et al. (2018), P. 633-645.

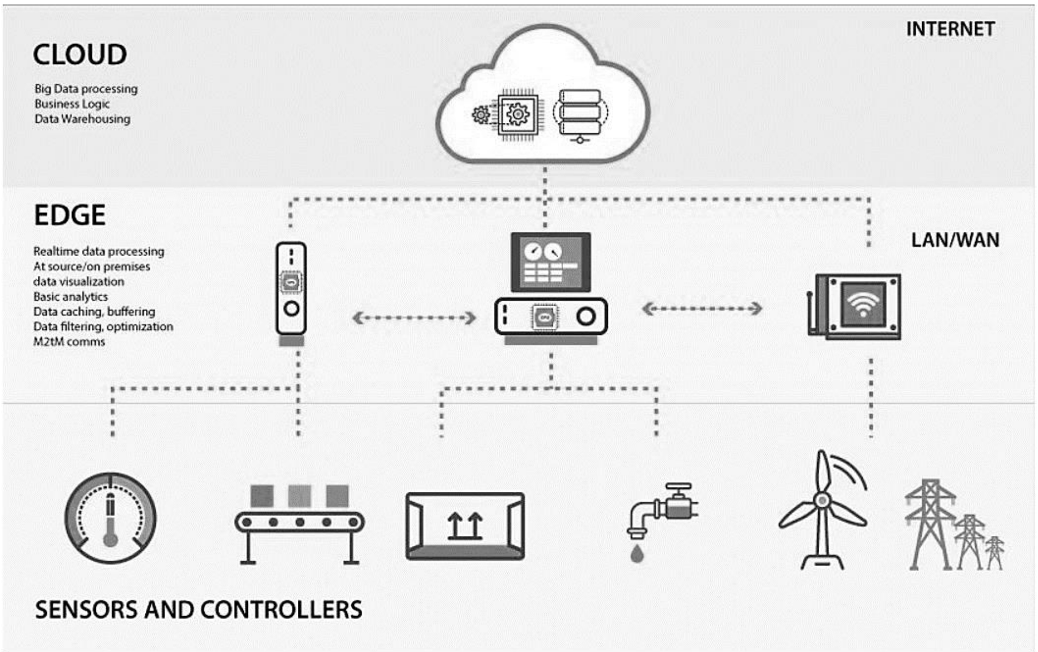

Figure 8: Edge Computing, Source: Online: OpenAutomationSoftware (2017) [State: 06/01/2019].

Edge Computing is a step further from Cloud Computing where substernal computing and storage resources, called cloudlets[64] are placed at the edge of the internet in close distance to the sensors and controllers.[65] The difference between edge - and frog computing is that Edge Computing handles mainly the sensorics of machines. Frog computing in comparison to that offers small calculating centres which offer a basic dater processing in the frame of decentralised IT infrastructure.[66]

In the next four points, the benefits of cloudlets are listed: [67]

- Highly responsive cloud services due to easier and faster connect ability to the cloudlets.
- Scalability via edge computing because only the extracted information and data must be sent to the cloud.
- Enforcement of the privacy policy via the cloudlets that are enforcing the privacy policy of its owner.
- Overcoming cloud downtimes.

[64] cf. Satyanarayanan et al. (2009), P. 14-23.
[65] cf. Satyanarayanan (2017), P. 30-39.
[66] cf. Online: Karlstetter (2018) [State: 22.05.2019].
[67] cf. Satyanarayanan (2017), P. 30-39.

Edge Computing does not only bring benefits it also brings a downside, which is:[68]

- Capacity shortages of the system, for example when big amounts of data must be processed or stored. To enable this, the system must be designed that it can handle these peaks.

2.6.3. Mobile Edge Computing

Mobile Edge Computing (MEC) is a new technology that provides IT service environment and Cloud Computing on the edge of a mobile network. MEC is emerging out of the wireless technology 5G and is a key factor.[69]

The idea behind MEC is to bring the processing power closer to the customer. Like in Edge Computing. The difference between Edge Computing and MEC is that it offers the processing power directly on the mobile edge. Nowadays the traditional way is that devices on the mobile edge act just as mobile aces points, but those stations just fulfil a data-transferring task no, other processing. MEC that is placed at the edge to the mobile network changes this.[70] [71]

Figure 9 shows the basic system of MEC. UE's are the mobile devices in the system that ate connected to the wireless network via the eNodeB which is a Radio Access Network. This eNodeB is than connected to the MEC server. This server also is connected to the hard-wired internet/ network. Via the SAE-Gateway the operator's network connects to the Internet infrastructure Providers (InPs). ASPs are the Application Service Providers that host applications for data centre and Content Distribution Networks.[72]

[68] cf. Online: Karlstetter (2018) [State: 22.05.2019].
[69] cf. Hu et al. (2015), P. 1-15.
[70] cf. Sun/Ansari (2016), P. 22-29.
[71] cf. Beck et al. (2014), P. 48.
[72] cf. Beck et al. (2014), P. 48-54.

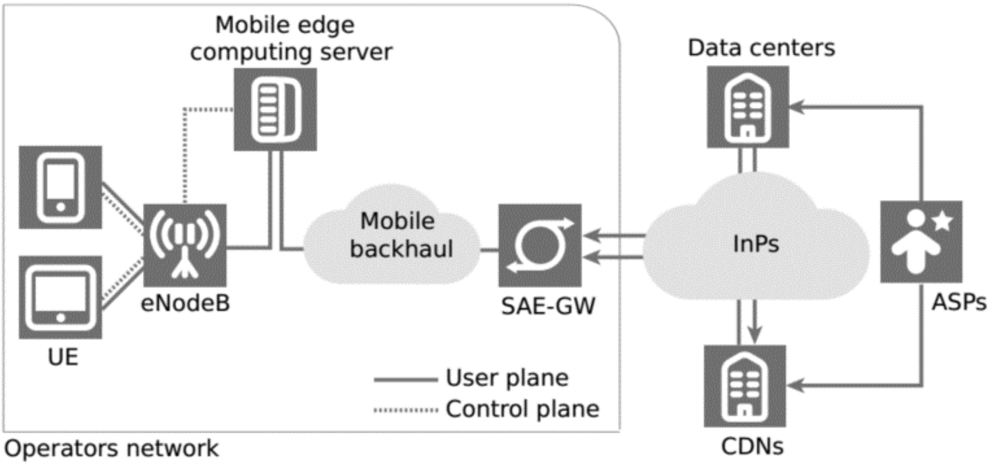

Figure 9: Mobile Edge Commuting structure, Source: Beck et al. (2014), P. 48.

Mobile Edge Computing brings several advantages for all the participants, but the one who benefits the most is the end user. The advantages are: [73]

- Reduction of communication delay for the end users.
- The implementation of new devices for example machines is due to the scalability of the mobile network cheaper and less affordable.
- Enabling new kind of applications because of the proximity to the end user.
- Better scalability and reduction of the bandwidth is a befit for the InPs.
- ASPs profit also from the scalability and faster services that enables them to host services on the edge which results in lower bandwidth demand within their datacentres.

To sum it up, a lot of research is invested into new ways of computing. Cloud Computing is now used in the industry because it is well developed and works. In comparison to that Edge Computing is still in the beginnings and not jet widely used, like it was with Cloud Computing some years ago. Some IT-Experts even think that Edge Computing will never replace Cloud Computing completely. They predict a parallel, complementary use of both systems.[74] Mobile Edge Computing is the future technology that emerges out of the 5G technology like explained above. To achieve

[73] cf. Beck et al. (2014), P. 129ff.
[74] cf. Online: Karlstetter (2018) [State: 22.05.2019].

a working MEC the technology behind 5G has to be fully developed, then it could offer completely new possibilities.

2.7. Options for information transfer of worker information

For a long time, the classical work instruction or worker information was paper based. This is now changing with the development of new media technology.[75]

To create an efficient work information, ten central questions can be used. Those questions can be seen in the list below: [76]

1. Who is performing the job? (Worker)
2. What must be done? (Process)
3. How to work? (Workflow)
4. What is needed for the work? (Work equipment)
5. Output of the work? (Target, goal)
6. Where is work done? (Workplace)
7. How many parts are needed? (Quantity)
8. What time will it take? (Time)
9. How accurate must the work be? (Quality)
10. How save must be worked? (Work safety)

By complete those ten questions a clear and understandable work instruction or technical documentation can be written.

Basically, the assembly process is characterised as a physical work it requires a not negligible cognitive work to understand and interpret the instructions correctly. Before starting with the actual work, the process of understanding the work instruction is an essential part.[77] By looking at the cognitive work, three characteristic process steps can be recognised:[78]

- The **information process** is the step where the worker realises, collects, sorts and provides the necessary work information on the work place. Also, it contains the collecting and remembering of the different assembly steps.

[75] cf. Rösener (2016), P. 131.
[76] cf. Online: Dogan (2016) [State: 21.05.2019].
[77] cf. Aehnelt/Bader (2014), P. 371.
[78] cf. Aehnelt/Bader (2014), P. 371-372.

- The following step is called the **knowledge process**. It combines all the cognitive processes to notice, process and use the information. Another part of this process is the monitoring and evaluation of the own work.
- The **work process** is the operative task that must be fulfilled and contains the step by step assembly preparation, execution and verification of the work.

Work instruction or technical documentation can be classified into different information products. Those can be spit up into guiding texts, that explains the steps that must be made and non-guiding texts, that offer just information without an exact instruction[79]. The different technical documents can be seen in Table 1.

Table 1: Classification of technical documents , Source: Broda (2016), P. n.p.

	Guiding text	**Non-guiding text**
Internal technical documents	• Assembly instruction • User instructions	• BOMs • Specification sheets • Computer-aided design models • Technical drawings
External technical documents	• User manuals • Maintenance manuals • Repair manuals	• Spare part catalogue • Product catalogue

Because IT is becoming a bigger part in the private life, the user behaviour is changing. For example, a survey of Bitkom in 2015 shows that people in every age use video-tutorials to understand and gain knowledge. With this table (Table 2) it can be expressed that mostly people of the younger age can be significantly supported in the production with the use of medial supported work instructions.

Table 2: Age and percentage of video tutorial users, Source: Online: Bitkom (2015) [State: 20.05.2019].

Age	**% already used a video tutorial**

[79] cf. Rösener (2016), P. 129.

Older than 14 years	37
14 – 29 years	39
Older than 64 years	32

One reason for this changing user behaviour, that also can be seen in this survey of Bitkom, is the shrinking motivation to read and understand a complex topic.

There are several ways how technical documents can be provided. Those can be divided into static media and dynamic media. Table 3 shows the different media with the corresponding form.

Table 3: Static and dynamic media , Source: Broda (2016), P. n.p.

Static media	**Dynamic media**
• Text • Picture, photo • Table • Sign	• Animation, moving pictures • Video, movie • Sound, Audio

Static media as shown in Table 3 has downsides compared to dynamic media. The first one is that they are not so capable of showing time flow and process steps. The second one is that the user of the technical documentation must be able to read and to understand the text, without this the information transfer is not possible.[80]

The following list shows different tools how worker information can be presented:

- **Paper** based work instructions are in the literature often explained as the past of worker information but in some companies, it is still state of the art.
- A **screen** is today state of the art and can provide the worker with important information. The user can change between different viewpoints or information that are necessary.[81]
  Usually, the user must change the different viewpoints manually because tracking of the assembly process is not given[82].

80 cf. Rösener (2016), P. 129ff.
81 cf. Feldmann et al. (2004), P. n.p.
82 cf. Lušić et al. (2016), P. 1114.

- In the case of **augmented reality (AR),** a computer generates the appropriate data in real time that is needed. Parts or objects can be placed in the seen reality[83]. One of the downsides is that the worker could be impaired by the head-mounted display or an activator.[84]
- Another tool is **augmented vitality (AV)** that connects a virtual scene into an image[85]. Currently, it is not very common in WIS to be used. It is possible to implement it into a fully virtually designed workstation while showing the worker necessary information. The benefit if there is a part just existing in real but not virtually must not be fully virtualised. The drawback is the high afford to build up the IT-system and the distraction of the user.[86] [87]
- The integration of a user into a simulated reality is called **virtual reality (VR)**[88]. VR technology has evolved to become a useful tool in recent years, which is making it a powerful tool. The way scientists and engineers are looking onto simulations and data visualisation has changed completely.[89]

  To simulate various scenarios VR is combining several human-computer interfaces like visual, haptic, auditory and so on, this offers the user a feeling of him/her being part of the virtual world. The user can move with natural movements like in the real world and can explore and test the virtual surroundings.[90]
- **Light guided** WIS uses light to provide information for the worker. There are several possibilities that use light as indicators like pick-by-light or put-to-light. It shows the user what part to take and where to put it. A projection of light signals is also possible.[91]
- The last two tools for a worker information system is **pick-by-shutter** and **pick-by-voice** but those are mostly in use in the logistics.[92]

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[83] cf. Schenk (2009), P. 344.
[84] cf. Lušić et al. (2016), P. 1114.
[85] cf: Drascic/Milgram (1996), P. 124-125.
[86] cf. Lušić et al. (2016), P. 1114.
[87] cf. Schenk (2009), P. 344.
[88] cf. Lušić et al. (2016), P. 1114.
[89] cf: Eddy/Lewis (2002), P. 899-908., cf. Zorriassatine et al. (2003), P. 513-530.
[90] cf. Seth/Vance/Oliver (2011), P. 1-4.
[91] cf. Lušić et al. (2016), P. 1114.
[92] cf. Reif, P. 37-39.

To sum it up, passing on work instructions is not as easy as it seems to be. The content of the information itself must be properly composed, for example by using the ten questions. The job gets faster and easier to understand for the workers and reduces the time a new worker needs to get used to the work instructions. If this is no standard in a company it makes sense to implement it.[93]

Another thing that can be noticed in the different literature above, is that the user habits about how to receive information has changes in the past with the increase of digitalisation. Users are less keen to read or even have trouble understanding the instructions that are provided in a text format. They tend to use more pictures or video supported instructions as seen in the survey of Bitkom, because it is more effective and takes less time.[94] The change of the industry also plays a role in this topic. The mass customisation of products increases the requirements for proper work instructions. This challenges the productions in a way that they must supply their workers with even more worker information. To accomplish these challenges modern technologies are available that can be used.[95]

2.8. Manufacturing Execution System

Manufacturing today is getting more complex and would not be possible to manage without the help of computer systems and software. A MES is set together by computer systems that are used to manage the production and processes above the level of automatization in a company.[96]

The idea of a MES started through data acquisition systems existing in the 80[th]. Different systems for each job existed. With the start of CIM, the IT-systems got implemented into the whole data process.[97]

In the Mid-90[th] the producers of data acquisition systems began to design and implement further tools into their specialised systems. It is called the extended combination system, which is already possible to implement in a lot of acquisition and

[93] cf. Online: Dogan (2016) [State: 21.05.2019].
[94] cf. Rösener (2016), P. 135.
[95] cf. Aehnelt/Bader (2014), P. 378-379.
[96] cf: Mehta/Reddy (2014), P. 593-607.
[97] cf. Kletti (2007), P. n.p…

evaluation systems. The sum of all these combination systems is explaining the range of functions of a MES today.[98]

The range of the function of a MES: [99]

- **Used in the production:** Machine data, operating data, DNC, production control station, material trackability, tool management, process handling and energy management.
- **Used for the staff:** Staff time recording, time management, deployment planning and entrance control.
- **For the use of quality assurance:** Manufacturing inspection, reclamation management, goods shipment, incoming goods, process data, measurement acquisition and incident management.

