Sebastian Müller, BSc

Concept development for utilization of operations data in value stream design and analysis for a sheet metal forming production

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

Dipl.-Ing. Hugo Karre, BSc

Institute of Innovation und Industrial Management

Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

Graz, November 2018

AFFIDAVIT

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Acknowledgement

In the first place, I want to thank Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer for the opportunity to write my Master's thesis at the Institute of Innovation and Industrial Management. I also thank my supervisors Dipl.-Ing. Huggo Daniel Karren BSc and the employees of the company for their continuous help. The aim of the work was to develop a holistic concept for the use of production data. This allowed me to get a deeper insight into the area of production planning and industry 4.0. I am very grateful that I had the opportunity to work on such a project.

I would like to thank my flatmates, Felix, Lukas and Raphael for the constructive words and the nice evenings we spent together during this demanding time.

Especially, I would like to thank my girlfriend Stephanie, who always supported and motivated me during this time. In addition, that she helped me a lot with the proofreading of this thesis.

Finally, I would like to thank my siblings, Florian and Nina as well as my parents, Helmut and Beate, for providing me unfailing support and help during my whole studies. Without this backing that would not have been possible.

Abstract

The aim of this master's thesis was to create a consistent Industry 4.0 concept for the metalworking department in Austrian crane manufacturing plant. In doing so, the necessary knowledge was to be gained from the existing production data and incorporated into the new concept. To get a better understanding of the current situation, a value stream analysis was made. The aim of this analysis was, on the one hand, to better understand the exact production processes and on the other hand, to identify possible weak points in production.

Based on the analysis, an overall concept should be developed. This concept should be able to receive and visualize data from production from three main topics. The three topics are: value stream, material tracking and the overall equipment effectiveness. These three topics were determined for the following reasons: In order to enable complete tracking of products in production, a material tracking system would have to be installed. The OEE serves the company to oversee the production and identify potential bottlenecks and weaknesses. The value stream must fulfil two tasks. On the one hand, the representation of the production data in real time and it should also be possible to simulate new production layouts with the data from the past.

The main focus in this first phase was to get an understanding of overall equipment effectiveness, OEE for short. It is a key figure that tells how efficient the machines are in production. Until the beginning of the Master's thesis, the company was unable to make any precise statements about the OEE in production. It was calculated theoretically, but this did not necessarily coincide with the actual production. Therefore, another element in the developed concept should be a system that detects the actual OEE directly at the machine. The biggest challenge for the automatic capture of the OEE is the large variance of workplaces that needs to be covered.

The second major topic in the master's thesis was material tracking in production. Since the company had already tried to ensure this, but failed mostly for economic reasons, a part of the thesis was to find an alternative solution. Here, the automotive industry was used as a source of inspiration. They use small trackers on load carriers to track material transports. With such a solution, it would be possible for the company to track materials in the workshop. Sophisticated software "notices" which material and which tracker is currently on a load carrier. This makes it possible to assign it unambiguously in the material flow. For the future, it should be possible to simulate and test new production layouts using historical material data. In order for the three systems to be able to communicate with each other without any restrictions, a platform had to be chosen that would enable this. To keep costs down, the already existing enterprise resource planning system SAP was used. This serves as interface and storage location of all generated data.

Kurzfassung

Das Ziel dieser Masterarbeit sollte sein, die Erstellung eines durchgehenden Industrie 4.0 Konzeptes für eine metallverarbeitende Abteilung bei einem österreichischen Kranhersteller. Dabei sollten aus den bereits vorhandenen Produktionsdaten die notwendigen Erkenntnisse geschlossen und in das neue Konzept eingearbeitet werden. Um ein besseres Verständnis der aktuellen Situation zu bekommen, wurde eine Value Stream Analyse gemacht. Ziel dieser Analyse war es, einerseits die genauen Produktionsabläufe genauer zu verstehen und andererseits mögliche Schwachstellen in der Produktion zu erkennen.

Aufbauend auf die Analyse solle ein Gesamtkonzept entwickelt werden. Dieses Konzept sollte in der Lage sein aus drei Themenschwerpunkten Data aus der Produktion zu empfangen und zu visualisieren. Die drei Themen sind: Value Stream, Material Tracking und Overall Equipment Effectiveness. Diese drei Themen wurden aus folgen Gründen bestimmt: Damit einen lückenlose Verfolgung der Produkte in der Produktion möglich wird, müsste ein Material Tracking System installiert werden. Der OEE dient dazu die Produktion zu überwachen und mögliche Bottlenecks zu identifizieren. Dadurch sollte frühzeitig erkannt werden wenn sich in der Produktion irgendwelche Probleme ankündigen. Der Value Stream muss dabei zwei Aufgaben erfüllen. Einerseits die Darstellung der Produktionsdaten in Echtzeit und es sollte auch möglich sein, neue Produktionslayouts mit den Daten aus der Vergangenheit zu simulieren.

Das Hauptaugenmerk in dieser ersten Phase war es ein Verständnis für den Overall Equipment Effectiveness, kurz OEE zu bekommen. Dabei handelt es sich um eine Kennzahl, die eine Aussage darüber trifft, wie effizient die Maschinen in der Produktion genutzt werden. Bis zum Beginn der Masterarbeit konnte das Unternehmen keine exakte Aussage über den OEE in der Produktion tätigen. Dieser wurde theoretisch berechnet, was Abweichungen zur tatsächlichen Produktion möglich macht. Deshalb sollte ein weiteres Element im entwickelten Konzept, ein System sein, dass den tatsächlichen OEE direkt an der Maschine ermittelt. Die große Herausforderung für die automatische Erfassung des OEE ist die große Varianz an Arbeitsplätzen die abgedeckt werden muss.

Das zweite große Thema in der Masterarbeit war die Materialverfolgung in der Produktion. Das Unternehmen hat in der Vergangenheit bereits einige Versuche unternommen dies zu gewährleisten, ist aber aus wirtschaftlichen Gründen wiederholt daran gescheit. Ein Aspekt der Arbeit war daher zu versuchen eine alternative Lösung zu finden. Hierbei wurde die Automobilindustrie als Inspirationsquelle genutzt. Dort werden kleine Tracker am Ladungsträger verwendet, um den Materialtransport zu verfolgen. Mit einer solchen Lösung wäre es auch bei dem Unternehmen möglich die Materialien in der Werkshalle zu verfolgen. Eine ausgeklügelte Software „merkt" sich dabei welches Material und welcher Tracker

gerade auf einem Ladungsträger ist und stellt so sicher, dass eine eindeutige Zuordenbarkeit im Materialfluss möglich ist. Für die Zukunft sollte es möglich sein, mittels historischen Materialdaten, neue Produktionslayouts zu simulieren und zu testen.

Damit die drei Systeme uneingeschränkt miteinander kommunizieren können, musste eine Plattform gewählt werden die das ermöglicht. Um mögliche Kosten gering zu halten, wurde dafür das von dem Unternehmen verwendete Enterprise Ressource Planning System SAP verwendet. Dieses dient als Schnittstelle und Speicherort aller erzeugten Daten.

List of abbreviations

TTM	Time To Market
OEE	Overall Equipment Effectiveness
PDCA	Plan-Do-Check-Act
WIP	Work In Progress
FIFO	First in First out
IoT	Internet of Things
IT	Information Technology
CPS	Cyber-physical system
B2C	Business-to-Customer
TCP	Transmission Control Protocol
IP	Internet Protocol
WLAN	Wireless Local Area Network
OPC	Open Platform Communication
PLC	Programmable Logic Controller
AGVS	Automated guided vehicles system
RFID	Radio-frequency identification
AR	Augmented Reality
1D/2D	One / Two dimensional
ERP	Enterprise resource planning
KTL	Cathodic dip painting
KPI	Key Performance Indicator
POT	Potential working Time
BPMN	Business Process Model and Notation
MYXL5.......................	Small part milling machine
MK20	Small part bending machine
PYHVK1.....................	Articulated arm staple box
PYHS1, 2	Push arm staple box
MFC26.......................	Machining centre
PRNS1.......................	Push arm finishing touches
ROY 13, 17, 14............	Welding robot
PYHK 1, 2	Articulated arm staple box

Table of content

1 Introduction

In the first chapter the company and the concerning department are introduced, followed by the aim of the thesis and the methodological approach.

1.1 Company overview

The company is an Austrian manufacturer of hydraulic lifting and loading equipment. The company was founded in Upper Austria and today its headquarters is still in Austria. The company is still a family-owned business.

The lifting solutions are mostly used on commercial vehicles and in the maritime sector. Innovation and internationalization of products, processes and services as well as flexibility are the three pillars on which the company is built. In order not to fall behind when it comes to digitization, the company has added a fourth pillar. The company stands for new core competencies, new approaches, new products, services and business models in the digital age. In order to have a decisive competitive advantage over its competitors, the company concentrates on high flexibility, competence in production as well as a worldwide sales and service networks.

The multinational corporation has 38 manufacturing and assembly sites in Europe, North and South America, the Commonwealth of Independent States and Asia. To be always close to its customers, the company has sales and service centres for all continents. This makes it possible to offer a complete pre and after sales offer for the respective needs of the markets. The company exports 95 percent of its products to more than 130 countries worldwide.

The group's main product is the loading crane. In this area, the company has more than 100 different models and a market share of more than 30 percent, making them world market leaders. Other divisions in which the group is active are in the field of forestry and recycling cranes, on- and off-road and hook lifts. In the last area, the enterprise is also the largest manufacturer. The product portfolio has steadily expanded in recent years. Now, forklift trucks, tail lifts or truck-mounted aerial work platforms, high-tech railroad applications and bridge inspection equipment are also part of the group's comprehensive offering. In the maritime sector, the company is the world's leading manufacturer of reliable, innovative and customized deck equipment and handling solutions. The product portfolio includes handling solutions, rescue equipment, cranes and winches. This department of the group operates in all maritime segments, including shipping and cruise, offshore, wind, navy and coastguard.

1.2 Sheet metal forming production

At the company, most of the metal parts are manufactured by them self. For this purpose, the raw metal panels are delivered by the steel producers and stored in a suitable intermediate storage facility. Different types of steel are needed for the different production parts. Heavily loaded crane parts require higher quality steel grades than non-load bearing elements. The plates are then placed in the lasers where the parts are cut out. For this purpose, the interleaver creates the pattern to keep the blend as low as possible. All these parts cannot yet be assigned to a sales order because the production of the parts is initiated from the small parts warehouse. The control of small parts production is based on a kanban system. If the preparer remove the parts from the small parts store and a certain minimum stock is undercut, this triggers the post-production of the parts.

After the steel parts have been cut out, there are basically two variants of the after treatment. The parts come either in the small parts production or directly in the small parts warehouse. For rush orders, there is beside the small parts warehouse an extra order warehouse. Here are the parts that are specially made for orders stored. This is much smaller, as these parts are usually stored only briefly before they are used in manufacturing. The larger part, 51.8% of the products is transported directly to the small parts warehouse. The remaining parts are subjected to at least one further processing in the small parts production. In this department there are two machining operations and a non-cutting one. Milling and drilling are part of the machining process, and edging of the non-cutting process. In total, there are eight different variants of how the small parts can go through this department. The exact description can be found in chapter 8.2.1 Results from small parts production.

After the preparer have taken the materials, for the orders from the small parts warehouse, these are brought to the different stapling boxes. Material transport in the workshop is carried out exclusively with transport trolleys and forklift trucks. The production can be subdivided from here into two strands: in push arms and articulated arms. Push arms are the parts of the crane that increase the radius of deployment (extension of the moving elements). Articulated arms enable the construction of more compact cranes, making it possible to fold the crane while increasing freedom of movement.

In the stapler boxes, the items are stapled with designated holders. Subsequently, the stapled parts are either transported to welding robots or to hand welding places. At these places the parts are completely welded. Depending on whether the parts are welded by hand welding or by welding robots, they must be reworked. This happens in the push arm finish or in the machining centre. Additional custom attachments like winches are installed in the final production process. Since the processes are the same for both push arms and articulated arms, this has been described only once. The final step in this metal sheet production department is cathodic dip painting. Here every production part undergoes a surface treatment that protects against corrosion.

1.3 Aim of the thesis

The aim of the thesis was to gain a deeper insight into the production area of the company plant in Austria, in the sheet metal forming department. In the past, in this particular department there was a great change, structural and technological, a closer examination with deeper analyzes made sense here. The first thing was to understand the complex processes. This was ensured by means of workshops and guided tours of the production hall. The team that supported this master's thesis ranged from the individual process supervisors to the production manager of the site. In the process, the actual flow of material was eliminated and the individual processes explained and described. From the peculiarities of the processes to the various possibilities of how the material is transported in production. All this information was necessary to reflect a precise description of the current situation in production. This information is required to build the first goal of this thesis, the current value stream. From these representations it was then necessary to gain the desired results by means of analysis tools. In particular, the focus was on the overall equipment effectiveness (OEE). The reason for this special interest in this key figure is that the company wants to control and measure its production. By combining the theoretical and the actual OEE, problems in production can be detected. Up to that point, the OEE was only theoretically available. Therefore, another point of the master thesis was to find a system that guarantees a real-time visualization and calculation of the OEE. An additional goal of the thesis is an actual traceability of the individual products through the production department. This information is needed to enable better planning in the production hall. This allows the machine allocation to be predicted more accurately and avoiding standstills. Likewise, patterns in the production hall can be identified, which machines deliver their material to which subsequent workstation. Out of this, it is possible to plan an optimized variant for future production layouts. Machines and workplaces that have a larger material flow, should then be close together to avoid long transportation routes. Since there have been some attempts on this subject, but they have been uneconomic so far. This was also one of the main objectives. In order to be able to react faster and more precisely to fluctuations in demand, both systems, material flow and value stream should be flexible and able to simulate different production capacities. The interworking of the material flow, and the value stream should then allow to design new production layouts in the future and simulate them under realistic scenarios.

The three components, value stream, material tracker and OEE tracker would work perfect in their special field. However, how do they work together as a unit, this was the final part of the thesis. A consistent and end-to-end concept should be created, which can meet the requirements. In order to do this, it had to be ensured during component selection that not only the individual tasks but also collaboration with other systems is possible. A central platform, either an existing or a new one, should serve as a central point of control. All the generated information should be stored and managed there.

1.4 Methodological approach

In order to work on the master thesis in a regulated form, it was divided into three phases: data collection, rough concept, and fine concept. In the first step, the current state should be determined. For the thesis, there was a defined period under review. This period was from 01.01.2017 until 01.04.2017. At the official kick off at the end of August 2017, the actual state was no longer recognizable in the production. During this period, various changes in the layout were made. This resulted in the first working step, raise the past step in theory on paper. The survey of the actual state took place in the form of workshops and targeted tours through the production with the responsible process supervisors.

The process managers and the workers at the workplaces passed on the required information. The information was not only how the current process is going, but also how it was before the change in production. Since almost all employees have several years of experience in their field of work, this process has been well managed. The information gained from the discussions then served to capture the current value stream. During further tours through the production, missing information could be obtained by process observations. These were mostly the transport routes in production and how they are managed. The process data did not have to be collected because they were known for each process and provided for the master thesis. In order to ensure the correctness of the information obtained, the progress was presented in the form of presentation to the team of supervisors. In addition, in this phase, it has already been defined which production data is required in order to obtain the desired and necessary information from it. Here as well, the overall concept was thought of, how it could look like and what it should be able to do.

In the second phase of the Master's thesis, the scientific aspect of the thesis was treated. Research in technical literature and evaluate what the current scientific state is. In order to do so, the first step was to ascertain which sources were suitable for the scientific research. The two major topics in which these were necessary are value stream analysis and design and industry benchmarking. Another big part of the thesis was to find Industry 4.0 tools for the production. Since there are already many providers, the task was to find the already established products and providers. The method for selecting the components is a pair wise comparison in combination with a utility analysis. This method was used for all areas in which a selection of components was necessary.

For the illustration of the material flow, a Sankey diagram was created. It is a graphical representation of flow rates. The peculiarity of the Sankey diagram is that the arrow strength represents a volume-proportional reproduction of the material flow. These diagrams should give you a faster understanding of material handling. It is also possible with this method to identify which processes have the most material exchange. If the Sankey diagram is layed over the production layout, it is possible to see the transport routes very well. This is very helpful for future production layouts because long transportation routes can be avoided.

In order to understand how the overall concept works and how the individual components interact, a method called Business Process Model and Notation was used. It is a graphical specification language that can use symbols to model and document workflows.

1.5 Structure of the thesis

The master thesis is divided into a theoretical and a practical part. In the first theoretical part an insight into the topic of the value stream is given. It is a guideline from creating an actual value stream to redesigning the production layout. Based on this, the thesis deals with the general topic of Industry 4.0. Here, the potential uses of digitization and its impact on companies are highlighted. Building on this section, the subject of benchmarking follows. It will show the current state of the industry and the areas in companies that have a future potential for implementation of Industry 4.0 technology. Another part of this chapter is the comparison between the company and other companies. The final part of the theoretical section is the research of Industry 4.0 tools that the company could use in its production.

In the second part of the thesis, in the practical part follows the value stream analysis and the analysis of the material flow. It will be explained how the results were obtained and these are interpreted as well. The final part of this section is the development of a concept to network the components required specific for the company. For this purpose, a Business Process Model and Notation was created, which should clarify the connections. At the end of the thesis, the conclusion gives a summary of the work and a look into the future.

2 Value stream

A value stream (Figure 1 value stream) consists of all the activities and work required to fulfil a sales order. The start and the end is always triggered by the customer. The customer can be both internal and external.[1]

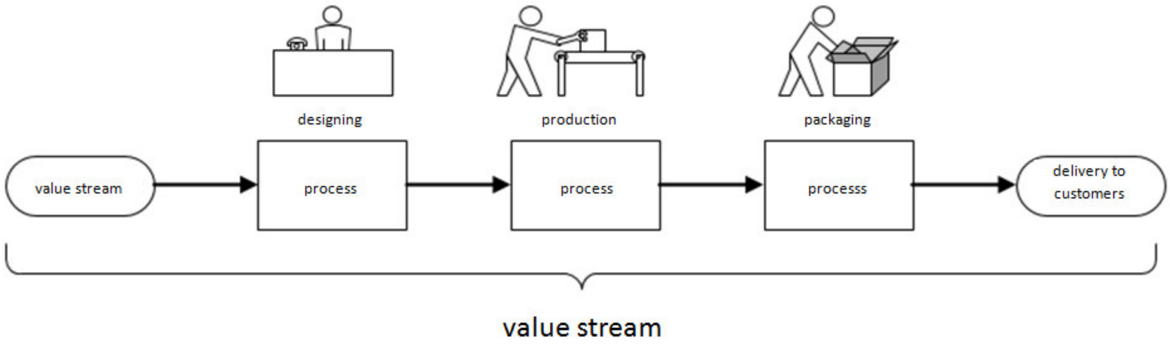


Figure 1 value stream[2]

The central idea of a value stream analysis is to look at the processes from the customer's point of view. The customer determines the requirements of the product and therefore the requirements of the overall process and the individual processes. The added value and the added waste of a product are oriented only to the customer, because he defines the product specifications. Considering the value stream, the main focus should not be placed on the individual process steps. Rather, the creation of the value of a product or service should be seen from a bird's eye view. Out of this perspective, it is possible to get an overview over the whole value stream. In addition, this approach makes it possible to apply any improvement to the whole chain and not just to the individual processes. Furthermore, it is possible to recognize relationships where improvement activities are necessary.[3]