In modern production, all these three factors must work together to enable a quick reaction on possible occurrences. A Modern MES provides the possibility to homogenise and standardise the data transfer to the ERP system and to the atomisation level. If everything is connected the MES can show a current and very detailed image of the production.[100]

In Figure 10 the basic architecture of a MES can be seen. MES is designed to fulfil the wide needs of a manufacturing enterprise. It connects the front office accounting with the supervisor's control systems and their/ the products.

Also, it combines the outputs of the different layers of the information systems.

The information systems are: [101]

- Those located in the planning functions, like the Material Resource Planning (MRP)
- Such as those that are used in executive functions. They could be a supervisor control software or quality control.
- The control systems that create the data needed.

[98] cf. Kletti (2007), P. n.p…
[99] cf. Kletti (2007), P. n.p…
[100] cf. Kletti (2007), P. n.p…
[101] cf: Mehta/Reddy (2014), P. 593-607.

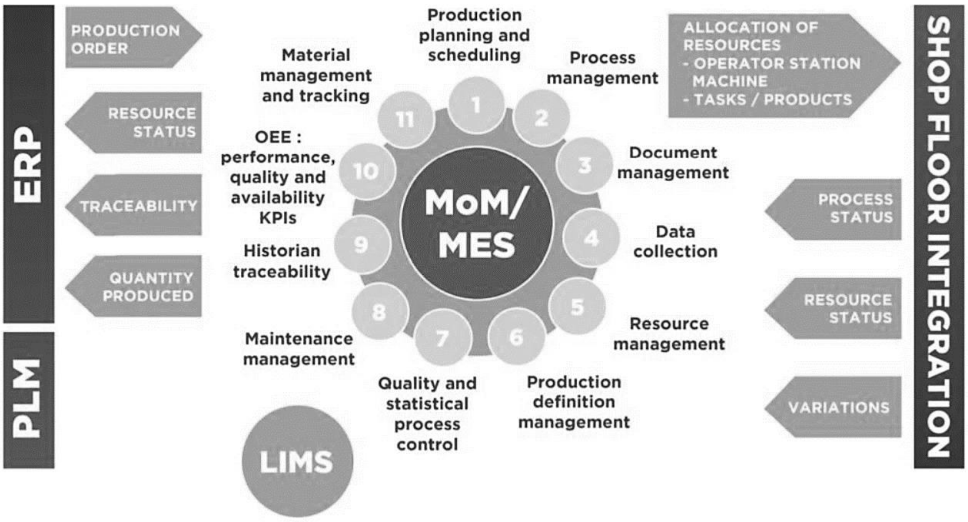

Figure 10: MES, Source: Online: Greg Cline (2017) [State: 11/01/2019].

Tools for scheduling, resource allocation, quality management, operations analyse, and process management are MES tools that are collected in real time on the shop floor. These data are transferred by the MES into information that is used by a management and control standpoint.[102]

The use of MES brings a lot of benefits, which include: [103]

- **The reduction of scrap and waste:** The system enables quick identification of problems, so the process can be stopped before a high number of wrong outputs are produced.
- **Increasing the uptime:** With this better-monitored process, the machines are running more often because the system only scheduled a task if the resources are available.
- **Precise capturing of the costs:** With the use of MES the labour, scrap, machining hours and most of the other costs can be captured. This leads to easier pricing.
- **Inventor reduction:** With the better monitoring of the inventory and the use it is easier to reduce the inventory because the safety inventory can be reduced.
- **Improvement in customer satisfaction:** Is affected by better quality and shorter delivery times due to extra monitoring.

[102] cf: Mehta/Reddy (2014), P. 593-607.
[103] cf: Mehta/Reddy (2014), P. 593-607.

2.8.1. Incident management

The way companies work changed a lot in the past years. They try to avoid keeping stock and time as a buffer. One of the goals of the 21st century is to have a slim production. However, this increases the risk. Incidences that were no problem in the past system can lead to big consequences in a slim/lean production. To avoid troubles efficient incident management is a major game player in the economic global competition.[104]

The problem is that sometimes small things or disturbances, like a missing screw are worth less than a euro, can have unforeseeable effects like a total stop of an assembly line. New production systems are so complex and nonlinear that this is becoming a huge problem.[105] In other words, the flapping of a butterfly in the Amazonas rainforest can trigger a hurricane in Europe. This is what the theory of the butterfly effect says.[106] Every single influence can be responsible for an incident. One of the goals of incident management is to monitor influence factors, detect them and get a quick response. This helps to reduce the effects. MES are supporting this process.[107] On average 25% of a company's revenue is the mistake costs[108]. Thereout it can be seen how high the potential for companies is.

The high variance and quantity of self-made and external incidents makes it too difficult. In Figure 11, the influence factors are shown. Every single factor can be the reason why there is a disruption in the production system. Also, combinations of defects are possible. The target of incident management is to monitor all the influence factors in real time to be able to react to occurring disturbances as fast as possible.[109]

[104] cf. Brehm/Aksoy/Wellbrock (2017), P. 1-4.
[105] cf. Schumacher (2009), P. 206-209.
[106] cf. Lorenz (1963), P. 130-141.
[107] cf. Schumacher (2009), P. 206-209.
[108] cf. Rehbehn/Yurdakul (2003), P. n.p…
[109] cf. Schumacher (2009), P. 206-209.

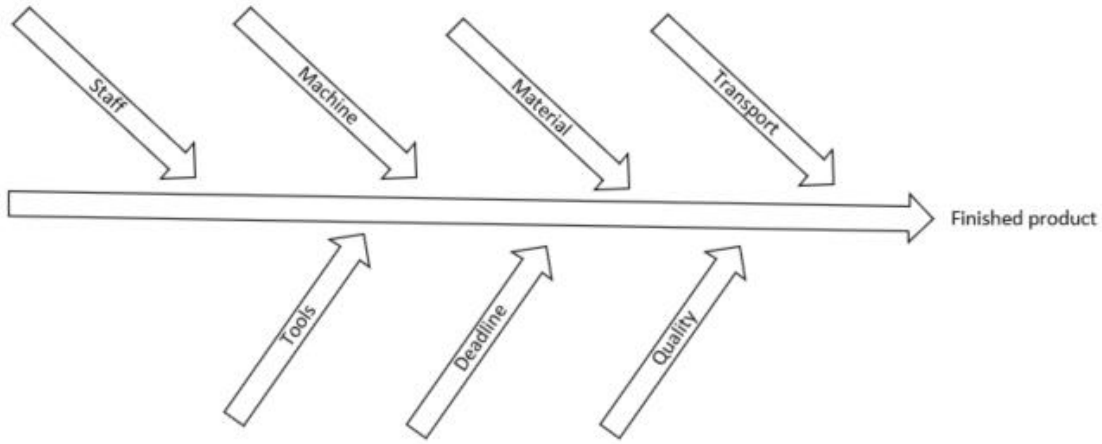

Figure 11: Influence factors on the production process, Source: Schumacher (2009), P. 206-209.

The companies MES is collecting the important process data of the production process. This offers the needed transparency for a working incident management. Several data from the MES can be used.

The next points show some examples: [110]

- Appointments and work progress
- Status of the machines
- Tool data
- Material information
- Personal attendance
- Quality data
- Process data

Without this data from the MES, the whole incident management would rely on workers feedback. In this case, it often takes long until the problem is solved, and high avoidable costs appeared. For the visualisation, the MES is offering tools that can be used to build up a virtual machine park. The user can immediately understand what the status of different components is. Another step for the information flow can be made when an escalation management is integrated into the MES and incident management system. With this, the information flow can be designed individually.

[110] cf. Schumacher (2009), P. 206-209.

Another benefit is that the needed information is automatically sent to the right person. This decreases the time between the occurrence of the incident to the point when someone is taking care of the problem. The notification can be delivered by a text message, E-mail or a specialised application. The MES can also be used to find correlations between differences that lead to an interruption of the process. For example, if machine x is using tool y it can be recognized with the recorded data that the chance for an incident is high. With this knowledge, a person can look deeper into this problem to solve it in a long-term way.[111]

2.8.2. Workers information system

The modern customer needs demand very high responsiveness. To achieve this a worker-oriented production with the customer as a creative performer is an advantage. Production sites have the challenge to adapt very quickly to changes in the production. Those are results out of the global competition and the increasing of the customer needs. Most of the products need customer specific adaptions which makes the process more complex. In the past the solution for everything was automatisation. However, a higher grade of automatisation results in a reduction in flexibility. To become a competitive product, it is more important to design a worker orientated production. This results in higher flexibility and efficiency.[112] Currently paper-based workshop drawings are used for communication in a company. Since IT found the way into the engineering process.[113] This also made its way into the production but to provide the workers with paper-based information brings some drawbacks. The IT-based substitute is called WIS and should minimize the problems that arise from the paper-based system and support the workers in manufacturing systems.[114]

To achieve this an optimal information system is very important because without this even the best educated, and skilled workers cannot provide efficient and qualitative work. Therefore, in an employee-oriented production, the supply of the information is a central and very important task. Employee information systems exist to connect the information- and knowledge engineering and provide the information at the right time

[111] cf. Schumacher (2009), P. 206-209.
[112] cf. Lušić et al. (2016), P. 1113-1118, cf. Dombrowski/Wesmann/Korn (2010), P. 282-287.
[113] cf. Spur/Krause (1997), P. n.p…
[114] cf. Lušić et al. (2013), P. 1113-1118.

on the right spot for the right job. Mostly it is divided into a hardcopy or IT-based WIS.[115]

This information can be delivered in different forms of communication:

- In oral form,
- as a graphic display,
- a video or
- a mixture of the three above.

The range of a WIS system is limited to the explanation of the tasks that must be done, no further information is displayed. Figure 12 shows a sample for the process structure in a production plant. Main processes are leadership- and support processes. Part processes are separating each main process into the part-processes that are needed. Those get split up into several activity steps which explain exactly every job and task.[116]

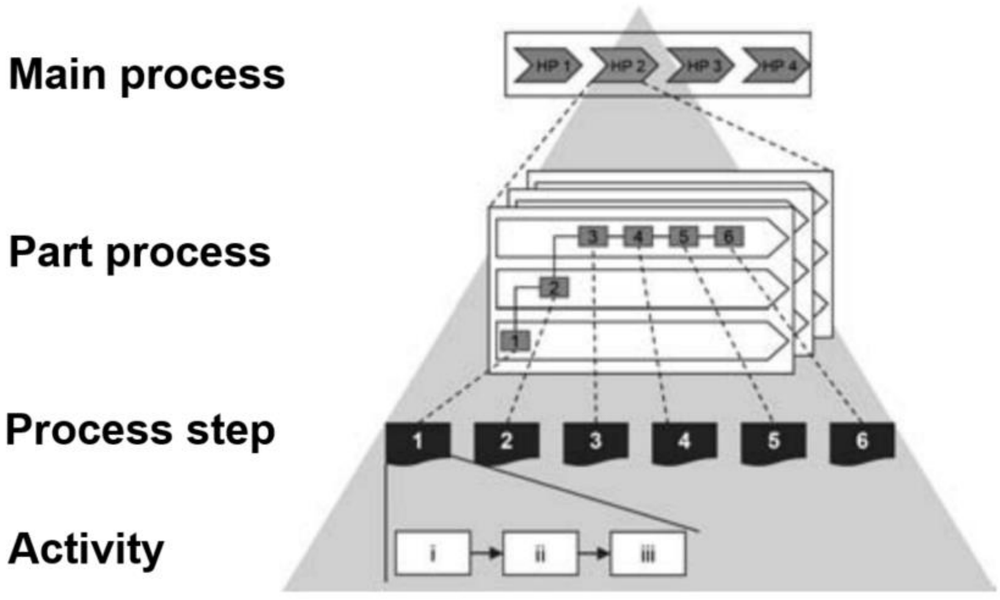

Figure 12: Process structure of a production, Source: Dombrowski/Wesmann/Korn (2010), P. 283.

[115] cf. Dombrowski/Wesmann/Korn (2010), P. 282-287.
[116] cf. Dombrowski/Wesmann/Korn (2010), P. 282-287.

When designing a WIS one of the main things that must be monitored is the workers needs to select the right WIS. It is necessary to look at the WIS from different perspectives because it could vary from one to the other process or user.[117]

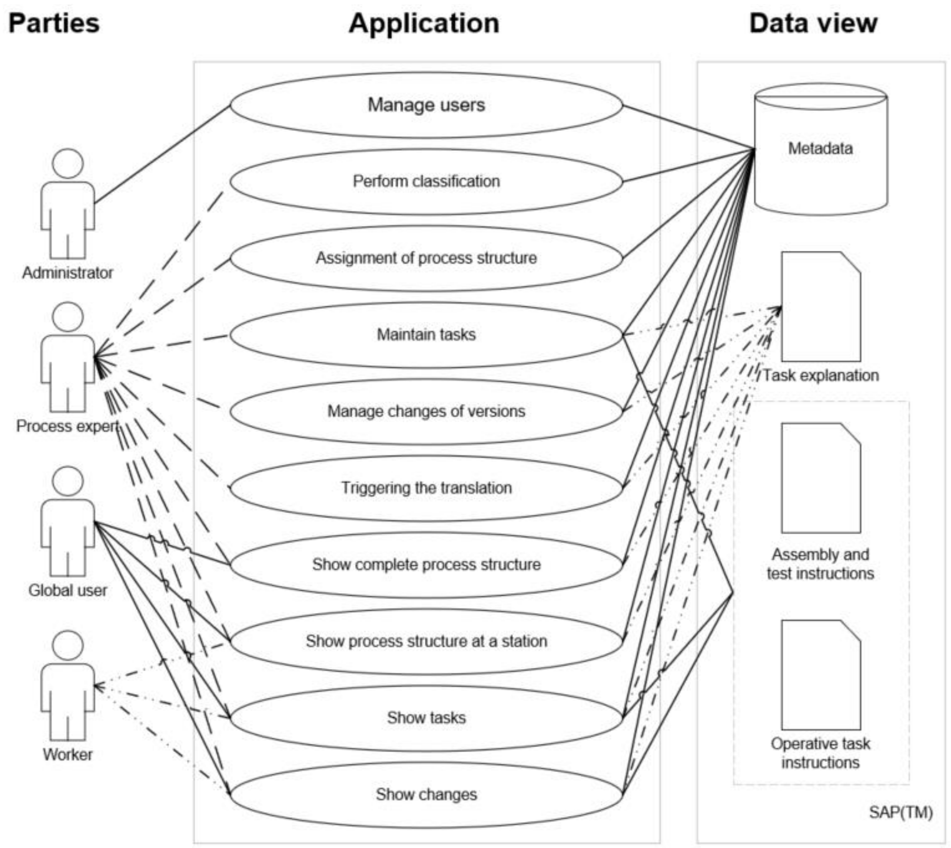

Figure 13: Application case diagram, Source: Gustafsson (2002), P. 285.

Figure 13 shows a diagram that is often used to specify the needs of the planned system. It shows the involved people, their dependence and their connections. All of them interact with different applications of the system and the data is saved in an ERP system. If a user, for example, makes a task explanation and saves it in the ERP, the worker can get the information from the ERP system. The process expert designs the WIS and is responsible for maintaining the data. The worker is the main recipient. The global user is getting an overview of the whole process structure to see if he can train the workers especially for a task where often incidents occur.[118]

[117] cf. Gustafsson (2002), P. 147-154.
[118] cf. Dombrowski/Wesmann/Korn (2010), P. 282-287.