The task of the management is the holistic consideration of the value stream. This task cannot be delegated to anyone. The manager is responsible for transporting and transforming the customer's requirements into the organization. Further, he must know what the customer is willing to pay for the product. Not all work steps increase the value of a product.[4]

Work steps that do not increase the value from the customer's point of view, falls under the category of non-value added work. This includes for example setup time, move time and waiting time. However, factors such as quality, function, delivery time and delivery reliability increase the value. For that, the customer is willing to pay money. There are different ways to find out what the customer's request is, which helps to spare the company misguided and

[1] Hines and Rich, 1997.
[2] Rolosixmelch, 2016.
[3] Hines and Rich, 1997.
[4] Tabanli and Ertay, 2013.

dissatisfied customers.[5]

2.1 Value stream mapping

This analysis, allows getting closer information about the actual state of the processes because it is recorded in detail. The knowledge gained is illustrated by appropriate symbols and data boxes. It is important not only to analyze sub-steps of the process, but also to record and analyze the overall process. The first challenge is to define the system boundaries correctly, so that all processes are holistically considered in the analysis. Besides the production processes, the material flow and the associated information flow have to be recorded as well. The aim of such an analysis must always be an efficient recording and clear presentation of all existing processes in a production facility.[6]

The scheme below (Figure 2 Value stream analyse) shows a proven methodology that provides a successful thread to optimize the value stream accordingly.[7]

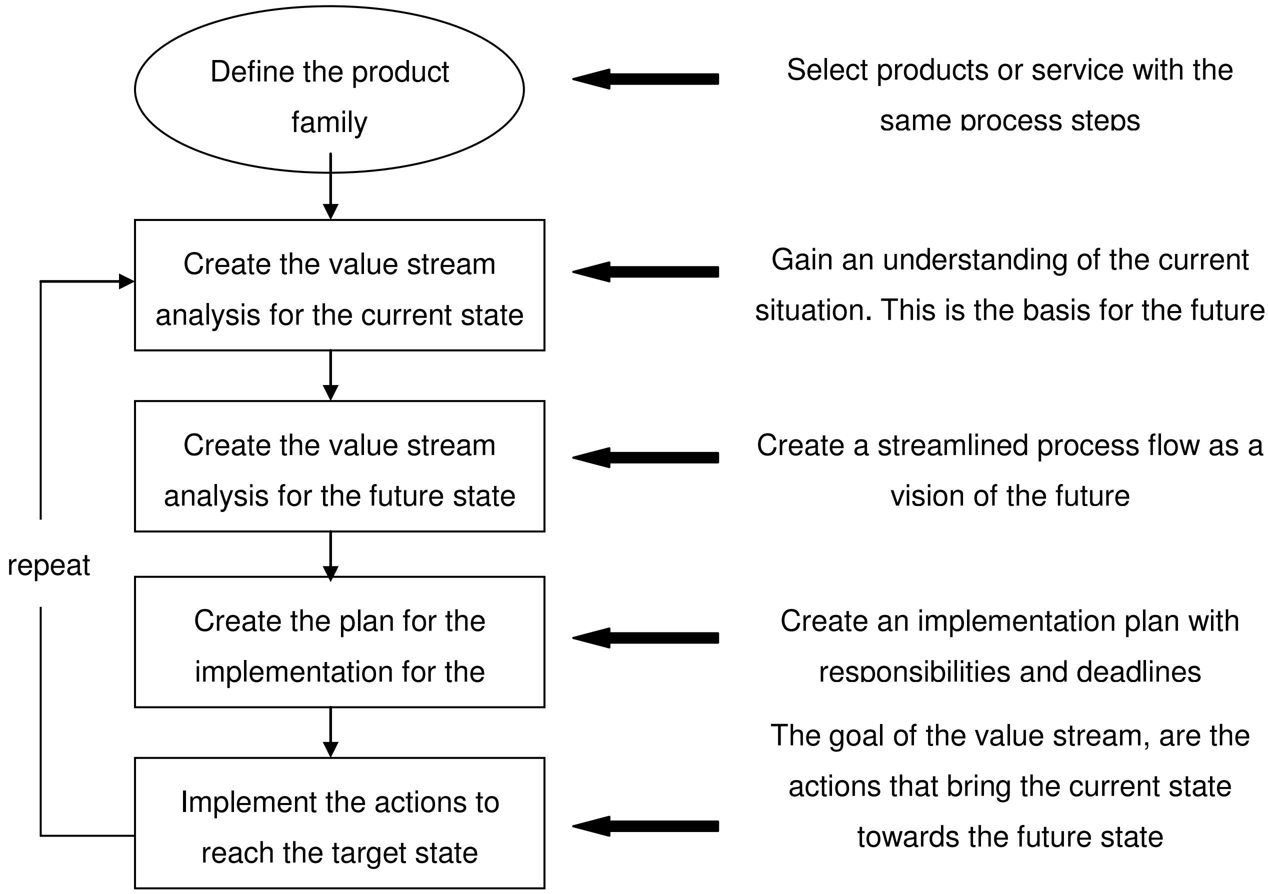


Figure 2 Value stream analyse[8]

[5] Hines and Rich, 1997.
[6] Patel, Chauhan, and Trivedi, 2015.
[7] Rolosixmelch, 2016.
[8] Rolosixmelch, 2016.

As can be seen from the illustration in Figure 2 Value stream analyse, it is not possible to achieve an optimal state in a value stream in the first try. Similar to the PDCA method (Figure 3 PDCA cycle) only a new target level is reached.[9]

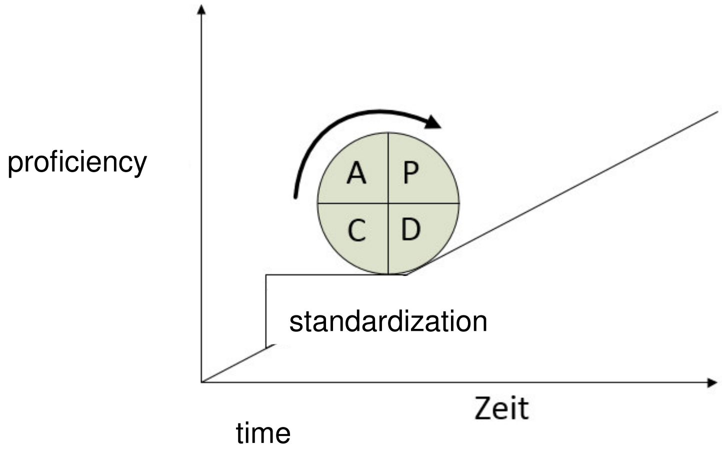
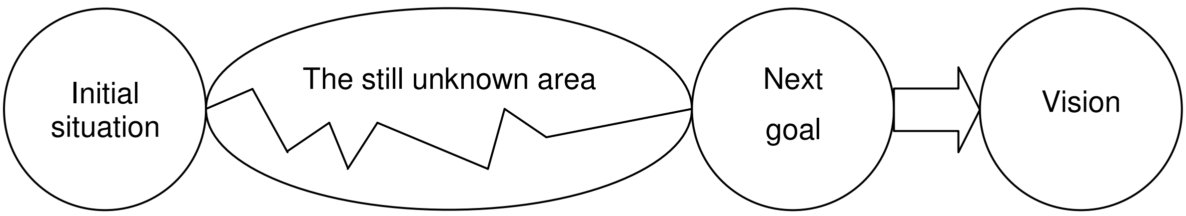


Figure 3 PDCA cycle[10]

The newly gained level must then be stabilized and standardized. Typical things which are adapted are the throughput time, process stability and efficiency. Depending on the outcome of the cycle, a decision has to be made whether these measures are sufficient to satisfy the customer, both internally and externally, nor not. If it is not the case, the cycle will go through again from the beginning. Through rethinking the picture above (Figure 3 PDCA cycle), this approach is easier to understand.[11]

A slightly different representation (Figure 4 way off to ideal condition), which also illustrates the path from the actual state to the desired state, emphasizes again that the path of optimization is not a straight line. The management tries to work in the right direction by means of the optimizations, but does not know if the path is leading to the desired goal.[12]



Where are we today?	What are we doing to get to the next goal? Implementation	What do we want to achieve next? value stream design	What is the ideal condition?

9 Roloixmelch, 2016.
10 Rolosixmelch, 2016; Tague, 2005.
11 Moen and Norman, 1996.
12 Roloixmelch, 2016.

Figure 4 way off to ideal condition[13]

The most important thing is that even the targeted goal is not reached on the first try, always keep the goal in mind. Thus, changes and deviations on the way are possible and one gradually approaches the desired destination. An adjustment of the value stream should always be carried out in the customer's interest in order to get closer and closer to the ideal value stream.[14]

The methodology of the value stream analysis creates a high level of transparency of the production processes. As a result, the processes crystallize out very clearly which do not contribute to the added value. These values must be attributed to waste. Besides the identification of waste, an additional aspect of value stream analysis is the presentation of delivery and lead times.[15]

The basic idea why this method was invented, was to reduce the cycle time. Like many other lean management tools, value stream analysis was invented by Toyota[16]. As the father of the Toyota Production System once said, "All we do is pay attention to the turnaround time. From the moment we receive a sales order to the moment we receive the money. We shorten lead time by eliminating all components that do not add value to the customer."[17]

An effective way to reduce cycle time is to look more closely at the waiting time. The composition of the cycle time (Figure 5 throughput time) consists of process times and waiting times. Process times are times when an action takes place on the product. Waiting times, on the other hand, are times when the product waits for the next process step. In the more detailed analysis, it turned out that the waiting times are the bigger share in relation to the process times.[18]

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[13] Rolosixmelch, 2016.
[14] Abdulmalek and Rajgopal, 2007.
[15] Langstrand, 2016.
[16] Ōno, 1988.
[17] Liker and Braun, 2013.
[18] Langstrand, 2016.

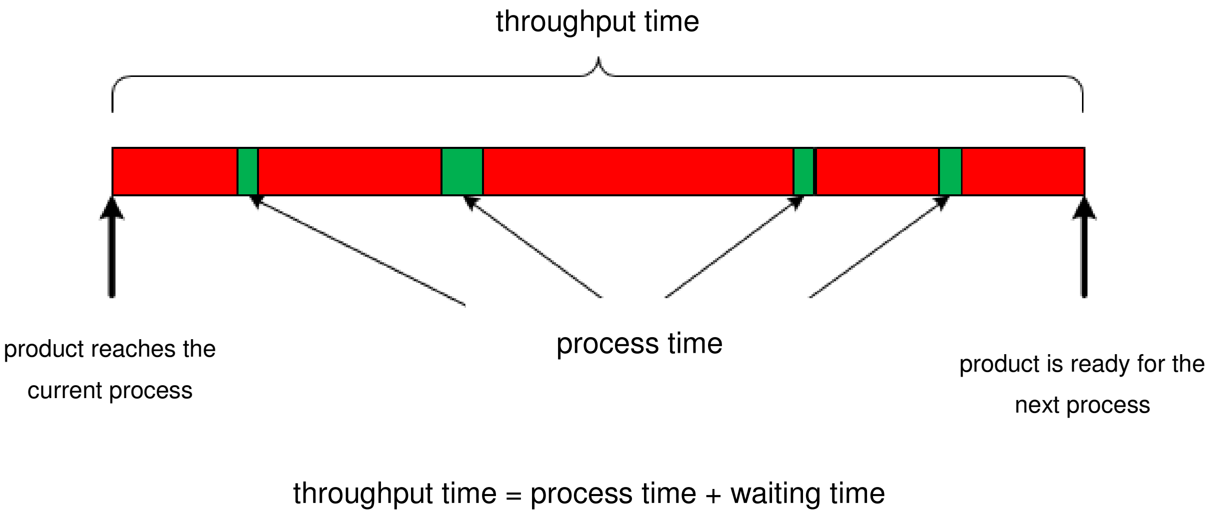

Figure 5 throughput time[19]

2.1.1 Objective of the value stream analysis

The main reason why companies do this analysis is to get clarity about the processes and their relationships. Since everyone has a different view or understanding of the processes (Figure 6 three states of a process), it is important that everyone speaks of the same thing. The method prevents confusion and misunderstandings as everyone has the same underlying data. It is easier to discuss an scheme that shows the whole production (information flow, material flow, production data) than a literal and theoretical description.[20]

[19] Rolosixmelch, 2016.
[20] Langstrand, 2016.

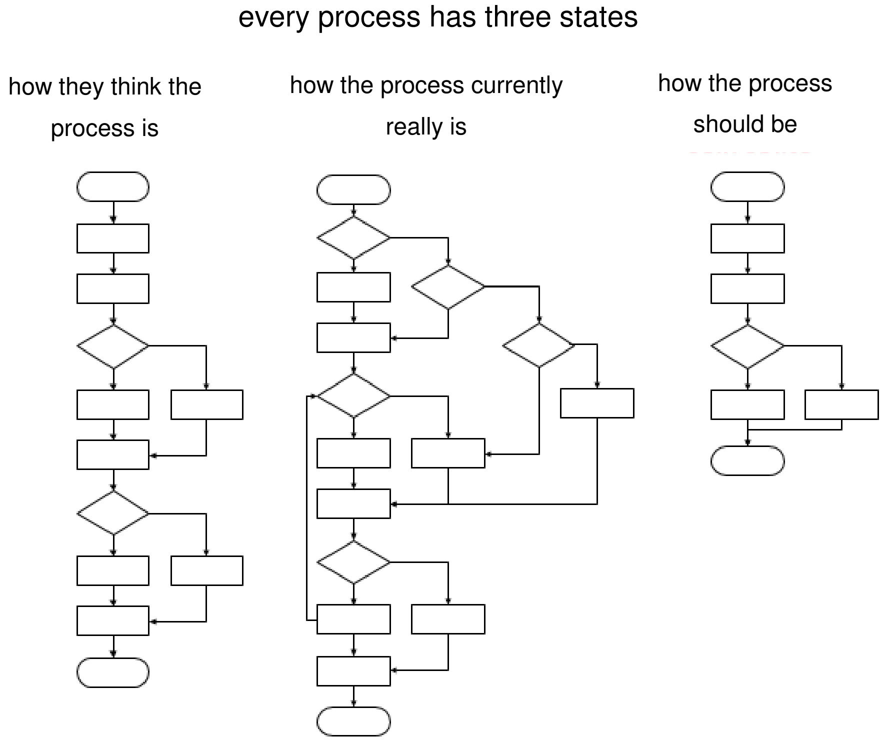

Figure 6 three states of a process[21]

In many companies, short-term or isolated improvements have shown that they do not bring the desired results. Only a holistic approach ensures that companies remain competitive. Value stream design, which will be discussed in more detail later, represent a future vision and a future goal. It gives a rough direction for the meaningful implementation.[22]

2.2 Value stream design

The actual state obtained in the value stream analysis is the basis for the value stream design. From the actual state, it is possible to find various improvements that should then lead to the desired state or the specific vision. Since human beings tend to improve everything as quickly as possible, these improvements are made without meaningful and structured procedures. These improvements are mostly doomed to failure.[23]

2.2.1 Types of waste

Since the improvement of the value stream is still a subject of lean management, it certainly follows its principles. The goal of lean management is to avoid waste. The design of the desired state can only succeed with strict avoidance of waste. Here lies the key to a profitable outcome. The seven types of waste should be minutely observed and prevented.[24]

[21] Rolosixmelch, 2016.
[22] Tapping, Luyster, and Shuker, 2002.
[23] Erlach, 2009.
[24] Kiran and Kiran, 2017.

Taiichi Ohno [25] defined the following types of wastage in classical lean management theory:[26]

- Transport
- Inventory
- Motion
- Waiting
- Over-production
- Over-engineering
- Defects

All these types of waste are interdependent. It may be that the overproduction leads to an increased stock, which in turn causes additional costs for the transport.[27]

2.2.1.1 Transport

The transport of objects is an activity that does not add value. This is pronounced in the factories: every loose piece of equipment and material is transported through the production. However, transport is one of the necessary wastes in production, as materials have to be fed into and removed from every production process. Nevertheless, it should be noted that this should be kept as low as possible. Moving materials binds resources that could otherwise be used for value-adding activities.[28]

2.2.1.2 Inventory

Inventory appears in the production in three forms. At the beginning of the value chain in the form of raw material, in production as "work in process" (WIP) and at the end of the value stream as finished product. Inventories in production tend to cover up grievances that have arisen elsewhere. This is a simple and quick way to hide process inaccuracies by increasing security. By this measure, the process problem is not resolved but postponed. High inventories lead to increased capital commitment and to a risk of impairment due to obsolescence.[29]

2.2.1.3 Motion

Motion includes both small and large movements. Any movement that goes further than absolutely necessary can already be counted as waste. Tools that are unnecessarily located further away, workplaces that are too large are just a few examples of waste at the workplace. Often the design of the workplace is not ergonomically thought out, which leads to unnecessary movements and subsequently to the restriction of the efficiency of the

[25] Ōno, 1988.
[26] Kiran and Kiran, 2017.
[27] Kiran and Kiran, 2017.
[28] de Bucourt et al., 2011.
[29] de Bucourt et al., 2011.

employee.[30]

2.2.1.4 Waiting

Either the employee nor the machine can do any value-adding work in the waiting period. However, it should be noted that it is not the employee who is waiting to continue working but the product itself. Much of the turnaround time for the production of a product is due to the lay and waiting times.[31]

2.2.1.5 Over-production

Overproduction means everything that is produced when there is currently no customer who takes the products off. In itself, the overproduction is a value-adding activity where the question arises whether the produced parts can also be brought to the customer at the end. This results in the lean doctrine of a value creation with a lack of demand, which is to be regarded as waste.[32]

2.2.1.6 Over-engineering

Over-engineering is when processes or manufacturing processes are unnecessarily complex without the need for the final product. On the one hand, this may be due to the fact that existing machines are used according to their potential or to the fact that processes are not adapted to technological progress. This topic is not limited to technical technologies but also to bureaucratic processes.[33]

2.2.1.7 Defects

Defects or rework due to lack of quality is generally attributable to waste. The invested work, respectively the added value is lost in case of defective parts which cannot be repaired. If reworking is necessary, another value has to be invested. Scrap and rework lead to delivery delays, not only in this part but also in follow-up orders. Since these problems can occur every day, the defects should be thoroughly identified and eliminated by root cause analysis.[34]

2.2.1.8 Order processing

The order processing is not directly production dependent. Order processing is an addition to the already mentioned seven types of waste. A large part of the value stream analysis is the flow of information. The flow shows possible shortcomings in the order processing, from the

[30] Chiarini, 2013.
[31] Patidar, Soni, and Soni, 2017.
[32] Szwejczewski and Jones, 2013.
[33] Vega-Rodríguez et al., 2018.
[34] Patidar, Soni, and Soni, 2017.

order entry to the order release clearly. This often requires multiple data storage.[35]

2.2.2 Implementation of the value stream design

A new value stream or a transformation of it into an efficient and customer-oriented value stream should be the objective. An increase in the efficiency of the new value stream is achieved by avoiding the eight types of waste. To be able to design an efficient workflow, it is recommended to build up the new value stream by following this five phases (Figure 7 procedure for value stream design).[36]

1. Structure of the factory and production structuring
2. Design of production processes and capacity dimensioning
3. Design of the material flow and production control
4. Design of the information flow and production planning
5. Planning the implementation and improvement measures