3. MES Benchmark

Predix MES, SAP Manufacturing Execution, Manufacturing Operations Centre Siemens and HYDRA MES are used for the benchmark because they are all in use in big industrial companies and partly developed by industrial companies with their own software division like Siemens and Genereal Electrics. To have a reverence about the ability of an open source MES software compared to the paid software Qcadoo also participates in the benchmark. To see what the best fitting MES solution for Siemens is a benefit analyse is done.

For the Benchmark benefit analyses and a criterion, weighting is implemented. This gives an overview of which MES system is the best fitting.

3.1. MES Software

Predix MES:

Predix MES suite is a tool developed by GE. Predix MES consists out of four different independent main tools that have different sub tools:

- **Plant Applications** is a tool for highly automated and fast-moving processes. It helps to collect and analyse data and helps to optimise the production process. This tool is used for example for Food and Beverage and Consumer Packaged Goods. The sub-tools are the **Efficient management** (for monitoring critical key performance indicators like downtime, waste, time between failure and mean time to repair), the **Quality management** (to ensure consistent quality in the production with real-time trends, statistics and notifications), the **Production management** (supports the full trackability of products through the production steps of the process, controls the production flow and reduces excess inventory) and the **Batch analysis** (analyses your existing and optimises your production batch).[119]
- **Predix Manufacturing Data Cloud** is a solution to bring the enterprise-wide data into a cloud that connects the whole enterprise. With this data analytics that is not only plantwide but also enterprise-wide can be made. It helps to keep critical data together and available.[120]

[119] cf. Online: General Electric (2017A) [State: 20.04.2019].
[120] cf. Online: General Electric (2018) [State: 20.04.2019].

- **Production Manager** Is a MES tool built for discrete manufacturing environment. The complete digitalisation of paper-based processes is possible with drawings, work instructions, BOMs and so on. This the tool that GE is using across its manufacturing business and is comparable to SIMATIC IT UADM.[121]
- **Tracker** is an advanced order tracking and execution management tool. It helps to cut costs by monitoring and managing the execution of production orders by collecting data from different sensors in the production. It also shows the specific process data like the status of products location and so on.[122]

SAP Manufacturing Execution (SAP ME):

SAP ME is a software for operating the shop floor and can control/ monitor and configure all the ongoing activities[123]. It is a tool that meets the requirements in discrete manufacturing and offers all the features of a modern MES with several functionalities[124].

The different functionalities are listed below:[125]

- ERP Shop Floor Integration
- Traceability
- Non-conformance Management
- Labour Tracking
- Production Transfer
- Production KPIs
- Engineering Change Management
- Visual Enterprise Integration
- Test and Repair
- Return and Repair
- Real-time SPC (Statistical Process Control)
- Machine Integration Layer

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[121] cf. Online: General Electric (2017B) [State: 20.04.2019].
[122] cf. Online: General Electric (2018) [State: 20.04.1019].
[123] cf. Online: STechies [State: 17.04.2019].
[124] cf. Online: IGZ [State: 17.04.2019].
[125] cf. Eric Thieren (2016), P. n.p.

The integration in the SAP ERP system is preconfigured and works without additional expense[126].

Manufacturing Operations Centre Siemens:

Siemens PLM provides with Manufacturing Operations Centre a software platform that provides different Manufacturing Operations Management applications for digitalisation in production companies. The different tools enable the customer to choose a specific product. The different products provide solutions for specific tasks or industry sectors. Below a short overview of the different products is given.

- **Camstar Medical Device Suite** is a software package that is specially designed for companies that work with the production of medical devices. It provides the necessary tools for the trackability of the products, paperless production, accelerates the innovation and reduces costs.[127]
- **Camstar Semiconductor Suite** is designed for frontend and backend semiconductor production. It offers all the standard MES applications like maintenance operations management, material tracking, process management and more.[128]
- **QMS Professional** is a quality management software that helps to optimise quality, reduce defects by increasing the process stability. The integrated analytics make it possible to detect errors quickly and reduce the risk to a high number of faulty parts or shipment of nonconforming material. It supports the availability to fulfil international quality standards like the DIN EN ISO 9000.[129]
- **SIMATIC IT eBR** is a MES solution specially designed for the needs of the pharmaceutical industry. It provides all the necessary MES tools like electronic batch recording or paperless production.[130]
- **Preactor APS** is a collection of production planning and scheduling software products that support the production planning to optimize it.[131]

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[126] cf. Online: IGZ [State: 17.04.2019].
[127] cf. Online: Siemens PLM (2019B) [State: 15.04.2019].
[128] cf. Online: Siemens PLM (2019C) [State: 15.04.2019].
[129] cf. Online: Siemens PLM (2019F) [State: 15.04.2019].
[130] cf. Online: Siemens PLM (2019G) [State: 15.04.2019].
[131] cf. Online: Siemens PLM (2019E) [State: 15.04.2019].

- **SIMATIC IT R&D Suite** helps companies to exploit their full R&D potential to develop products faster. It also supports the design of a more efficient and streamline product development process.[132]
- **Manufacturing Intelligence** connects manufacturing data and provides it in a sorted an easy to understand way. Out of the different operation data from the production it calculates the KPIs needed to monitor the process. Manufacturing Intelligence gives the operator a big picture of the production site and allows to spot weak points and trends.[133]
- **SIMATIC IT Unified Architecture Process Industries** is a MES system specially designed for the process industries.[134]
- **Camstar Electronic Suite** provides a fully digital manufacturing solution for the electronics industry. It brings tools through the whole value chain.[135]
- **SIMATIC IT Unified Architecture Discrete Manufacturing** is the MES Tool that is shaped to fulfil the needs of industries that handle products limited volume high complexity and high variance. It provides a powerful tool to ensure greater process flexibility and efficiency. Combined with the ERP it forms a big part of the manufacturing technology.[136]

HYDRA MES:

HYDRA MES is a modular system that offers different applications to build the best fitting MES system for any user. It offers several different applications in the area of quality management, human resources and manufacturing control. The following list explains the different applications: [137]

- **Shop Floor Data** is a tool that can be used to collect all the shop floor data. This data is, for example, the progress and delay of orders. The different measurements are analysed and can be used for controlling the shop floor.
- **Machine Data** brings transparency and efficiency in the company's machine park. It monitors the machines shows the performance in real time and increases availability.

[132] cf. Online: Siemens PLM (2019H) [State: 15.04.2019].
[133] cf. Online: Siemens PLM (2019D) [State: 15.04.2019].
[134] cf. Online: Siemens PLM (1019) [State: 15.04.2019].
[135] cf. Online: Siemens PLM (2019A) [State: 15.04.2019].
[136] cf. Online: Siemens PLM (2019I) [State: 15.04.2019].
[137] cf. Online: mpdv (2019) [State: 18.04.2019].

- **Shop Floor Scheduling & Detailed Planning** is a tool used for production control. This tool transfers orders from the ERP system, can create Gannt chats and orders based on real-time data.
- **Tool and Resource Management** supports the company with the precise planning of maintenance of the tools and machines. It offers a digital tool and resources management.
- **Material and Production Logistics** offers control and monitoring of the material flow in the production. It can be used for material availability planning.
- **DNC & Configuration** is used for NC programmes and setup data of machines. The data is automatically up- and downloaded and offers an integrated NC editor with online plausibility check.
- **Energy Management** evaluates the energy consumption and detects energy waste. It leads to a reduction in the production costs.
- **Process Data** is the application that monitors process values and detects the trends. Tolerances and limits can be adjusted by the user of the application to customise it to the company's needs.
- **Track & Tracing** offers reliable logging of all steps in the manufacturing process to enable overall traceability.
- **Dynamic Manufacturing Control** is a tool to model, control and monitor a multi-variant production process. This application has several functions like connection and controlling of production lines. The connection and visualisation and documentation of real-time data. It can be also used to define quality inspections and rework loops.
- **In-Production Inspection** is used for order-oriented inspections and operator self-inspection of parts in the production. The intervals can be set individually on real-time data.
- **Incoming Goods Inspection** is a tool that supports the incoming goods department with the checking of the goods that arrive from suppliers.
- **Complaint Management** automatically processes and analyses complaints that can occur external or internal with the resulting costs.
- **Test Equipment Management** manages the test equipment of the company and tells the operator which equipment must be used for a specific task.
- **FMEA** (Failure Modes and Effect Analyses) is a tool that creates, manages and analyses FMEAs.
- **Time & Attendance** offers a digital punch card for the workers.

- **Personnel Scheduling** provides the worker with the right qualification at the right place at the right time.

These are the most important applications of HYDRA MES. There are some more but they are about access control to areas and about the payment and for this study they are not relevant. HYDRA MES offers a standard integration into SAP.

Qcadoo:

Qcadoo is a MES that also has an Open Source version. The systems are an internet application for production management and is designed for small and medium-sized companies. The software offers different preconfigured implementation into selected ERP systems. Those ERP systems are Subject GT, Comarch ERP Optima, CDN XL and enova. Qcadoo MES offers several different functions to handle different tasks.[138]

The different functions will be explained below:

- **Manufacturing orders** is a tool that handles all the planning of the production. A manufacturing plan can be set up and uses all the additional information's like shift times and available workers to design an optimal production. This information results in standard work orders that can be customised for several different products. Those customised work orders are called master orders. In the end, the software creates work instructions that show exactly the operations to accomplish the task.[139]
- **Material requirement** enables to have control over the raw, required and used materials in the productions. This tool supports the operator with the material requirement planning to have the needed material at the right time on the right spot. The needed information to plan this comes from the manufacturing orders tool. Additional it monitors the available stock by adding up the incoming goods and subtracting the goods that are required by the work orders. If material runs out a request can be filled out. This is automatically saved into a list for purchase orders that can be directly used to order material at the suppliers. The already ordered material is listed in a separate table where the operator can see the status of the different deliveries.[140]

[138] cf. Online: qcadoo (2019H) [State: 22.04.2019].
[139] cf. Online: qcadoo (2019B) [State: 22.04.2019].
[140] cf. Online: qcadoo (2019C) [State: 22.04.2019].

- **Purchasing management** is a tool that supports the company with the order of material. It handles the vendors with their details and the material that is normally ordered. The generated Request for Quotation can be sent automatically to the vendors. The orders are automatically listed in a scheduled delivery list where the status can be seen. As an extra benefit, the tool offers an automatic best offer order. It looks at all listed suppliers who offers the best price and orders at this vendor.[141]
- **Subcontracting your services** provides help with subcontractors. It lists all the subcontractors of the company and their field of action. If a part is outsourced the tool shares the technical information and drawings directly to the contractor and monitors the work in progress at the subcontractor. This is then reported in a list where all the outsource parts are listed, this makes it easy to keep track. The use of this tool is a benefit for both sides the contractor gets all the information about the job and the company gets information about the progress.[142]
- **Product genealogy** shows the parts that are used to fabricate one product. This has several benefits one of those is if there are any reclamation of material this can be used to find the products where this part is used, which makes is less affording to replace or repair. The usage of this tool enables a full trackability of every part in the production.[143]
- **Plan manufacturing orders** will help to plan the production orders with considering the technology, time consumption, performance of machines, production lines, and several other aspects. The operator of the software plans the operation of the machines on a graphical planning interface that shows all the different machines and the tasks on every machine. The tool offers specific functions that helps the operator to plan the work orders in a maximum efficient way or to figure out the optimal batch size for large volume costumers. The actual progress of the production is shown in a chart and the actual consumption of raw material is shown in a table with colour specific marking. With this information, it is easy to keep track of the production.[144]
- **Calculations** is the tool that supports the company with the calculation of the price of a product. All relevant finance data like employee wages, cost of material,

[141] cf. Online: qcadoo (2019G) [State: 22.04.2019].
[142] cf. Online: qcadoo (2019J) [State: 22.04.2019].
[143] cf. Online: qcadoo (2019E) [State: 22.04.2019].
[144] cf. Online: qcadoo (2019D) [State: 22.04.2019].

machine costs, time, and additional margins are listed in the tool which then gives accurate pricing for each order.[145]

- **Production accounting** gives knowledge about the actual costs in the production. It allows seeing which order brings profit, and which generates a loss.[146]
- **Register production** offers the possibility to keep track of the production by the registration of different production steps. This production steps can be defined in the tool. For the registration, the workers get a barcode scanner for the different production steps. The tool knows the progress of the orders.[147]
- **Technology** is a combination of a BOM with the production schedule. The combination of a detailed list of all raw material required to manufacture of a given product an all task that must be performed makes a successful operation possible.[148]
- **Warehouse management** is there to achieve full control over the warehouse stock, supplies and shortages of the production. The documents are automatically generated by the system and the information generated in the other tools. In several tables, the operator can see all necessary information about the warehouse logistic and the stock.[149]

3.2. MES product rating

In the following tables in this chapter, the different MES systems will be rated with different criteria. Those are chosen because of relevance for the integration and use of a MES in the existing production and IT infrastructure of Siemens Mobility Graz.

The following bulleted lists will explain the differences in the options for each evaluation criteria.

Software tools available:

Shows the adaptability of the MES to the customer's needs. A high adaptivity increases the value for the customer because getting an additional software tool if

[145] cf. Online: qcadoo (2019A) [State: 22.04.2019].
[146] cf. Online: qcadoo (2019F) [State: 22.04.2019].
[147] cf. Online: qcadoo (2019I) [State: 22.04.2019].
[148] cf. Online: qcadoo (2019K) [State: 22.04.2019].
[149] cf. Online: qcadoo (2019L) [State: 22.04.2019].

there is one needed in the company is easy. The more specific the software can be designed, results in a higher rating.

- **Only one specific software:** The software firm offers just one software without any chance of adaptability. If the software brings one function not it is not available for the customer.
- **Software packages:** The software provider offers several different MES software that are specific for the industry the company is working in. This software offers the needed tools. There is no further adaption of the software to the customer's needs.
- **Base Software + APPs:** It is a basic software for every customer that can be adapted to the needs by adding applications for special tasks to the base software.
- **Several independent APPs:** The customer can choose from a high variance of different applications to build the MES that meets the needs perfectly.
- **Open source:** Open source offers the most benefits for the customer because the whole system can be used for free and an additional software can customarily be programmed. Therefore, it is rated with 5 points.

User-Interface:

The section User-Interface rates the way how the worker operates the system that provides information about the job at the workplace. It is important that it is as simple and intuitive as possible. Another important aspect is that it is easy to clean and should provide a touch interface. Therefore, a keyboard is rated with only one point and a multitouch is rated with five points.

Display of work instructions:

This section rates the presentation of the work instructions the worker at the production line gets. The more explicit it is, the better. A description that is just a text is rated with fewer points than a screen with text and picture.

- **None:** Means that the MES system offers no work instructions display function.
- **Text:** The work instruction is shown as a text document on the screen.
- **Picture:** The worker gets his information in the form of a picture.

- **Text + Picture:** The MES system combines the benefits of both formats so that the worker gets a very accurate description.
- **User-defined:** The user of the software can choose what the best format to present the information is.