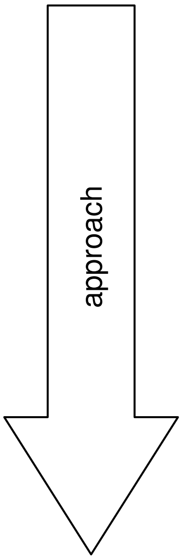

Figure 7 procedure for value stream design[37]

2.2.2.1 Production structuring

Since there are usually several different technologies for the production of the products in a factory, a demarcation is necessary, similar to the value stream analysis. The value stream design also refers only to a defined area within the factory. Defining this area corresponds to the task of factory planning. The whole factory is divided into individual production structures or segments. Basically, there are two types of subdivision, on the one hand in a horizontal and on the other hand in a vertical segmentation. The horizontal segmentation is based on the required resources and the vertical segmentation on production processes.[38]

Resource-oriented segmentation

Subdivisions of the production into horizontal layers, across the production process, are different resource-oriented segmentations. The production processes have an influence on the decision criterion. The bundling of competences is an advantageous way of structuring

[35] Chiarini, 2013.
[36] Patel, Chauhan, and Trivedi, 2015.
[37] Erlach, 2007.
[38] Dickson and Ginter, 1987.

the factory, if the processes are negligible and if there is a suitable factory structure. A typical outcome of a horizontal structuring is the bundling by equipment or by qualifications. The classic example is the workshop production, where the individual areas are named after their activities, like milling and turning. This type of subdivision brings great benefits but also has negative effects. By concentrating technological competencies, excellence is achieved in this area, but at the same time, the different departments are drifting farther and farther apart, even though they are all needed for one product. This approach, contrary to the production process, contradicts the idea of the value stream. For this reason, this method will not be further elaborated here.[39]

Product-family oriented segmentation

If a vertical segmentation is performed, like most companies do, the factory will be split up according to the production process for different product families. This creates segments in which all processes required for the production of a product are included. Unlike horizontal subdivision, the same technologies will occur in multiple segments because multiple value streams consume the same process. The formation of product families is one of the first steps in a production structuring in the value stream design. The challenge of creating a uniform production workflow is particularly difficult in parts production according to the workshop principle. However, in case of succeeding carrying out a consistent partial file formation, then the non-transparent and complex workshop production become controllable and a flow-oriented part production.[40]

For the value stream design, a classification into the product families is sufficient. For the redesign of the production, it would also be sensible to check the value stream design to see whether a product family is suitable for forming a production structure. A further subdivision would make sense from the market perspective, this could lead to other criteria such as unit numbers, demand trends, and market development. This could provide business plans, so it is possible serve specific market segments with one product family. The goals of production structuring should be that it leads to an unbundling of the material flows, which leads to an increase in transparency on the shop floor level. The focus of the individual segments should lie on the market-specific customer requirements. Incorporating employees into changing production processes is important to create an understanding of why these actions are needed at all. This leads to an increase in acceptance and can also be a motivating measure.[41]

[39] Sausen and Tomczak, 2015.
[40] Dickson and Ginter, 1987.
[41] Smith, 1995.

2.2.2.2 Design of the production processes

After the segmentation of a factory, a technological design of the production processes should take place through dimensioning and redesign. When dimensioning, it is first determined which equipment is needed and in which capacity. Capacity dimensioning is particularly important in manufacturing processes, as miss dimensions can often lead to lower capacity utilization or bottlenecks. In the redesign, several means of production are combined into new groups. The new groups have an extensive integration in a flow production process. This sometimes results in serious changes in the individual production processes. As a result, there may be a significant modification in the resources used and the resource requirements. In the assembly process, the greatest increase in efficiency can be achieved through process integration. However, this should not be underestimated in production either, since a coupling of the individual production processes in production lines allows a substantial increase.[42]

The customer tact time is the average production time that elapses between the disposal of two products. The tact time is the time between the completion of two successive products. The customer tact time is the target for capacity sizing in value stream design. The tact time should be approximately the same but never exceed the customer tact time. Compared to the actual state, the tact time of the individual production processes should be better coordinated with each other so that on the one hand excess capacity and on the other hand bottlenecks can be eliminated. The customer tact time is thus the first design guideline for an optimal value stream. The tact tuning chart (Figure 8 Tact tuning chart) offers a visual aid.[43]

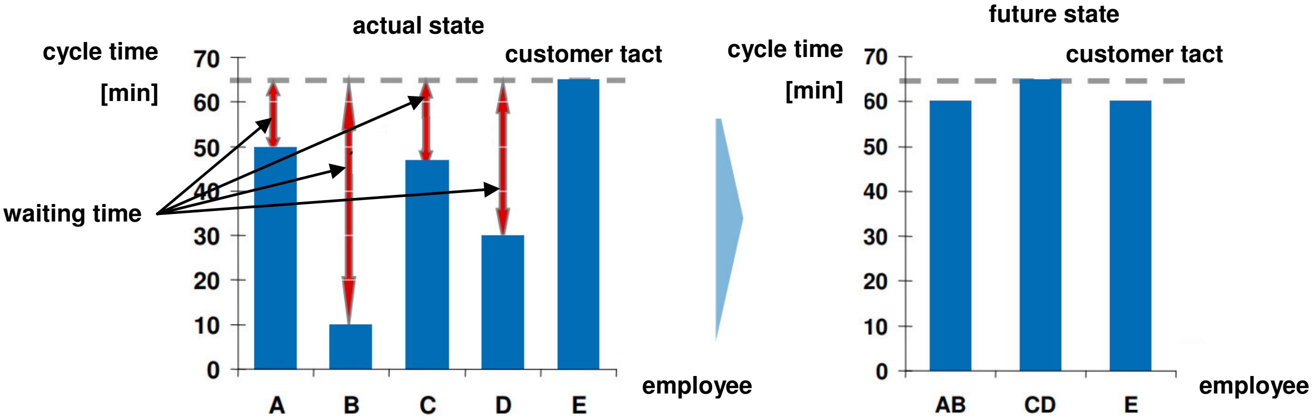

Figure 8 Tact tuning chart[44]

The chart shows the relationship between capacity supply and capacity requirements. The resources (for example machines or workers) must always be chosen in an integer, it is possible to approximate the resources to the customer tact time by increasing the production

[42] Hehenberger, 2011.
[43] Gabler, 2006.
[44] IPT, 2002.

or reducing the loss times.[45]

Workplaces that are spatially arranged in a line as a result of the work tasks, are understood by the principle of flow (DIN33415). The work load is divided into several work stations. In order to achieve a continuous flow production, an additional condition must be added. It was assumed that each workstation has a finished product. Another name that is often used for this is the so-called one piece flow principle. A product ordered by the customer is produced in the ideal production from the raw material by a continuous chain of well-utilized work steps. A continuous flow production is basically a single production process, which is subdivided into process steps. It follows that the ideal value stream is a process that goes from the raw material to the end of the product without interruption. This can be achieved by combining separate processes in the actual state through integration into one. This is the second design guideline.[46]

2.2.2.3 Production control

After the technological planning of the production processes in the value stream, through the introduction of a flow production, follows the conception of the production control. Production control is designed to make the material flow from goods receipt to shipping as smooth and steady as possible. A value stream is most efficient, when it is as predictable and uniform as possible. To ensure control, there are three guidelines: a fixed order execution, well-timed order release and low inventory for short lead times. The low throughput times and the precise execution of a defined sequence enable high controllability of the production. The order release at one point prevents that not well coordinated or even contradictory control impulses influence the otherwise predictable production. The order release is the interface to production planning.[47]

The definition of the steering rules prevents a prognosis-oriented planning approach from influencing the quantities to be produced and therefore from decoupling. The forecasting problem applies to all plans, it is not possible to predict the exact future in advance. The further someone plans in the future and the more complex the processes are, the less accurate the results become. In this context, the term "turbulence" has been established. The turbulence or turbulence problem is influenced by three factors: customer, production process and supplier. The behaviour of the three factors, with all their possible deviations is impossible to determine. In addition, the transitional time influences these as well. This is always scheduled between two consecutive processes. If this value is too high for safety reasons but the production runs trouble-free, the orders will be completed much earlier than

[45] Brenner, 2015.
[46] Erlach, 2007.
[47] Khojasteh, 2016.

planned, which in return will lead to an increase in stocks. This can lead to a morale, that the deadlines don't need to be kept for standard orders, because a lot of buffers were planned anyway. If an urgent order is brought forward, it slows the initial production down, what eventually leads to turbulence in planning and control.[48]

Production control should be as simple and standardized as possible. The strict adherence to once defined standards by employees and the management is necessary. Reliable, coordinated and customer-oriented production processes are required. The task of production planning is to enable a flexible and nevertheless uniform reaction to the turbulent environment of the factory.[49]

It can also be that production processes cannot be integrated into a flow production, a series production must be considered as an alternative. The classic approach in this case is a FIFO coupling. FIFO stands for first in first out. Since it also occurs that, for technical reasons, set-up times are incurred, repetitive parts must be linked to a warehouse in a lot production. A proven system to enable this control is the kanban system. The kanban rule causes internal production processes to be placed in a customer-supplier relationship. The removal of parts from the warehouse triggers a re-production of the same pieces. That way only the amount that is effectively needed is reproduced. Planning errors are eliminated and overproduction can be prevented. The lean material flow can be guaranteed by three design guidelines: continuous flow production, FIFO coupling and kanban control. Single processes or flow production are the parts of the value stream that are linked by FIFO or kanban.[50] When linking, a couple of things should be considered. Pacemakers take on an essential task. They ensure that there is only one point of entry in the entire production. The pacemaker controls production processes. A big advantage of this control is that there can be no misunderstandings or conflicting control instructions. This one process, which is adapted to the customer tact time, is also called pacemaker process.[51]