External software implementation:

- **Not possible:** The software offers no interface to connect it to other tools or software. This brings a big downside for the company because the integration of existing software is not possible.
- **Only software from provider:** The software that can be implemented must form the same provider than the MES software.
- **One interface:** The MES software offers one interface that can be used to implement different software tools from other providers.
- **Multiple interfaces:** The integration of other software can be handled with the use of several different interfaces. This brings wider usability of the software.
- **Open source:** The open source software makes it possible to integrate every software into the MES. To achieve this sometimes a higher effort must be calculated. On the other hand, if an Opens source software is popular several other Open source applications can be used that have already a preconfigured interface to the Open source MES software.

Requirements for ERP integration:

If an ERP system exists in a company the MES system must be integrated into it. The connectivity of the MES and the ERP system and the afford is rated by this. The higher the afford to integrate the MES into the ERP is, the less points are given.

- **A complete system of one provider:** The MES and the ERP system must be from one provider to work together.
- **Self-Programmable:** The interface needs to be programmed by the user.
- **Additional Interface:** To enable an integration of the MES in the ERP system a specially designed integration software is needed.
- **To selected ERP systems:** The MES offers already out of the box preconfigured integration to some ERP systems. The ones that are not integrated need an additional integration software.
- **Standalone:** The MES system works without the connection to an ERP system.

Operating system:

This rating shows the needed operating system of the provider. The more systems the MES supports the more points are given.

- **1-4 Systems:** The MES can be operated on 1, 2, 3 or 4 OS.
- **Universal:** The MES can be run on several OS that are common on the market.

Support:

The support, the software developer provides is another factor for the decision of a software. If the system is not working or there are any issues with the handling of the software a fast and reliable support is needed.

- **No Support:** The software provider offers no support at all. This means that there is no contact person for the company in case of a breakdown or questions.
- **Periodical paid support:** To get support for the software from the developer the user company must pay for the service for a defined period.
- **One time paid for support:** The user must pay one time a fee to get support for the use period of the software.
- **Free support for a period:** The software supplier offers free support for a defined time after this the customer must pay to have further support.
- **Free support:** The software company offers free support for the life of the software.

Predix MES:

Table 4: Evaluation table Predix MES, Source: Own representation.

Criteria / Points	1	2	3	4	5
Software tools available	Only one specific software	Software packages	Base Software + APPs	Several independent APPs	Open source
	o	x	o	o	o
User-Interface	Keyboard	Keyboard + Mouse	Touch Pen	Single touch	Multitouch
	o	o	o	o	x
Display of work instructions	None	Text	Picture	Text + Picture	User defined
	o	o	o	x	o
External software implementation	Not possible	Only software from provider	One interface	Multiple interfaces	Open source
	o	o	o	x	o
Requirements for ERP integration	A complete system of one provider	Self-programmable	Additional Interface	To selected ERP systems	Standalone
	o	o	x	o	o
Operating system	One system	Two systems	Three systems	Four systems	Universal
	x	o	o	o	o
Support	No Support	Periodical paid support	One time paid for support	Free support for a period	Free Support
	o	x	o	o	o

SAP Manufacturing Execution:

Table 5: Evaluation table SAP Manufacturing Execution, Source: Own representation.

Criteria / Points	1	2	3	4	5
Software tools available	Only one specific software	Software packages	Base Software + APPs	Several independen t APPs	Open source
	x	o	o	o	o
User-Interface	Keyboard	Keyboard + Mouse	Touch Pen	Single touch	Multitouch
	o	o	o	x	o
Display of work instructions	None	Text	Picture	Text + Picture	User defined
	o	o	o	x	o
External software implementation	Not possible	Only software from provider	One interface	Multiple interfaces	Open source
	o	o	0	x	o
Requirements for ERP integration	A complete system of one provider	Self-programmabl e	Additional Interface	To selected ERP systems	Standalone
	x	o	o	o	o
Operating system	One system	Two systems	Three systems	Four systems	Universal
	x	o	o	o	o
Support	No Support	Periodical paid support	One time paid for support	Free support for a period	Free Support
	o	x	o	o	o

Manufacturing Operations Centre Siemens:

Table 6: Evaluation table Manufacturing Operations Centre Siemens, Source: Own representation.

Criteria / Points	1	2	3	4	5
Software tools available	Only one specific software	Software packages	Base Software + APPs	Several independent APPs	Open source
	o	x	o	o	o
User-Interface	Keyboard	Keyboard + Mouse	Touch Pen	Single touch	Multitouch
	o	o	o	o	x
Display of work instructions	None	Text	Picture	Text + Picture	User defined
	o	o	o	x	o
External software implementation	Not possible	Only software from provider	One interface	Multiple interfaces	Open source
	o	o	0	x	o
Requirements for ERP integration	A complete system of one provider	Self-programmable	Additional Interface	To selected ERP systems	Standalone
	o	o	x	o	o
Operating system	One system	Two systems	Three systems	Four systems	Universal
	x	o	o	o	o
Support	No Support	Periodical paid support	One time paid for support	Free support for a period	Free Support
	o	o	o	o	x

HYDRA MES:

Table 7: Evaluation table HYDRA MES Source: Own representation.

Criteria / Points	1	2	3	4	5
Software tools available	Only one specific software	Software packages	Base Software + APPs	Several independent APPs	Open source
	o	o	o	x	o
User-Interface	Keyboard	Keyboard + Mouse	Touch Pen	Single touch	Multitouch
	o	o	o	o	x
Display of work instructions	None	Text	Picture	Text + Picture	User defined
	o	o	o	x	o
External software implementation	Not possible	Only software from provider	One interface	Multiple interfaces	Open source
	o	o	0	x	o
Requirements for ERP integration	A complete system of one provider	Self-programmable	Additional Interface	To selected ERP systems	Standalone
	o	o	o	x	o
Operating system	One system	Two systems	Three systems	Four systems	Universal
	x	o	o	o	o
Support	No Support	Periodical paid support	One time paid for support	Free support for a period	Free Support
	o	o	o	o	x

Qcadoo:

Table 8: Evaluation table Qcadoo, Source: Own representation.

Criteria / Points	1	2	3	4	5
Software tools available	Only one specific software	Software packages	Base Software + APPs	Several independent APPs	Open source
	o	o	o	o	x
User-Interface	Keyboard	Keyboard + Mouse	Touch Pen	Single touch	Multitouch
	o	x	o	o	o
Display of work instructions	None	Text	Picture	Text + Picture	User defined
	o	x	o	o	o
External software implementation	Not possible	Only software from provider	One interface	Multiple interfaces	Open source
	o	o	o	o	x
Requirements for ERP integration	A complete system of one provider	Self-programmable	Additional Interface	To selected ERP systems	Standalone
	o	o	o	x	o
Operating system	One system	Two systems	Three systems	Four systems	Universal
	0	o	x	o	o
Support	No Support	Periodical paid support	One time paid for support	Free support for a period	Free Support
	x	o	o	o	o

3.3. Benefit analyses

The benefit analyses and the criteria rating are done referred to "Handbuch Fabrickplanung"[150].

To get a significant rating of the different criteria four employees that are involved in the digitalisation at Siemens Graz filled out a pair to pair comparison of the different criteria. This pair to pair comparison is shown in Table 9. The person who rates always compares the horizontal line with the vertical line. The points that can be given are:

- 0 for not as important as
- 1 equally important
- 2 more important than

Table 9: Pair to pair comparison evaluation, Source: Wiendahl/Reichardt/Nyhuis (2014), P. 485-503.

	Software tools available	Support	User-Interface	Display of work instructions	External software integration	Requirements for ERP integration	Operating system
Software tools available	0.0						
Support		0.0					
User-Interface			0.0				
Display of work instructions				0.0			
External software integration					0.0		
Requirements for ERP integration						0.0	
Operating system							0.0

For example, if software tools availability is more important than support, 2 must be written in the box with the oval shaped marking.

[150] cf. Wiendahl/Reichardt/Nyhuis (2014), P. 485-503.

To get average importance of the different criteria the individual ratings of each comparison are summed up and divided through the number of people that filled out a pair to pair comparison sheet. The result of the pair to pair comparison can be seen in Table 10. The weighting for every single criterion is calculated. This is a value in percent that is then multiplied with the points given in chapter 3.2 for each criterion in the tables of each MES software. By summing up the final points at the end, the most suitable software is the one with the most points.

Because the system, explained in chapter 15 “Synergetische Fabrickplanung” of the book “Handbuch Fabrickplanung”[151] does not work accurately with the decimal values that shows up because of calculation the average another way to calculate the percentual rating of the criteria is decided. This is explained on Sixsigmablackbelt [152].

Table 10: Pair to pair comparison, Source: Own representation.

	Software tools available	Support	User-Interface	Display of work instructions	External software integration	Requirements for ERP integration	Operating system	Sum	Priority [%]
Software tools available	0.00	1.50	0.75	0.75	0.75	0.75	1.00	5.50	13.10
Support	0.50	0.00	0.25	0.25	0.75	1.25	2.00	5.00	11.90
User-Interface	1.25	1.75	0.00	0.50	1.75	1.75	2.00	9.00	21.43
Display of work instructions	1.25	1.75	1.50	0.00	1.50	1.75	1.50	9.25	22.02
External software integration	1.25	1.25	0.25	0.50	0.00	1.00	1.50	5.75	13.69
Requirements for ERP integration	1.25	0.75	0.25	0.25	1.00	0.00	1.50	5.00	11.90
Operating system	1.00	0.00	0.00	0.50	0.50	0.50	0.00	2.50	5.95

[151] cf. Wiendahl/Reichardt/Nyhuis (2014).
[152] cf. Online: Roland Schnurr (2013) [State: 26.04.2019].

Table 11: Ranking MES systems, Source: Own representation.

	Relevance[%]	Predix MES	Satisfactory value	SAP Manufacturing Execution	Satisfactory value	Manufacturing Operations Center Siemens	Satisfactory value	HYDRA MES	Satisfactory value	Qcadoo	Satisfactory value
Software tools available	13.1	2	26.2	1	13.1	2	26.2	4	52.4	5	65.5
Support	11.9	2	23.8	2	23.8	5	59.5	5	59.5	1	11.9
User-Interface	21.4	5	107.1	4	85.7	5	107.1	5	107.1	2	42.9
Display of work instructions	22.0	4	88.1	4	88.1	4	88.1	4	88.1	2	44.0
External software integration	13.7	4	54.8	4	54.8	4	54.8	4	54.8	5	68.5
Requirements for ERP integration	11.9	3	35.7	1	11.9	3	35.7	4	47.6	4	47.6
Operating system	6.0	1	6.0	1	6.0	1	6.0	1	6.0	3	17.9
SUM			**341.7**		**283.3**		**377.4**		**415.5**		**298.2**
Ranking			**3**		**5**		**2**		**1**		**4**

The rating in Table 11 shows that the MES that fulfils the needs best is HADRA MES followed by Manufacturing Operations Centre Siemens and Predix MES.

3.4. Conclusion

This benefit analysis shows that the different suppliers of MES on the market follow individual ideas about the software they want to provide. This leads to a big variety on the market and enables the customer to choose the most suited.

Following to the Benefit analyses, the implemented MES should be HYDRA MES. This system meets the exceptions of the team the most. After several discussions about the system, the management made the decision to use a Siemens software in a Siemens production site. The goal of the management is to realize a light house plant in the Siemens group. To achieve this, the software used for the digitalization of the company should also be provided by the Siemens software department Siemens PLM. This is the main reason why the choice fell to the Manufacturing Operations Centre Siemens.

4. Current challenge in the production

This chapter is explaining the issues the company faces because of the way how data and communication are handled and the planned way of digitalization at the moment.

It is necessary to analyse the current state to discover the areas for successful future improvements. The focus lays on the incident communication between the shop floor worker and the organisational plane, the machine operation in shifts and the way how the worker receives information.

To understand the following explanations a short insight is given about the employee structure. The structure is not completely the same in every department of the factory but altogether the differences are not decisive for the structure.

The foundation of the production is formed by the blue colour workers who work in the different workshops like assembly, paint shop, machine shop and welding shop. Those are subjected to a team leader which has several projects to handle. One supervisor is responsible for all the activities of the team leaders and blue colour workers in one subdivision of the departments. The different supervisors of one department are subjected to a department manager which is directly subordinated to the production manager. All of them are directed by the plant manager.

This step to modernise those systems came up to be able to handle the high number of bogie orders that must be built in the future in Graz. The main project is the cycle

assembly called Cycle Assembly 2.0 which also includes the topic of the digitalisation of the communication channels and the development of a multi-machine operation software.

4.1. Cycle Assembly 2.0

Nowadays the assembly of bogies is already partly using the cycle system. Different projects like metros and trains are separated on different cycle lines. Projects that are very similar to each other get assembled in the same production line like for example if they use almost the same frame. The cycle steps depend on the projects that are assembled in the different lines and reach from two to four steps. The cycle time is set to the customer specific order so that the bogies get delivered to the builder of the wagon at the right time.

Cycle Assembly 2.0 is the name for a project that changes the bogie assembly completely. It is one assembly line with six stations (cycle steps) that are spread along one complete side of the building. The new production layout enables to assemble most of the produced bogies in one single line. There are several points that must be considered in the process of the redesign. Some of those points are the supply with A, B and C parts by the logistics, the training of the workers so that they can handle the higher variation of products. Another aspect is the way how blue colour workers receive and pass on the information. Due to the high number of different projects in the production line, the information for the assembly (assembly drawings and BOMs) must be delivered to the right station at the right time that the workforce gets the information about the production. This is possible by a modernised application-based system. Paper-based worker information will not lead to success in the future and needs too much capacity of the team leaders to keep them updated.

Another important modernisation that helps to make the process of assembly more efficient by changing the surroundings is the integration of digitalised incident management.

Those two systems will support the workman in the new cycle assembly in the future because they are the foundation for a successful working Cycle Assembly 2.0 (T2.0) line and the future growth of the bogie production in Graz.

4.2. Current incident management

In the next few pages, the current incident management system is described.

Most of the time the information is not passed on in the fastest way. A delay of the process occurs by the information transfer between several persons within the production. This slows down the information process or the information about incidents get lost.

The most common way how incidents are passed forward from the sending to the receiving person is a simple but not always effective process.

If an incident in the production occurs the responsible worker for this job must decide the urgency of the problem. In some cases, the worker waits until the team leader or supervisor comes by and passes on the information about the issue.

If the issue leads to a stop of the production line the worker walks to the supervisors and team leader office and reports the trouble. The following steps are the same for urgent and less urgent incidents. The team leader or supervisor informs the responsible person to take care of the issue. This person solves it or is responsible that someone is solving the issue. This system of passing on the information from one person to the next until the right person has been reached is sometimes slow and leads to mistakes. Important details can get lost on the information flow from A to B. Another struggle with this system is that some persons do not feel responsible for a task or the importance, so they do not solve the problem as fast as possible.

The basic information flow that was designed during a workshop held with several different experts, can be seen in Figure 14. It shows the explained system, how most incidents are handled without looking at the rare exceptions. This was limited to the bogie assembly because the new Call System will start in this production area.