2.2.2.4 Production planning

The design guidelines of the production planning should handle the whole chain, from the planning logistics to the order release. So far, it has been assumed that order release has always been done in an ideal way. However, under real circumstances this is never the case. The goal is to create a steady flow through production. To ensure this, production planning must fulfil three tasks. The customer orders are to be converted into production orders in the first step. This must be reconciled with the pacemaker process. One approach to continuous production is to create lots of equal release quantities. This form of volume-based production

[48] Moinet, 1995.
[49] Schleipen et al., 2010.
[50] Ōno, 1988.
[51] Erlach, 2007.

adjustment results in a queuing process when the customer demand fluctuates. The production orders must be subsequently placed in a corresponding order. This happens through production balancing of all product variants. In the third step, the release times and the sequence of the orders still have to be adjusted on certain capacitive and technical limitations.[52]

As already mentioned in the first task of the production planning, one of the main tasks of it is to ensure that there is an equally, constant production load in the production. This is usually done with the pacemaker process. This is a precisely defined volume of work, supplied in the same rhythm. This also leads to a production smoothing, since always the same batch sizes enter at constant time intervals. The product range usually consists of several variants and products. So it is a task of the production planning to ensure that a production order is determined. Since the manufactured products are usually not always the same, this must be planned. The objective here is to achieve a production balance with the sequence formation. Balancing the production mix means changing the variant after each release interval.[53]

With the adjustment of the production volume and the balancing of the production mix, the planning logistics for production processes is completed. It often happens that the capacity in production varies, the planning must also deal with this. The frequency with which orders are released must be based on the process with the smallest capacity. If the process with the smallest capacity is also the pacemaker process, further planning is unnecessary. If it is not, there is a bottleneck in the value stream. On the one hand, this bottleneck can dictate the maximum number of pieces in the value stream. On the other hand, it can specify the order of the production sequence.[54]

2.2.2.5 Conception and implementation

This section can be seen as a kind of summary of how to cope with the redesign of a production taking into account the value stream. The first step is to create an area or product group which is of interest. Based on this, we build up the future concept of the value stream taking into account the ten design guidelines. [55]

1. The determination of the customer tact time has the highest priority.
2. Summarize production processes, through technical integration or the introduction of flow production.
3. Coupling of the production processes from supplier to shipping using FIFO logic.
4. Introduction of a warehouse pull system controlled by a kanban system.
5. Redesign of the shipping principle, direct shipment, or shipping from a finished goods

[52] Fargher and Smith, 1992.
[53] Hübl, 2018.
[54] Hübl, 2018.
[55] Erlach, 2007.

warehouse.
6. Define the appropriate kanban quantity and container size.
7. Define which process is the pacemaker process.
8. Definition of the release unit for production levelling.
9. Design of sequence formation
10. Consideration of possible bottlenecks that may arise due to capacity or restrictions.

These ten rules are a standardized way of leading production to a significantly improved production process. However, the actual success of the redesign will only set in, if it is possible to make the way with an innovative transformation. The difficulty is not to fall back into old patterns of behaviour. In the workshops for designing the new layout, the more creative and unprejudiced the work is, the greater are the chances of success. Likewise, the consent of all members of the project staff involved must exist so that not only a concept but also a consensus is reached.

Once the target concept has been adopted, an implementation plan must be drawn up. This should set the path to the new value stream design and contain the parameters to be achieved: tact time, set-up time and lot sizes. Since the improvement measures have already been defined but not yet implemented, they should be marked with a lightning bolt. This flash comes from the Japanese Kaizen philosophy. This should visualize the continuous improvement. The value stream allows a transparent view of the entire production, an evaluation of all measures of improvement can be made here, as all are visible. Subsequently, sections are defined in which measures are necessary. These sections must then be redesigned according to the specifications until the desired state is reached.[56]

The first process to be redesigned in a fixed sequence is the pacemaker process, as it has the greatest impact on production. Based on this, all downstream processes are adapted to the pacemaker. The material supply of the pacemaker process should be very lush at the first time so that there are no bottlenecks at the beginning. Once the process section provides the desired results, one can continue in the process chain upstream, from the pacemaker process on to the conversion measures. These steps always go as far as the next kanban control cycle specifies. In parallel with the redesign, the existing production planning system can be dismantled.[57]

The typical improvement measure that can be achieved by the redesign is the drastic reduction of the turnaround time. Elimination of waste in the production processes is a way to reduce the tact time, so it undercuts the customer tact time. Improvements in maintenance increase process reliability. Considerable reduction of set-up times are achieved through

[56] Gabler, 2006.
[57] Lasa, De Castro Vila, and Goienetxea Uriarte, 2009.

optimization measures or elimination of set-up times due to jig construction.[58]

2.3 Benefit of the value stream analysis

As some of this was already mentioned, this is kind of a summary. The value stream design method facilitates to grasp everything that is related to the considered production area. Not only the processes are recorded but also the information flow. This creates a basis that makes it much easier to talk about this area. When people are discussing about the value stream, there are no misinterpretation or communication problems, since everyone sees on the scheme what is being talked about. Another positive aspect of creating the value stream is the fact that it becomes visible and conceives the process flow.[59]

Quite strange patterns of behaviour often emerge, as the process flow deviates from the planned one. After completion of the value stream, it generates an excellent overview of the entire process flow. The bird's eye view does not help to see only a few details, but the big picture. As a result, optimization measures are not only applied to a small area, but also applied to the entire process flow. The danger was always optimizing only one process, which only shifts the problem in manufacturing and does not solve. The optimization measures that have been adopted are not immediately implemented holistically in almost all cases. By means of the value stream design, it illustrates a roadmap, where the future projects are implemented. This makes planning much easier and no projects are overlooked. A very important aspect of the value stream is the acquisition of a continuous transparency along the whole production. This makes it very easy to identify wastes and to eliminate them specifically. By eliminating waste, not only does the value of the product increase, but focus is more on the issues that increase your value to the customer.[60,61]

Targeted and systematic waste reduction that in most circumstances will deliver significant cost reductions through low cost or no cost improvements. A lot of the continuous improvement (kaizen) focused on eliminating the eight wastes, typically require rethinking current practices and not significant capital investment. The disciple that will be gained in the control of the value stream will have significant qualitative benefits for the customer. As companies reduce their lead-times and become reliable, their service reputation will grow. Dealing with the challenges of growth is so much more enjoyable. It will become obvious which organisations are creating difficulty in the ability to improve and maintain consistency of the value stream.[62]

[58] Erlach, 2007.
[59] Patel, Chauhan, and Trivedi, 2015.
[60] Vega-Rodríguez et al., 2018.
[61] Schlechtendahl et al., 2014.
[62] Patel, Chauhan, and Trivedi, 2015; Abdulmalek and Rajgopal, 2007.

3 Overall Equipment Effectiveness

Overall Equipment Effectiveness is a measure defined by the Japanese Institute of Plant Maintenance. The key figure provides information about the value added of a machine, as well as a worker. The productivity as well as the losses can be represented simultaneously with this one figure.[63]

The measure consists of three components: availability factor, performance factor, and quality factor. The three factors can each take the value between 1% and 100%.[64]

In order to be able to achieve comparability in production, it must be ensured that the data collection happens in the same way in every process. For this purpose, a detailed plan must be prepared in advance so that no deviations occur during the installation of the data collection system.

3.1 Calculation of the OEE

The OEE calculation is based on subtracting times. Starting from a production period, the system downtime is first deducted. After that the losses due to slowed plant operation and finally the losses due to not-in-order parts. The result is the period in which flawless products were produced at maximum speed. The ratio of the two periods gives the OEE as a percentage. The figure (Figure 9 OEE calculation) shows the OEE in steps with time periods and loss types.[65]

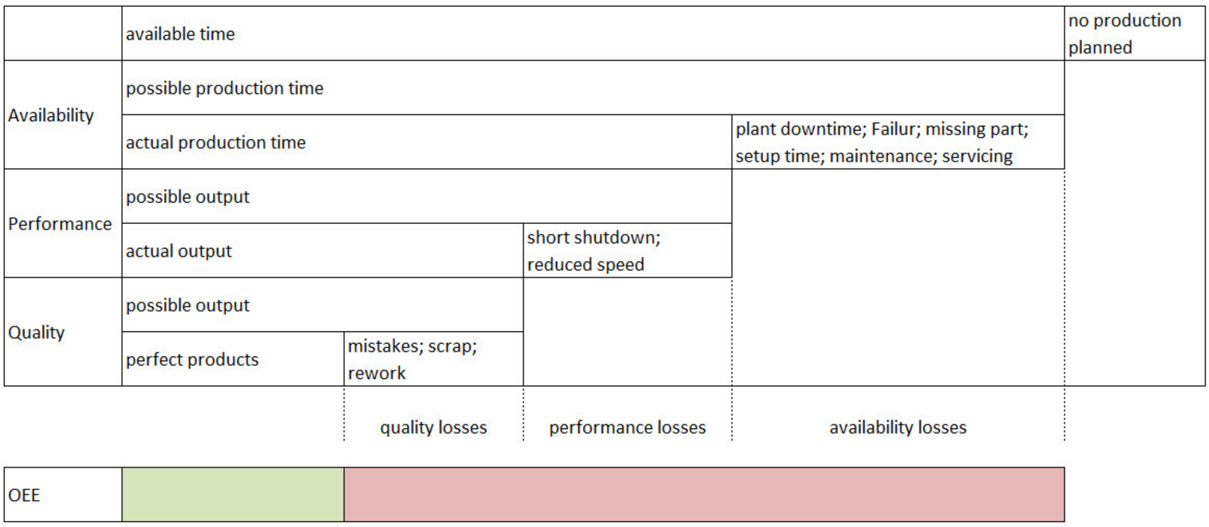

Figure 9 OEE calculation[66]

In the technical literature, the Overall Equipment Effectiveness[67] is calculated as follows:

[63] Kiran and Kiran, 2017.
[64] Ōno, 1988.
[65] Focke and Steinbeck, 2018.
[66] Focke and Steinbeck, 2018.
[67] Nakajima, 1988.

$$Availability = \frac{Run\ Time}{Planned\ Production\ Time}\ [\%]$$

Availability is the share of actual production time in the possible production time. It is reduced by all events that are not planned. Classic examples are strikes, missing personnel, missing orders, failures due to environmental influences.[68]

$$Performance = \frac{Ideal\ Cycle\ Time *\ Total\ Count}{Run\ Time}\ [\%]$$

The performance factor is a degree of loss due to deviation from the planned quantity. Caused by minor disturbances or failures.[69]

$$Quality = \frac{Good\ Count}{Total\ Count}\ [\%]$$

The quality factor indicates how much loss is due to broken or overworked parts.

$$OEE = \frac{Run\ Time}{Planned\ Production\ Time} * \frac{Ideal\ Cycle\ Time\ X\ Total\ Count}{Run\ Time} * \frac{Good\ Count}{Total\ Count}\ [\%]$$

The OEE is calculated by multiplying the three values. The result of this calculation is a percentage of a statement about what proportion of the planned machine run time was actually produced. The value will usually be well below 100%, as the individual values are already significantly lower. If in practice a value of 85% is achieved, this is already considered "very good".[70]

[68] Focke, 2014.
[69] Focke, 2014.
[70] Bicheno, 2004.