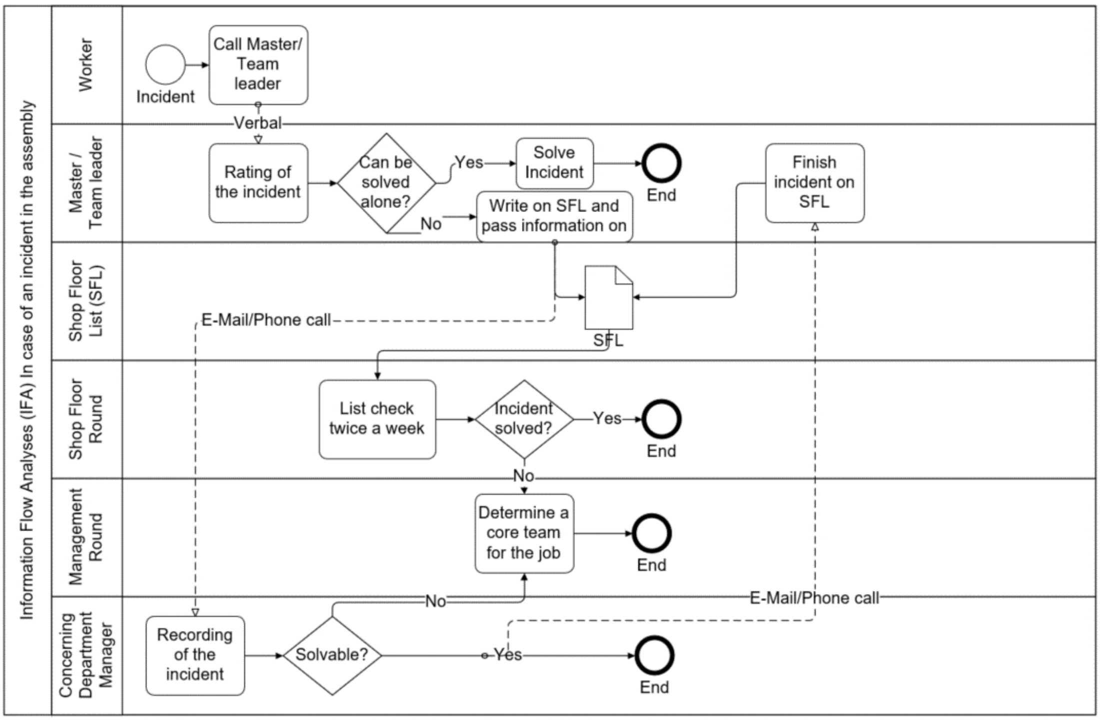

Figure 14: IFA incident in bogie assembly, Source: Own representation.

Some other tools are also in use for transferring information to other levels like the shop floor management that takes place three times a week and hosts all the important persons of the process relevant departments. Another tool for the improvement in the production is a CIP made by CIP practitioners. Those use tables where all the problems and improvements are collected and can systematically be solved. The use of those tools as a form of incident management will be explained in the following paragraphs. The shop floor management is a very important tool and has wide use in the production shops now. The shop floor meeting is held three times a week. The place for the meeting is always next to a glass wall where all the important information is listed. The workers are represented in this meeting by the team leaders and the fore-worker. All the other departments, like the logistics, quality, engineering and material handling send representative persons to the shop floor round. Because of the attendance of the different faculties, the gathering is an important meeting. Issues with quality, missing materials and safety problems can be discussed. At the end to every of this point, a person is set into charge to solve the task. Afterwards, it is written down onto a so-called shop floor list. Topics that cannot be handled in the normal shop floor meeting are marked with a red pen and will be discussed in the following management meeting. The management meeting is put together by the managers of the different departments and the production manager.

These two channels are mostly used to transfer information from one person or department to the next. But there is no standard process in use that must be followed in case of an incident.

4.3. Worker Information System

The second focus of this master thesis is the modernisation and digitalisation of the WIS. This subpoint explains the current way of how workers receive their information now and what the weak points are.

Figure 15 shows the result of the current flow of documents like drawings and BOMs from the engineering department to the assembly workers. This flow is always the same it does not matter if the information is for the production start of a completely new bogie assembly or if it is because of a change in an existing bogie production. The engineering (EN) adapts the engineering drawing and the engineering BOM (EBOM). When this is done the Production Engineering (PE) changes the plant drawing and the manufacturing BOM (MBOM). Afterwards it is sent to the Material Planning. They must check which parts need to be available for the production start and which they must order. At the end they set a date the beginning of the change.

When this date is set the master and team leader get an automated print of the new drawing and BOM. They must replace the drawing afterwards when the change gets into action in the project folder.

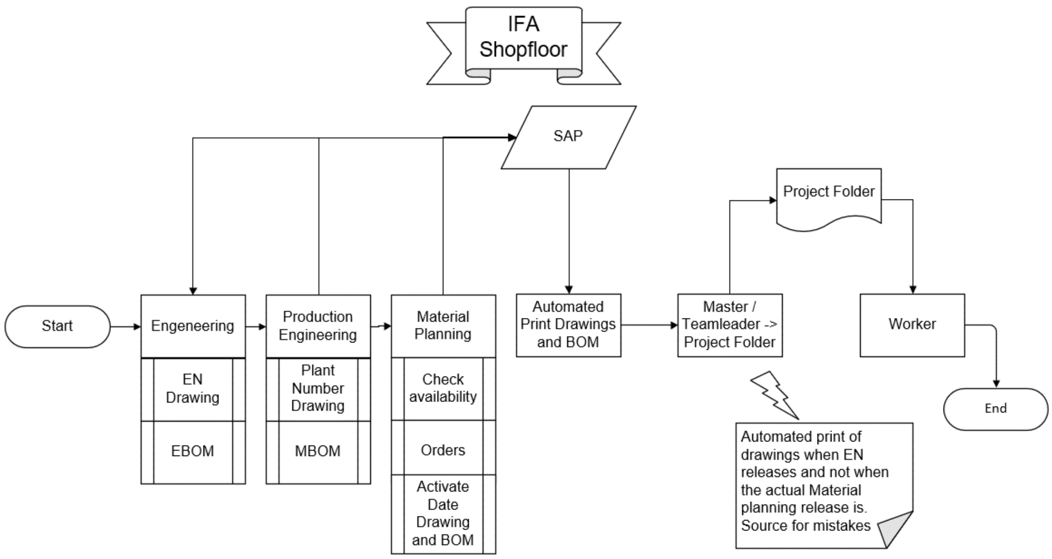

Figure 15: Worker Information Flow Analysation (IFA), Source: Own representation.

At the time most of the needed information in the production line is supplied as hard copy on every production place or line. There is a folder for every project that contains the different drawings of subassemblies and the associated BOM. Big drawings in A0 are also supplied in the assembly stations where they are needed.

Another information that is important is the production plan which is provided close to the line. The production plan displays the projects that are planned for production within the next week with their time schedule for the first assembly station. This plan can be changed by the production planning or even the management in the assembly if due to irregularities the plan cannot be fulfilled. Factors of this could be missing components like engines, a frame, other important parts that makes an assembly impossible or strategic reasons.

The second information the workmen are supplied with are project folders. There is a folder for every single project and if there are different types of one project there is a folder for every subtype as well. This means that if there are bogies produces for one train, but this train contains driven bogies and non-driven bogies there are two different types of bogies. This results in two folders for this project, one for the driven and one for the non-driven bogie. In those folders a lot of valuable information can be found and for better handling, they are always set up in the same way.

The outside is colour coded with a project-specific colour and is marked with the name and the type of the project on the outside of the folder. On the first page, there is a table of content where the different subassemblies are listed with their location in the folder. For each subcomponent, an assembly drawing, a BOM to the drawing and further instructions can be found. On the BOM the additional information to each part can be found. Every single part that is mounted into any bogie has its own material number which makes an allocation possible. This material number is also the used number to find the components in the IT software like in the ERP software. All components that are brought to the assembly line are market with their material number so that the workers use the right parts at the right place. This paper-based shop floor information system has several drawbacks.

The information material like the project folders are not available at every workplace in the assembly line. Only one folder for every project exists. This is not a big deal if the number of different projects is very low, and the assembly workers know their job without checking the folder for every step. This is changing if a new person starts to work or the number of projects increases. In this case, the workers must check the folders several times. This leads to a less productive process because of the wasted time that is needed for checking and walking to the project folder.

Another issue is a result of the fact that a bogie that is designed and allowed for production gets changed several times in the years of production. After every change, this project folder must be adapted to keep the work instructions up to date. This process, as seen in Figure 15, is not automated up to now. If a change at the bogie is changed and approved by the engineering the scheduling department release a date when the new version is going into action. Until this date, all the parties have time to change their work orders to the new design and to organise new material if needed. For example, the team leader must change the relating chapters of the project folder and must notify the workers that their task will change with date X. Otherwise, it can happen that the employees do not look into the project folder and keep on assemble like it is shown on the old drawings because they know their old task by hard. This leads to big problems if an accident or technical defect occurs because of an assembly mistake. To avoid this and get a more efficient production the WIS is the main point that needs to get modernised.

4.4. Multiple machine operation

To handle the higher demand of frames for bogies the decision is made to automate parts of the welding jobs in the frame production. Several jobs that are used to be manual welding are and will be made by robots. This decision is made because of the lack of welders on the job market and the missing will to work in the third shift.

Those robots need special educated operators that can handle the tasks the machine brings with it. For this training welders out of the weld shop can volunteer. To operate the welding robots in an efficient way a three-shift operation is necessary. One big drawback is the lack of workers in the third shift. This lack and an efficient operation can be solved with multiple machine operations. To support the worker with the handling of several machines an application will be provided. This application shows all the automated machines in the workers working area. The application tells the operator when the next activity must be done and at which machine. This application can run on any device that has an internet connection.

5. Concept and solution

The main task is not to design a MES for the whole bogie production in Graz. This is a project for several persons and IT experts. Figure 16 shows the complete project coverage with all subpoints. This master thesis is focusing on two of those points. The first one is the interface for the workers the WIS and the second one is the call system. To explain the whole system would be too extensive for a master thesis.

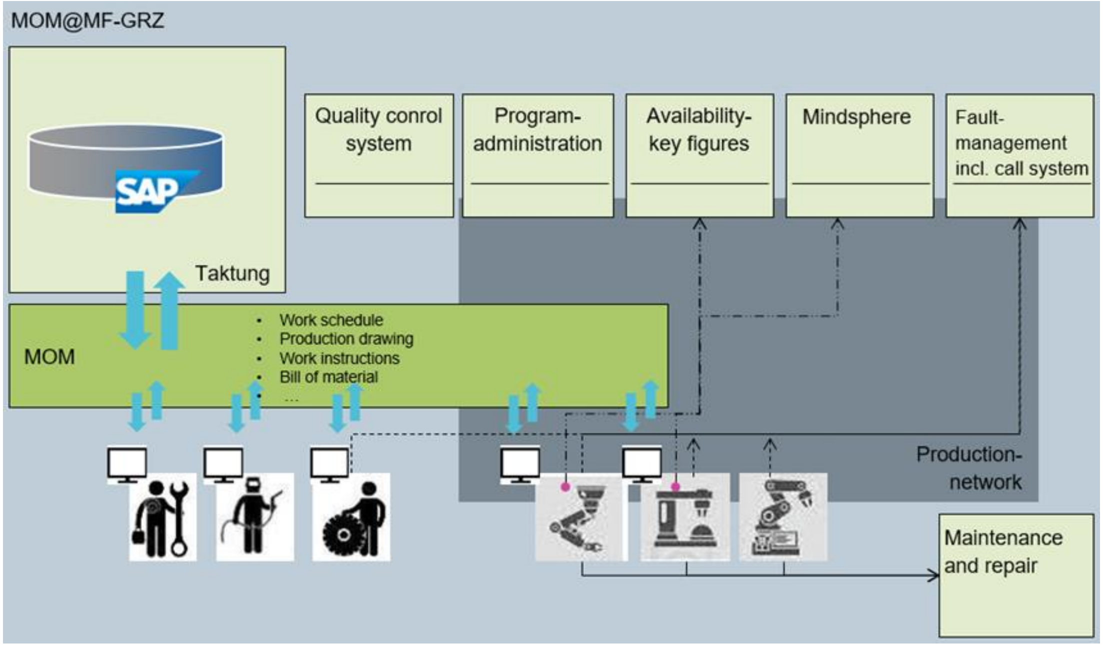

Figure 16: MOM @ Siemens Graz, Source: Peter Pensold (2018), P. 2.

Figure 16 shows the first concept and is the result of a workshop where the goals for the system were defined. It does not show the actual system or how it will be realised. The ERP system will not change in close future. An interface between SAP and the concerning MES must be found. The process of changing to a different ERP tool overuses the limits of human resources at the moment.

For the pilot line of the new pace assembly of the bogie production, the WIS and the Call system will be the first representations of the MES in the future. Those systems will help the workers in the production to handle their new tasks and make the change from the current production system as easy as possible.

5.1. Worker Information System

Together with internal experts and the shop floor workers the requirements the WIS must fulfil were defined. Those requirements are shown below:

- The WIS must offer an integration to the existing ERP system.
- The system must be easy to operate.
- Integration of third-party software (E-Torc).
- Software should be extendable.
- The software has to offer a good customer service.
- Should not require more space than the present tool trolley.
- The information must be displayed that it is easy to recognise.
- Multitouch operation of the worker interface.
- Operable with gloves.
- The trolley must fulfil the lean standards of the company.

Those are the requirements that were defined at the beginning of the project.

The first thing that will be explained is the hardware design of the WIS. A more detailed scoop is displayed for the software of the interface.

The design of the rack is almost like the prototype that already is tested in the production. The main parts that changes are the dimension and the implementation of the mechanical tools and the electronic torque wrench for the work cell. The idea to implement the tools into the rack of the WIS came up due to the lack of space in the production. There is a separate tool trolley in every assembly cell. Now a separate trolley for the WIS would be added. The lost space in the cell is too big and limits the workers.

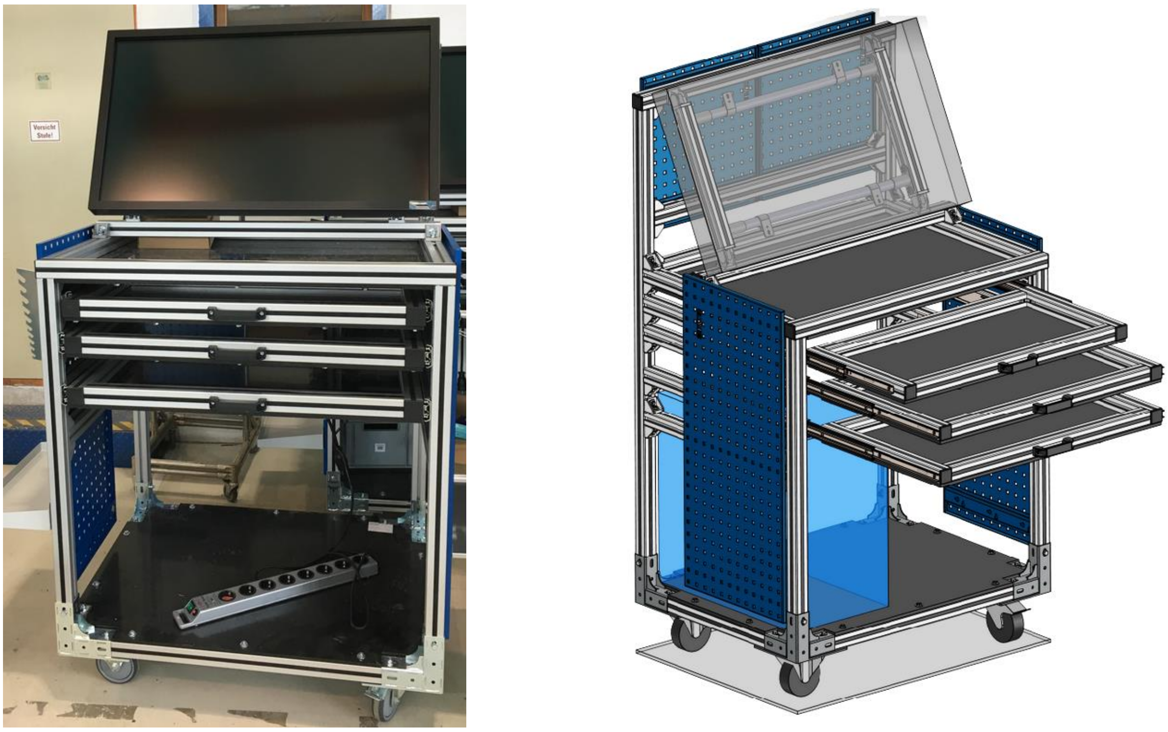

Figure 17: New WIS + tool trolley, Source: Own representation.