4 Industry benchmark

Benchmarking is the comparison of results or processes against a baseline. Companies mostly use this method to compare themselves with their competitors. This clarifies how well or how poorly the other company, department or competitor performs, compared to oneself. All known business areas and functions are analyzed. The winner of each comparison criteria represents the reference point, the benchmark, also known as "best practices".[71]

4.1 Four types of benchmarking

There are four different variants of benchmarking: the internal, the competitive, the functional and the transferring concept.[72]

Internal benchmarking

To make a comparison it is not always necessary to leave the company. It is possible to do this within the company boundaries. Corresponding partners are absolutely necessary. Multinational corporations or individual profit centres usually use this variant. Large corporations can compare individual divisions in the group with countless levels of comparison. For example, marketing measures can be compared across different regions. Why does the same campaign work better in one part of the world than in another? Where are the biggest fixed costs incurred? As a result, structural problems can also be identified. In such a comparison, different cultural working methods have been adopted all over the world, they must also be taken into account. These data are already available in abundance (see Geert Hofsted: The Dimension Paradigm[73]).[74]

The prerequisite for internal benchmarking is that processes, problem solving and manufacturing methods within a company are different. These differences usually develop from the history of a location. However, the biggest obstacles to an internal benchmark comparison remain the own employees. This usually requires persuasion and explanatory work. The concern of the employees that other departments could work more efficiently, makes many comparisons impossible. However, some employees oversee the opportunity of their departments to learn from a more efficient department. The internal comparison is not only intended to compare with other departments, but also to create a basis for comparison with competitors.[75]

Competitive benchmarking

Competing with competitors is not a new invention. This practice is the same age as the

[71] Rau, 1996.
[72] Andersen and Pettersen, 1996.
[73] Hofstede and Bond, 1984; Adeoye and Tomei, 2014.
[74] Crom, 1995.
[75] Mertins, Kempf, and Siebert, 1995.

market economy itself. Being inspired by other companies and taking on an idea is a tried-and-tested principle for surviving tough competition. In doing so, patents and laws should protect the competition against overly fast access. Nevertheless, these same laws also create the biggest problems in competitive benchmarking. Many try to achieve the same status as the competitor with this method. Benchmarking should be used to find a condition that outperforms the competition. The processes of the comparison partner should serve to make one's own better. Often very creative approaches are needed. Often, it also helps to move or redefine the object of the comparison. This allows to bypass any possible limits.[76]

At the same time, the goal of obtaining useful information about the competitor's products, processes, work processes and economic data must not be forgotten. It is recommended not only to compare the criteria with the market leader, but also with the midfield. They are also trying to catch up with the market leaders. Therefore, they often have differentiated and creative approaches that can inspire the company substantially. However, the biggest problem with a benchmark comparison with competitors is to get the information. Partnerships have to be built up over the years to maintain them. In practice, only basic procedures and methods are revealed.[77]

Functional benchmarking

Many companies shy away from the great expense of a co-performance benchmarking comparison. Since information gathering is always the deciding factor, functional benchmarking was introduced. It does not limit itself to the competitors, but looks at other industrial companies that are ready for a partnership. These partners often have more interest in sharing processes and workflows. Some competitors always see themselves as better off and therefore will not want their processes to be revealed.[78]

The reason why functional benchmarking works is because the information that is shared is not a company secret. Companies from different branches but of similar size handle tasks in a similar way. A good example is the company canteen. By means of similar process structures of different companies one tries to achieve an optimal process structure for his company. Sales and warehousing, order acceptance or service organization are just a few other areas of application where functional benchmarking works. This results in a huge field of possible companies. The goal is to find the best on the market for its recognized vulnerabilities. The same framework conditions must apply to both. The key to the success of such underpinnings lies in the fact that those who are responsible for calculating or market

[76] Zairi and Leonard, 1996.
[77] Rau, 1996.
[78] Andersen and Pettersen, 1996.

leaders are determined by the same customer requirements.[79]

Transmitting benchmarking

The distinction between functional and transmitting benchmarking is not easy. These two methods are therefore often summarized. It is quite clear that there is a demarcation. The transferred benchmarking can be used with partners in other industries as well as in their own industry.[80]

The transmitting benchmark should be approached very abstractly. The three variants before were about finding comparable objects. This is no longer the case with transmitted benchmarking. With this method, not similar companies are compared with each other, but with the use of basic functions of one work steps to integrate it in a different process. An example should explain the topic: The knotting technique of a nylon fishing net serves as an improvement suggestion for carpets. By means of such very far-fetched comparisons very good comparison processes can be found.[81]

4.2 Benchmarking as a process

The term benchmarking describes almost always a process. The inventor of this systematic approach is Robert C. Camp. He developed a five-step model (Figure 10 Benchmark process flow in five steps after Camp), which is still used in most companies today. Of course, the variants used today are adapted to the individual application cases. The five levels can be subdivided further, leaving a total of ten individual steps.[82]

[79] Camp, 1989.
[80] Mertins, Kempf, and Siebert, 1995.
[81] Rau, 1996.
[82] Rau, 1992.

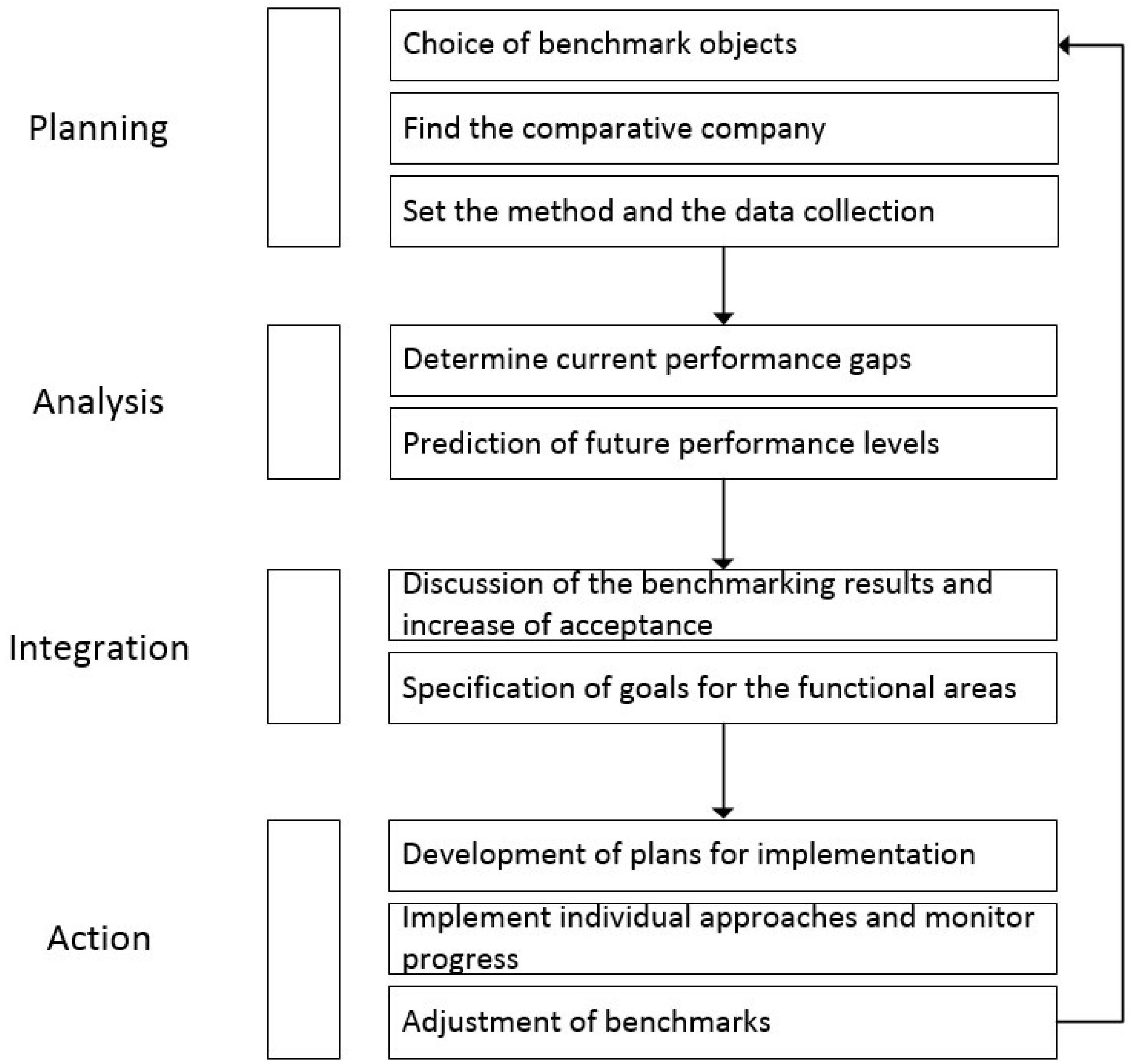

Figure 10 Benchmark process flow in five steps after Camp[83]