The design of the new trolley can be seen in Figure 17. The left picture shows the assembled trolley, but the missing IT components make the use at the time when this thesis is written not possible.

On top of the trolley is a 42” touchscreen with infrared touch technology to enable operation with gloves or any other object like a pen. This screen is connected to a workstation that runs the necessary software. As an interface, the workers can use the touchscreen or a standard keyboard and mouse. To scan barcodes, a scanner is also provided. On the top drawer of the trolley, the torque wrenches for different torque spans are placed and connected to the workstation. This connection is necessary because the torque wrenches need a software that uploads the right torque for the next screws and then saves the actual momentum into a certification sheet.

The second and third drawer is for storage of different tools that are specific to the work that must be done in the assembly cell where the trolley is placed.

The perforated panels on the outside of the trolley can be used as additional storage or for tools that do not fit in the drawers.

More important is the part of the software that runs the WIS. As a Siemens flagship location for Industry 4.0, it is important that the software is supplied by Siemens PLM. Siemens has its own Manufacturing Operations Management software packages for different applications like planning, quality, manufacturing, research and development[153]. The software that is provided manufacturing is SIMATIC IT Unified Architecture Discrete Manufacturing (SIMATIC IT UADM).

The new information flow of the worker information in the case of a change or a new project in the production line can be seen in Figure 18. It shows that the main error with outdated worker information in the production is due to the redesign and the new implemented WIS solved. The WIS is getting the up to date Information from the ERP system in this case SAP. The main change of the system is in the operational level how the workers get their information.

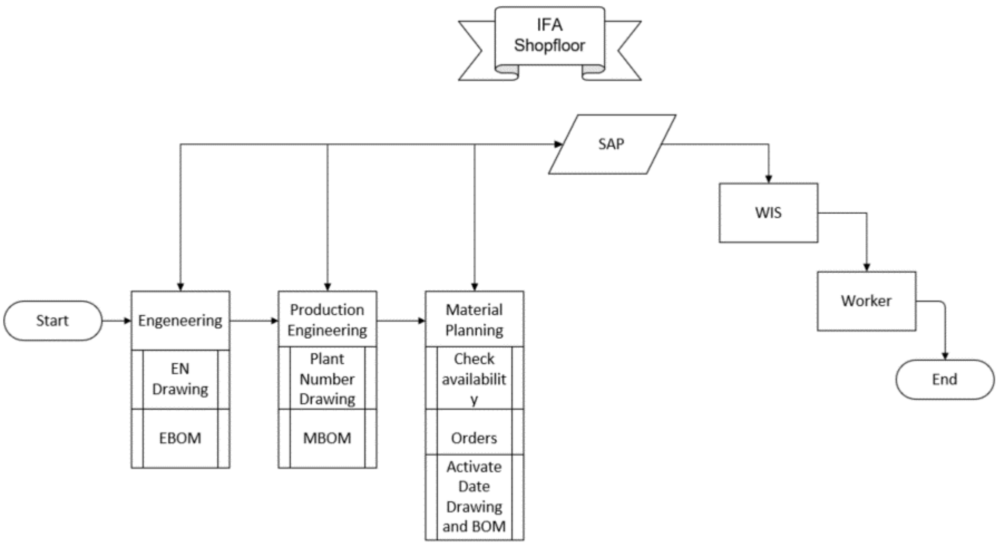

Figure 18: Worker Information Flow Design (IFD), Source: Own representation.

5.1.1. SIMATIC IT Unified Architecture Discrete Manufacturing

SIMATIC IT UADM is a MES that is specialised into discrete manufacturing. The assembly of products in sequential steps, individual lot slices and with the use of BOMs is called discrete manufacturing[154]. It provides a system that helps to raise the process-flexibility, to synchronise the production, to optimise the supply-chain management and because of all that, to reduce the operation costs. It can be

[153] cf. Online: Siemens PLM [State: 23.03.2019].
[154] cf. Online: Batchmaster (2019) [State: 23.03.2019].

combined with any PLM or ERP system that already exists in the company. The most important part for the WIS is that it can provide a high grade of shop floor visibility.[155]

One application of SIMATIC IT UADM is the WIS that provides the working information to the workers in the production line. To enable that SIM IT UADM and SAP can exchange data with each other, an interface is needed. This interface software is called CML4S and is also supplied by Siemens PLM. In this master thesis, the interface will not be explained more accurate.

In Figure 19 below, the tools provided by SIMATIC IT UADM and the implementation of an ERP system with the use of CML4S are demonstrated. The data transfer from the ERP to the MES are material specifications and manufacturing orders. The MES sends to the ERP product declaration as if an operation is completed or in process. The consumed material is also sent back to the ERP system.

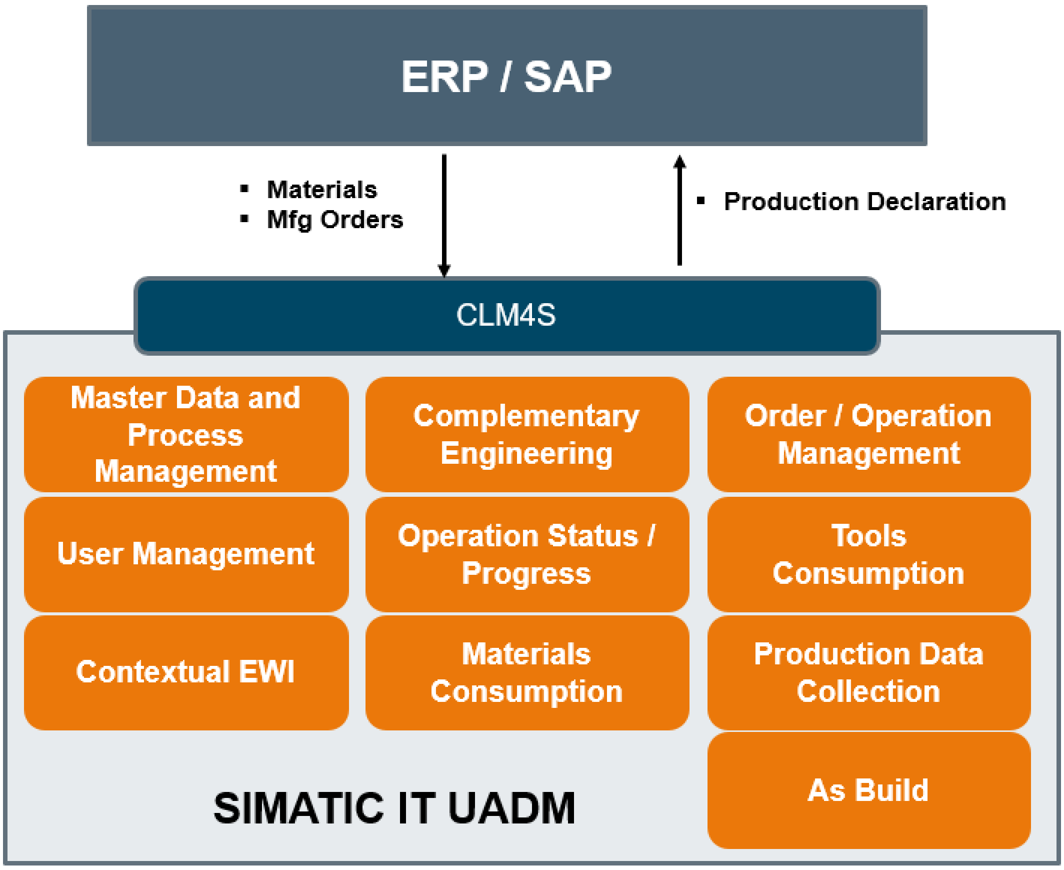

Figure 19: SIMATIC IT UADM + ERP implementation, Source: Online: Siemens PLM [State: 23.03.2019].

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155 cf. Online: Siemens PLM [State: 23.03.2019].

Due to the reason that the design and implementation of the MES at the plant in Graz is delayed and will not be available at the start of the new production line, a plan B is designed to bridge the timespan to the implementation of SIMATIC IT UADM. This plan B is an SAP Operations Account. Nevertheless, first, the future WIS of the SIMATIC IT UADM is explained. In chapter 5.1.3 the SAP Operations Account is explained.

5.1.2. SIMATIC IT UADM Worker Information System

The whole WIS is set together from different elements, those elements are the orange boxes, seen in Figure 19. The different building blocks have different functionalities that are used from different departments in the company, but all of them affect the results in the assembly of bogies.

The different building block are:

- **Complementary Engineering:** Is used by the SIM IT UADM Administrator to perform the configuration of the system to support the production execution. It can define different User Roles, Users, Plant Models, Certifications and several more options. The different process information that is relevant for the assembly process can be defended by the administrator. Those are the vision of the panel, the operations that must be executed, tools, materials and the material to be produced. Another thing that can be done by the administrator in the Complementary Engineering is to enrich the system with process information like the work instructions, operations executions and related documents.[156]
- **Data Collection:** The task, the data collection fulfils is when there are any tasks that the operator must do, like measure something or fill out a checklist. The results can be entered in the Data Collection. What the operator must do can be supported by instructions and pictures. Figure 20 shows the user interface for the worker on the assembly line.[157]

[156] cf. Madlencnik/Fürlinger (2019), P. 64-85.
[157] cf. Madlencnik/Fürlinger (2019), P. 87.

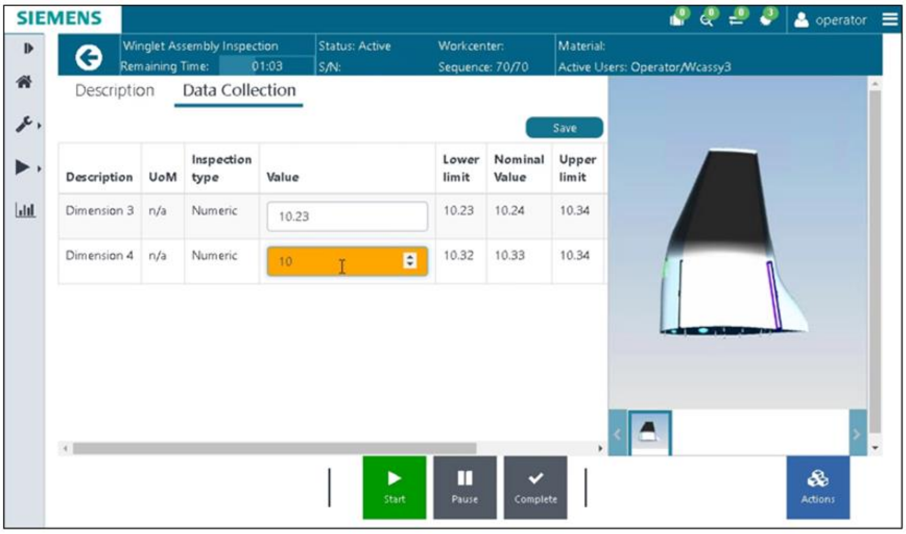

Figure 20: Data Collection example , Source: Siemens PLM Software, P. 7.

- **Production Coordinator Dashboard:** Allows the supervisor to monitor the Work in Progress of the work orders and how much of one work order has been completed. This is shown in a Percentage of Completion. Another thing that can be seen by the supervisor is the total amount of produced products and the ones that got scrapped. This second information about the scrap is not important at the beginning because at the department where the system gets first implemented is the assembly. A whole bogie will not be scrapped here. Later, when the implementation gets extended, this point gets important because the other departments actual produce single parts where scrap can appear.[158]
- **AS BUILT, Genealogy:** This function displays the historical data of different work orders and can be filtered for detailed information. Every work order is saved with its specific number, name, description and status. The Work Order Genealogy screen provides various work orders and their status in a tree structure. Filtered information within the tree structure can be displayed. Information like date and time of the execution and the person in charge can be seen.[159]
- **Operation Execution:** This is the most important part of the WIS. It is the function the assembly worker works with and achieves the information from.

[158] cf. Madlencnik/Fürlinger (2019), P. 81.
[159] cf. Madlencnik/Fürlinger (2019), P. 99.

The whole process starts when a work order is released to the production by the production coordinator. The operator then can start the work order and will get all the information needed for performing the task.[160]

Because of the importance of the project and the future WIS, the operation execution is explained in depth.

When the production coordinator releases a work order the worker in the assembly can see it in SIMATIC IT UADM on a subpoint for work orders. Figure 21 shows the screen where the worker can choose the work order he wants to start next. Every single grey box is one work order. In case of the bogie assembly in Graz it is the assembly of one bogie.

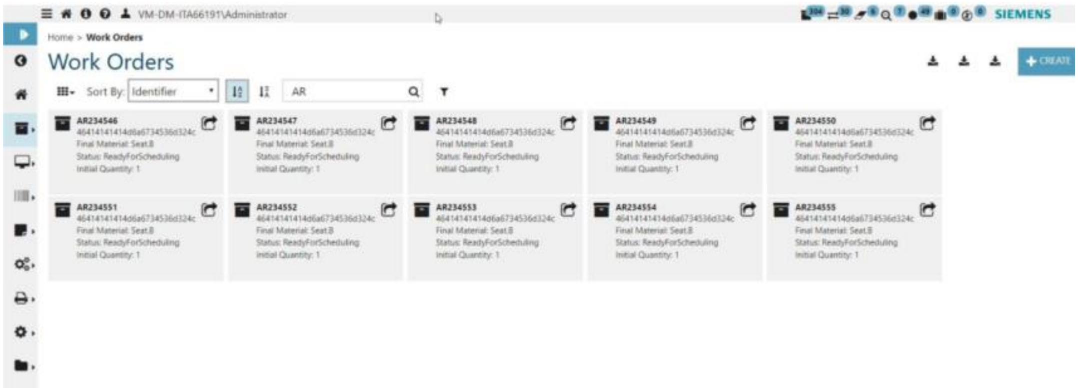

Figure 21: Work Orders in SIMATIC IT UADM, Source: Madlencnik/Fürlinger (2019), P. 70.

When the operator opens one work order the system shows him all the main work tasks that must be done in the current workstation. This is shown in a horizontal line of all the separate work tasks like shown in Figure 22.

[160] cf. Madlencnik/Fürlinger (2019), P. 82.

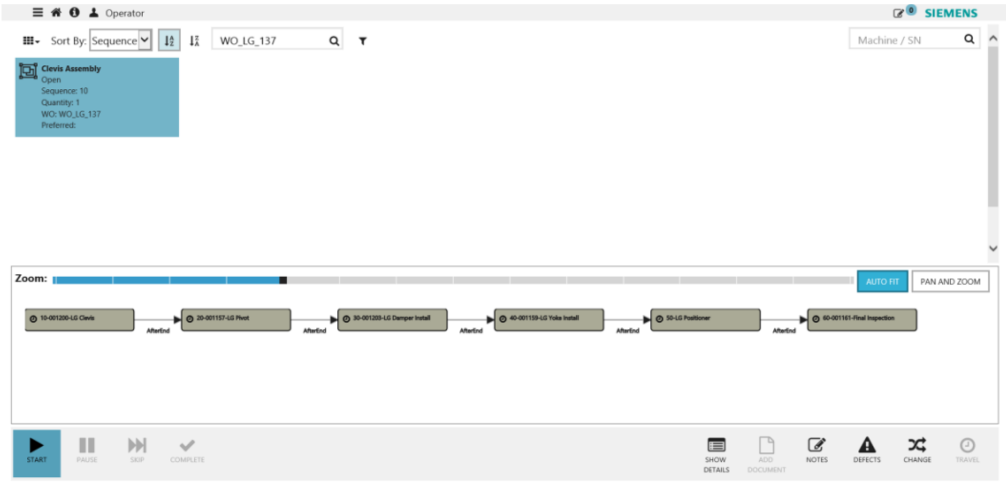

Figure 22: Work tasks for one project (Work Order), Source: Madlencnik/Fürlinger (2019), P. 82.

Every work task is then separated into single work steps. Those show exactly what a worker must do and visualises the task with pictures. It is called the Electronic Work Instruction. On this screen, the worker can also see additional information. On the top of the page, the time that is left for the assembly is shown and on the left side the following steps of the assembly process. If the worker needs to make a break the pause button can be pushed and the time stops counting down. Figure 23 shows the screen the worker sees while assembling the component.

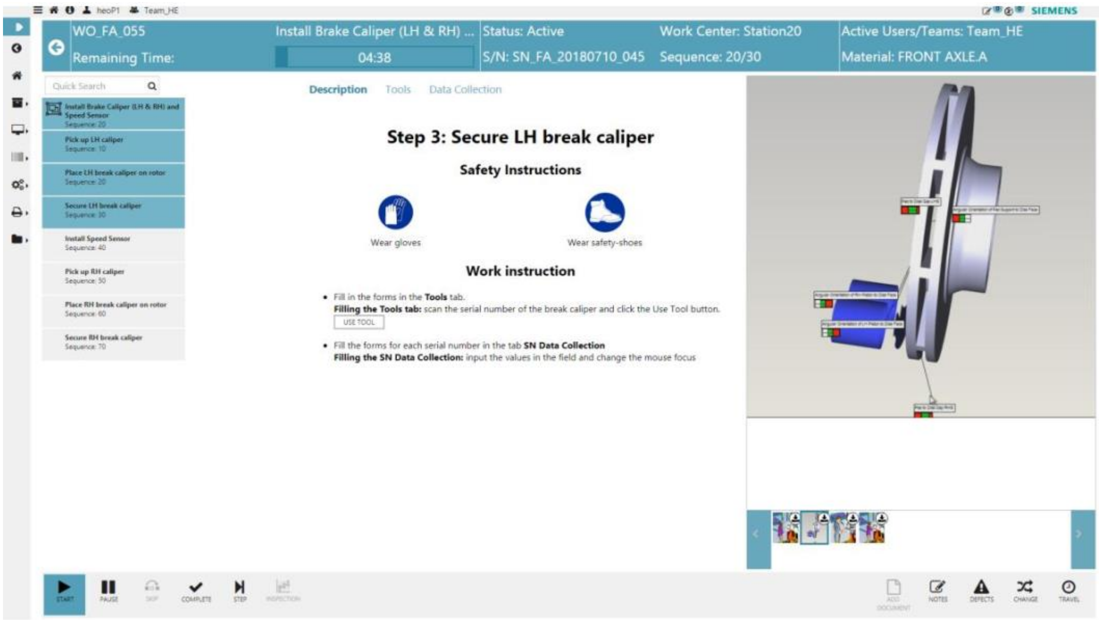

Figure 23: Electronic Work Instruction example, Source: Madlencnik/Fürlinger (2019), P. 83.

The Materials & Tools consumption and traceability function shows and tracks all the relevant information about materials consumption and tool usage that must be used during the process of assembly. This information is the serial numbers of all the parts with the quantity of this part already assembled and the quantity of the parts that still must be assembled. The interface can be seen in Figure 24.

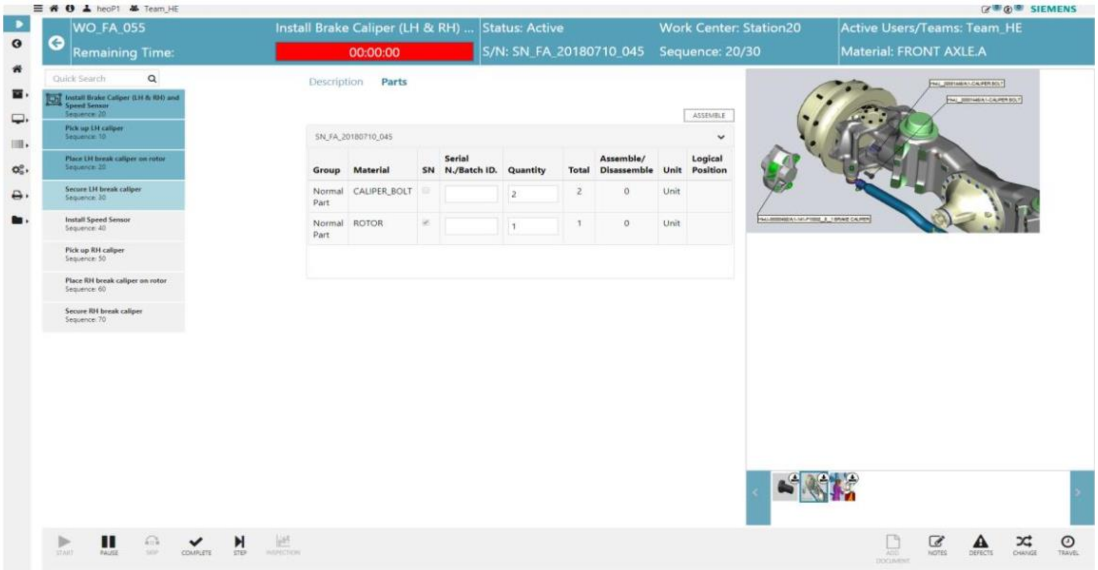

Figure 24: Material and tool consumption, Source: Madlencnik/Fürlinger (2019), P. 84.

This system SIMATIC IT UADM is going to be the future WIS at Siemens Mobility Graz and is implemented with the start of the whole MES. Because this process takes longer than the start of the new pace assembly a solution for in-between is needed. To bridge this time the idea with the SAP Operations Account is used and will be explained in the following chapter.

5.1.3. SAP Job Cockpit Worker Information System

To cover the period between the start of the T2 assembly and the implementation of SIMATIC IT UADM a job cockpit is designed. This tool provides the needed information for the assembly in a costumed SAP application. This application replaces the actual project folder and LIMA system and brings always the updated and correct drawings and BOM's to the assembly workers.

Every produced frame has an individual number. This work order is normally created by the production planning several weeks before the production of the bogie. Between the creation of the work order and the start of the production there could be changes on the design or assembly of the bogie that can get overseen because of the old status of the work order. This used to be a problem in the past as described in chapter 4.3. and is solved with this bridge solution.

With this tool the problem is solved because only the documents that are up to date are used to create the work order. If a drawing has revision status B at the creation of the work order and on the day the bogie starts the production, the revision status is already C the tool still takes revision B. As a result, complications mainly because of not available parts can be eliminated.

When a new frame drops in the work cell the worker can enter or scan the work order number at the SAP start page of the WIS interface, which is the same that is later used for SIM IT UADM. This start screen of the job cockpit can be seen in Figure 25. Not all the available boxes must be filled. One way of choosing the information is that the worker enters the work order number (Auftrag) and the other one is the looking for available work orders in a timespan. The plant number (Werk) are at all station the same and preconfigured. The workplace (Arbeitsplatz) depends on the work cell. This is also preconfigured at every single station and does not need to be changed because the WIS interface will always be at the same workplace. This start screen can be seen in Figure 25.

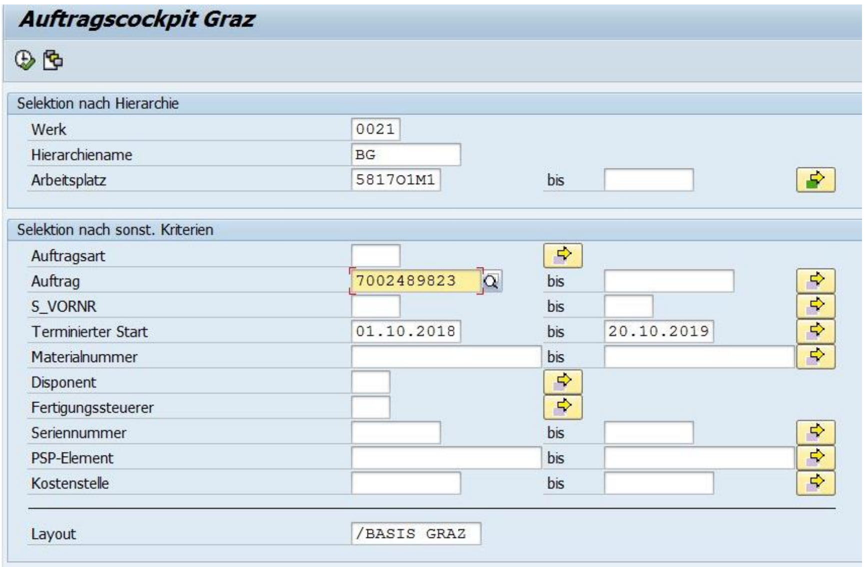

Figure 25: Job Cockpit start screen SA, Source: Own representation.

After using the clock symbol, SAP jumps to the next window where the different work tasks that must be done in this station are displayed. By marking and clicking the button, documents appear. In Figure 26 the big yellow buttons in the top right corner open a new window. The pop-up window also seen in Figure 26 shows all the different operations for the workplace and the worker can choose the one to open.

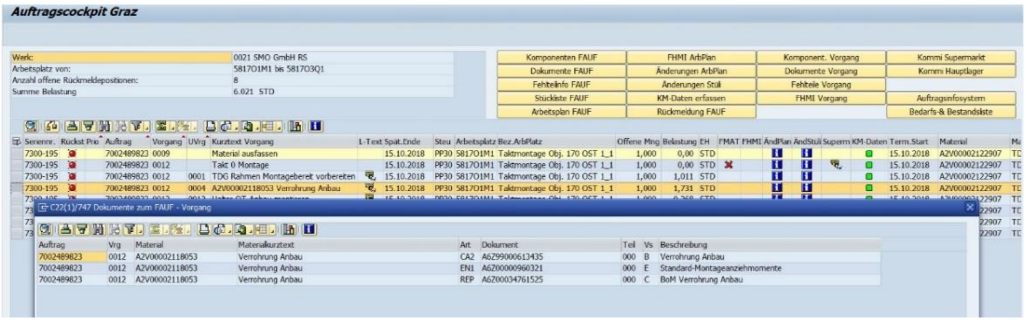

Figure 26: Documents for this workplace SAP, Source: Own representation.

By clicking the document number of the related operation, a window opens where the drawing for this operation is displayed. In this screen, the operator can zoom in and look for all the details needed.

This tool will be replaced completely with the MES explained in the following chapter as soon as it is available and ready to implement.

5.2. Call System Applications

In the following chapter the two different Call Systems for manual working places and multi-machine operation are explained

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5.2.1. Call System Application for manual production lines

The system combines several different interfaces that connect to an application on MindSphere®. In this chapter, the already partly realised Call System is explained.

The requirements that are defined by the management for this system are explained below:

- Extendable to all manual work places.
- Easy to use for the worker.

- Integration of signals for the status of the production line.
- Indication of the status for every workplace.
- Incident notification delivered to smartphone.
- Automated escalation of the notification to a higher level if receiving person is not answering.
- Direct notification for quality and logistic problems.

First, a new information flow for the bogie assembly was designed. This is the result of a seminar with external experts and internal experts. The result can be seen in Figure 27.

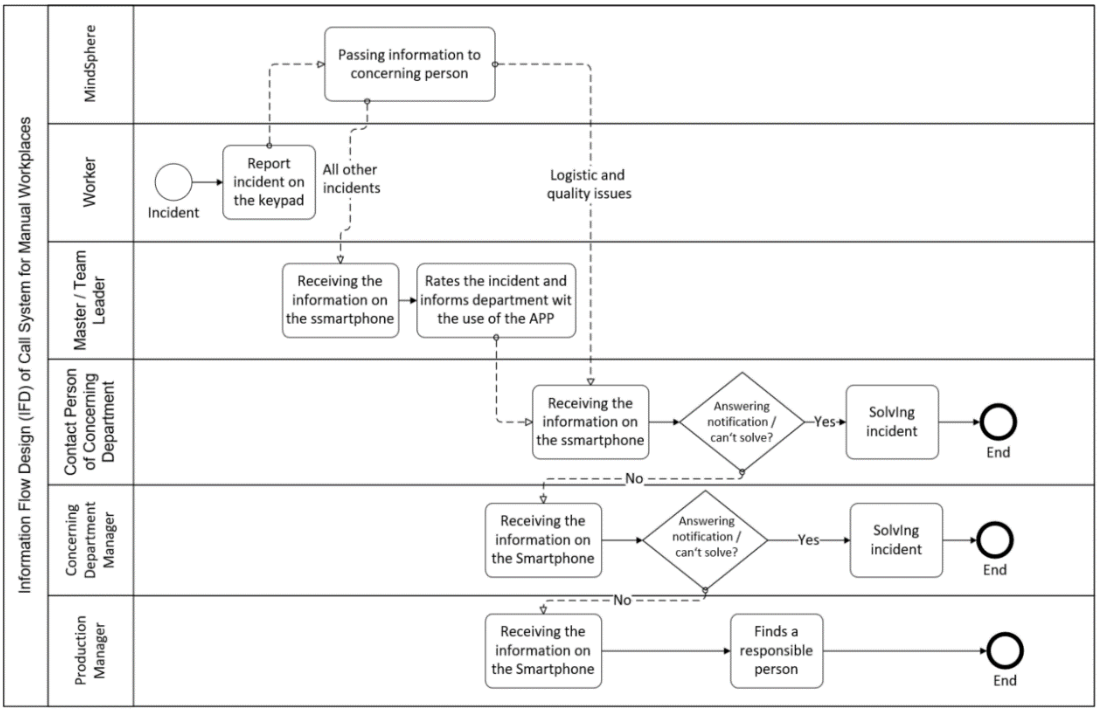

Figure 27: IFD for incidents in the bogie assembly, Source: Own representation.

This shows the planed information flow with all the included parties. The whole system is based on an MindSphere® application. The actual system and how it works is explained below.

The interface for the workers in the assembly line is provided by a field with six buttons on it. Every single button has a different function that is explained below. The design and key assignment of the interface are shown in Figure 28. A target is to keep the interface as simple as possible and not offer to many different opportunities to choose. These six buttons provide the most important process and incident notifications that this type of production needs. This interface is connected to the network and uploads the information given by the worker by the click of a button to MindSphere®. This information is than passed on to the right person which receives it on the smartphone. The programming of this application was not part of this thesis this is why it won't be explained more in depth here.

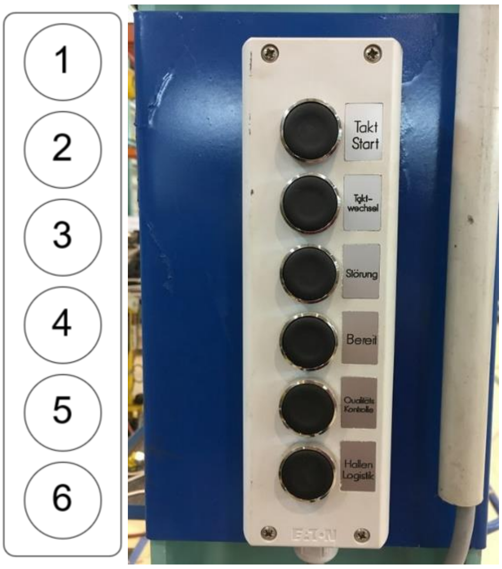

Figure 28: Design and key assignment of worker interface with six buttons, Source: Own representation.

- **Button 1:** This button must be pushed after every shift change to set the takt time to zero. When the last shift ended, the workstation is closed with the same button.
- **Button 2:** Whenever a workstation is finished with the work they push this button. It shows that the concerned workstation is ready for lifting the bogies to the next station.
- **Button 3:** This button is for incidents that are not quality, or logistics related. If this button is pushed the team leader receives a notification and decides who is in charge to handle the incident and passes it on.
- **Button 4:** This is used for the ready signalisation. Whenever a workstation had an incident that has been solved, the bush of this button will bring the system back in the state before the incident.

- **Button 5:** When quality issues occur the worker in the concerning work cell can call directly a person from the quality department with the push of this button.
- **Button 6:** For any logistical issues this button is used. The logistic worker of the shop floor receives a direct notification.

Connected to the button field is a signal light as shown in Figure 29. There is always one light placed at each work station where it can be seen easily. In the case of the test line, the crane pillars next to the work stations are the optimal position (Figure 29). Every signal light can show four different colours, green, blue, yellow and red.

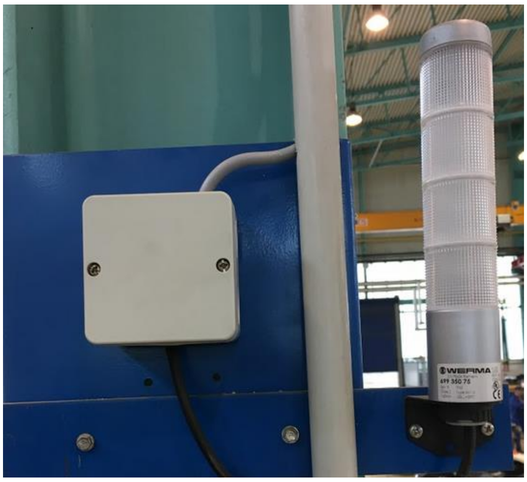

Figure 29: Signal light, Source: Own representation.

The different meanings of those colours are explained below:

- **Green**: means work is in progress as planned and is activated by the push of button 1.
- **Green blinking**: The green light starts to blink when the station confirmed with the push of button 2 that their work station is finished and ready for lifting the bogie to the next station.
- **Blue**: This light shine when the worker pushes button 5 or 6 because of a quality or logistic problem.

- **Red blinking**: Shows that there is an incident in this work station. This is activated by the push of button 3.
- **Red**: Stands for a production hold and can only be activated by the team leader.
- **No light:** If nobody is working in the line the light is turned off.

The above-explained system is already implemented in the assembly line and will be expanded on manual workplaces companywide.

The application explained below shows the handling of incidents and is implemented as soon as the program is finished. The application is explained schematically.

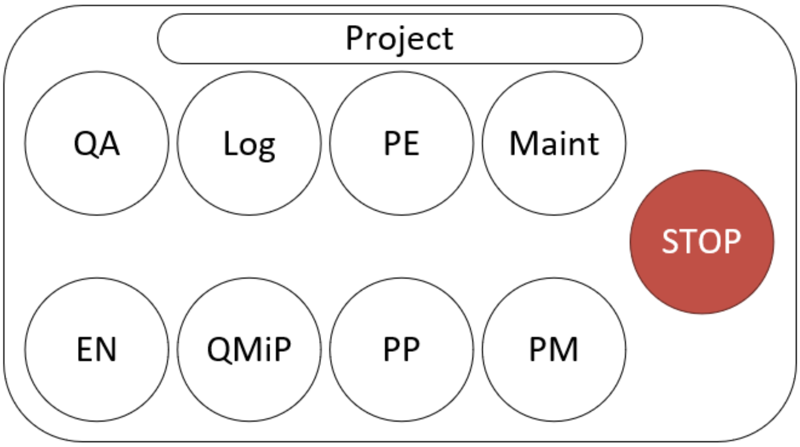

Figure 30: Interface team leader, Source: Own representation.

Figure 30 shows the functions of the smartphone interface for team leaders and supervisors. With this surface, they can send notifications to the project-specific contact persons of the different departments.

The button configuration is:

- QA: Quality Assurance
- Log: Logistics
- PE: Production Engineering
- Maint: Maintenance
- EN: Engineering
- QMiP: Quality Management in Process
- PP: Production Planning

- PM: Production Manager
- Stop: Is to stop the whole production line where the incident happened

A notification is generated and sent. This receiving person gets a pop-up notification. By opening the application, a screen describes the incident and the time it happened. The options “takeover” or “forward” can be chosen. If nobody is answering the notification it is automatically forwarded. The design of this interface can be seen in Figure 31.

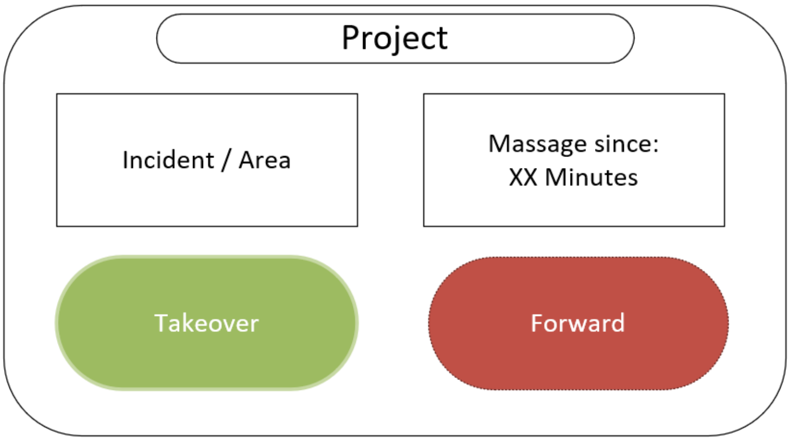

Figure 31: Interface contact person, Source: Own representation.

5.2.2. Call System for multi-machine operation

Another application that is developed within the Call System is named Kobold. Kobold is an application to enable multi-machine operation in the future. A short debauch to the name of the application. The name Kobold is chosen because it is like the small being on your shoulder that tells you what you must take care of next.

The requirements for this system are:

- Fist integration of the welding robots.
- Extendable to all automated machines.
- App solution for the smartphone.
- Gives information about the next activity a person must accomplish on a machine.
- Alert when there is a full stop.
- Direct call of maintenance and welding supervisor.

Technically a MindSphere® application runns in the background. The machines are connected to the MindSphere® with a so-called MindConnect®. This MindConnect® collects predefined machine data and uploads it to the cloud. This application is specially designed to be used on smartphones.

For the first pilot series, the welding robots get connected to the MindSphere®. Those robots send specific data like, time until the program ends, time until next action by the operator is needed, what the operator must do in the next stop and the activity of the robot. The operator, team leader, fore worker and the other persons who have access to the application get this information in an application on their mobile device displayed.

The first screen is a bird view picture of the complete plant. This Screen shows all the buildings in a colour that changes if there are any occurrence. The first screen looks like displayed in Figure 32. The grey buildings are jet not implemented in the application or no automated machinery is placed inside.

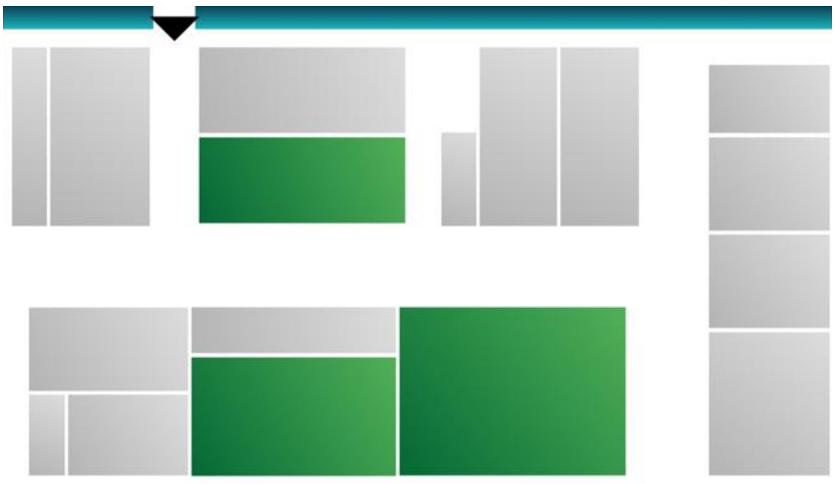

Figure 32: Birds view in KOBOLD, Source: Zöhrer (2018), P. 7.

The buildings can have three colours, red, orange and green. If the building is green everything is working. An orange building means that something, in the close future, must be done. If the colour of a building is red an incident or machine stop happened, the worker must intervene immediately. The operator can get a view of the machine status inside of every building by selecting the concerning building. The application shows the inside of the building as it can be seen in Figure 33.

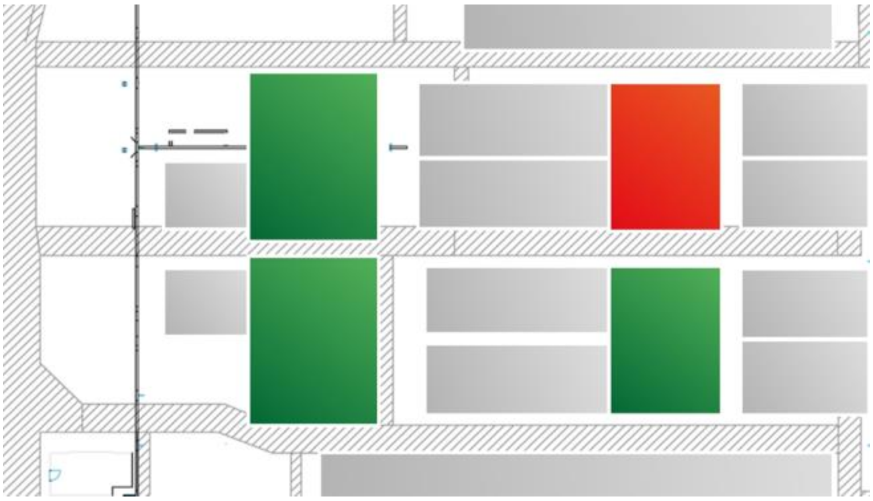

Figure 33: View of shop floor KOBOLD, Source: Zöhrer (2018), P. 8.

The colour code is the same as in the overview. In Figure 33 the four already implemented welding robots and their status can be seen. The grey boxes are manual welding station that are not implemented. Three of the four robots are working normal and one is at a non-planned still stand. This can be caused by a program stop where the operator must react and has not arrived jet or because of a technical defect. For planned program interruptions, the operator knows by using the application what must be done at which machine. Whenever the colour of a machine in the application turns to orange the operator gets a notification and he can see why the colour changed. With a click on the machine in the application a new window opens in the that shows all the available data of the machine. Figure 34 shows an example of such a machine information interface.

Figure 34: Machine view in KOBOLD, Source: Zöhrer (2018), P. 11.

In this case, machine IGM-QT2 shows the colour orange because a task where the operator is needed comes up. The task is a contact pipe change and must be made in four minutes. Another information that can be found is the time when the program ends. Here this would be at 16:04 o'clock. This enables the operator to plan jobs ahead, what must be done next and makes a multiple machine operation easier to handle. The button "IH rufen" is there if the operator needs to contact someone from the maintenance department. If a welding supervisor is needed the button "SAP rufen" can be clicked. In both cases, the concerning persons get a notification on their smartphones and they can handle the task.

The button "Maschine übernehmen" is not in use till now and will be implemented in a later phase. If there are more operators that service, the machines all of them get the notifications of the machines. In this case, the one who has time to take care of the task can click the button and the others see that the task has already been accepted.

6. Summary and Conclusion

Overall the time I worked on this master thesis brought several findings. Digitalization / Industry 4.0 / IIoT are terms that are frequently used in the media and on conferences. In some companies, the reality looks different.

To change an existing traditionally grown production into a digitalised production or even a smart factory needs changing old structures that exist for a long time and worked well. This can lead to fear of change for involved people and the terms “never change a running system” or “is there really the need for …” appear daily. Sometimes missing support is a major slowdown of efficient integration. A problem realised in this case, which might also appear in other production companies, is the low afford put into digitalisation in the past. Maybe the was no need for it, nobody thought about it or there were no capacities left to start with this topic. Due to a changing group decision or a management decision, the digitalisation better starts yesterday than today. To plan and set up a roadmap is basically a good idea, but the dates and the goals need to be realistic. Otherwise, it results in ineffectiveness. Sometimes a more structured solution with accurate market research and the time to formulate a specific specification sheet could be the faster solution with less rework at the end.

A positive aspect is that almost any imaginable software solution exists on the market. With an efficient market research, the best fitting solution or solutions to push the company further in the direction of a smart factory can easily be found. The software suppliers offer their MES with different ideas from the one in all MES solution to the highly individualise able APP store like MES solution. This gives the company the chance to get exactly the solution they need. As it shows an existing ERP system from another supplier than the additional software is also not a problem, the software companies offer specially designed interfaces to enable the data transfer between the ERP system and the concerning software.

The focus of this thesis is mostly on the digitalisation of the shop floor level. One of the big challenges is to convince the shop floor workers with the new concept and to include them so they support the project. In general, a focus must be on the workers who use the system frequently to accomplish motivated and efficient workers.

The big challenges are the worker information, incident management and the multi-machine operation. Most of the MES offer integrated tools for each of those tasks that can be used. But the project team for digitalisation decided that they will use a combination of independent tools for the different tasks in the beginning and later implement or substitute some of them with the tools the MES provides. With the systems that are and will be implemented soon, it eliminates several issues that exist with the current way how these things are handled without compromising any other factor. It allows the company to grow and fulfil future orders. The interesting thing is that, this project shows a lot of irregularities in the production process that were not in the focus of the team at the beginning. Those irregularities are now, without a sophisticated digitalisation, not a problem, but in the future, with a higher grade of digitalisation, the process must be more structured and with less room for error. To find these is again a positive point because all the grown structures and processes must be overlocked and redesigned so that they work in a digitalized production.

To put it all in a nutshell it is a great chance for a student to learn a lot in this kind of project with the possibilities and downsides that appear by implementing a higher-grade digitalisation. One thing that the research shows is the fast development of new technologies and how they change the economy. Another interesting task is to research the different MES and the way how to sell those systems to the worker in the production. To convince the workers seems not like a big deal within a modern company but, it is harder than it sounds them. Altogether it shows the challenges that modern companies face in the future be and to stay a competitive player on the market.

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