- Planning phase

  Planning is the first step. The system limits are determined. It's defined what should be compared. Mostly the first mistakes are already made here. The most common mistakes are: projects too broad or objects not clearly marked. In practice, a popular tool has been established: "Everything that is measurable is suitable for benchmarking". The tool is also called "product of the business function". Since not every parameter is tangible, solutions for this problem have to figure out. How it is possible to express customer satisfaction in a number for example? The choice of measuring methods is very decisive. They must be chosen so that they actually reflect the result. As the statement, the task is challenging. This requires a lot of experience in order to choose the decision criteria.[84]

  At this stage, the partners for a benchmark are chosen. The four approaches (internal, competitive, functional and transmitting benchmark) are taken into account. As mentioned

[83] Rau; Camp, 1989.
[84] Elmuti and Kathawala, 1997.

above, obtaining information is one of the central themes. If this is not possible on a usable level, meaningful benchmarking cannot be used. Data collection should also be considered at this stage. There are various options available to a company: these range from internal data to public data or data mining through fieldwork.[85]

- Analysis

  In this phase, the output of the benchmark is already available. The interviews and the data collection have already taken place. The data is prepared and ready for analysis. The analysis deals with comparing the different data obtained with the own internal data. The result of this analysis will always be either a positive or negative competition gap. A positive gap would be the goal, because that means its own object is better than the comparison object.[86]

- Integration and implementation

  In this phase, the first changes are defined. Before that, the results must be communicated comprehensibly to everyone who was involved. Often the outcome of these results will face not much acceptance. Especially if the competition gap is negative. In order to bring the change to the employees, explanatory work and persuasion are necessary. For easier understanding, the comparative values are often used to highlight the problems. Likewise, in this phase, possible functional goals are formulated. These goals are achieved by adopting the selected processes.[87]

  If the goals out of the benchmarks are clearly formulated, the next step is the implementation. Always start with those who promise the greatest chance of success. It is important to develop action plans and implementation plans. These lead to the achievement of the set goals. By gaining information where other companies work more efficient, the best possible industrial standard should be created for the own company. Building on this, it will develop the company further. Larger companies should pay attention to an implementation that affects the whole company. If it’s possible, it should be avoided to rehabilitate only a small part of the company. Therefore, the result of benchmarking should always be included in the overall planning of a company.[88]

- Controlling and adjustment

  After the implementation of the improvement activities, a constant review is necessary. This ensures that falling back into old patterns is not possible. In more detail, the measured variables must be adapted to the new conditions. This ensures a constantly evolving process and not standing still. Based on these changes, it is possible to see if the company is developing in the desired direction. Benchmarking always brings some

[85] Zairi and Leonard, 1996.
[86] Rau, 1992; Camp, 1989.
[87] Bhutta and Huq, 1999.
[88] Ahmed and Rafiq, 1998.

uncertainty factor into the company, it is important to anchor it in strategic management. This will dispel the last hurdles in a company.[89]

4.3 Comparison benchmarking between the company and its competitors

After the theoretical part, the idea was to bring benchmarking to life. As described in the section competitive benchmarking, this task is difficult to implement. The plan was to make a benchmark comparison, but this attempt of practical work of benchmarking was prevented early. This study is commissioned by the company, so direct competitors refused to provide information about their production. Apart from that, it was prohibited to grant any insights into their production to the competitors. These circumstances resulted in a certain predicament, gaining the needed information about other companies. Fortunately, several others had the same problem, which resulted in the research topic: "Industry 4.0 international benchmark, future options and recommendations for production research".[90]

In the first part, the paper captures the status quo of where the different countries currently stand. Since Austria and Germany are very closely connected, the same data is used in a simplified way.

4.4 Country benchmarking

In Europe, the topic of Industry 4.0 is differently understood then in other parts of the world. Here the attempt is made to bring industrial value creation into co-operation with human cooperation. So this is a socio-technical challenge. Sustainability and increased productivity are just as important as an excellent infrastructure. Germany is trying to become a technology leader in intelligent production systems. Compared to Europe, the topic of Industry 4.0 is quite different in the US. They are trying to create the greatest possible value for the customer. The Internet of Things (IoT) and tomorrow's business models are the two topics that are particularly in focus. Japan and South Korea are more likely to increase their production even more. Although it has already been greatly optimized. The intelligently networking production systems should bring them the desired success. In China, politics dictate the digitization of the economy as one of the central themes. China concentrates on the small and medium enterprises. Here the connection to the world leader in the field of advanced manufacturing is to be accomplished.[91]

Since there are also differences in Europe, a closer look at Germany’s attempts follows. In Germany people are trying to transform engineering expertise into the digital world. In doing so, they want to become the leading supplier of products for Industry 4.0. Excellent

[89] Rau, 1992; Camp, 1989.
[90] J. GAUSEMEIER, 2016.
[91] Brian, 2017.

experience from mechanical engineering to production technology is one of Germany's strengths. This should be further promoted and improved through the use of network system. The education system offers Germany a big advantage. Early specification in the dual education system allows companies to access a broad base of professionals. Germany still has some weaknesses in the area of information and communication technology. There is a lack of suppliers in the IT sector and the use of intelligent products. The drivers of Industry 4.0 are changing business in established markets. New competitors, who are shifting from hardware to software, are also drivers in the marked. The challenges that companies face are in particular the overcoming of current business models and the barriers to data protection.[92]

4.5 Focus area of benchmarking

This chapter aims to show where the focus areas of Industry 4.0 are. These following 15 fields (Figure 11 Focus area of benchmarking) have been defined, in which benchmarking should be considered.[93]

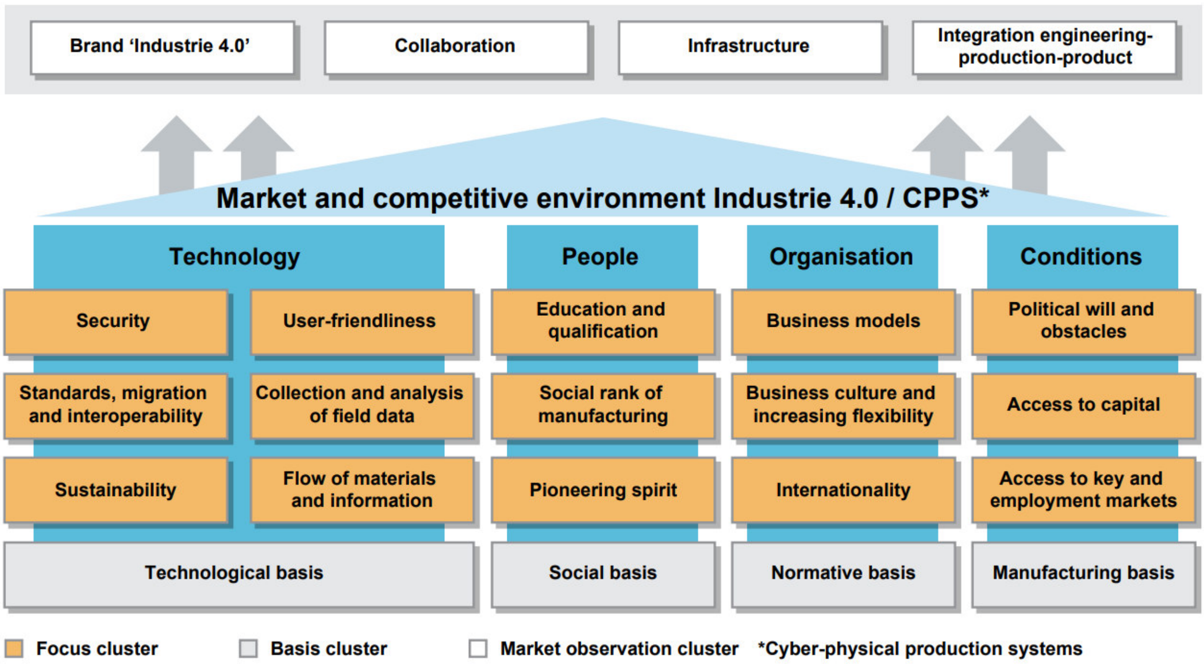

Figure 11 Focus area of benchmarking[94]

The subdivision was again divided into 4 main groups: technology, human, organization and general conditions.

- Technology

  Security issues in this context include security concepts for cyber-physical systems and

[92] Kearney, 2018.
[93] Gazsemeiser and Klocke, 2016.
[94] J. GAUSEMEIER, 2016.

the generalization of industrial security. Standards, migration and interoperability are the standardization of open interfaces and participation in international standardization processes. Appreciation of sustainably produced goods are drivers for companies to take these issues more seriously. The ease of use of the products and the man-machine interface is an important part of the success of the products. At the same time, aspects such as ergonomics and occupational safety should not be forgotten. In order to be able to improve the adaptation of products to customer requirements, as much data as possible should be collected. The field data recording is essential. From the generous data, the customer requirements can be better read and analyzed. The flow of materials and information plays a central role in the context of Industry 4.0. Digitization in this area is clearly increasing corporate transparency.[95]

- People

  Workers will continue to be the key figure in manufacturing companies. The steadily improved training enables companies to access new resources. Wherever people work, they always generate appropriate knowledge.[96] To ensure that this knowledge is not lost, appropriate systems must be installed. These should manage to store the knowledge in the company and provide it to the next generation. In order to improve the value of production, efforts are made at directing production towards technology or manual labour. These two perspectives make it possible to see the view of production as a cost or value driver. It should endeavour to awaken the pioneering spirit of the co-workers again. By lowering risk aversion and promoting entrepreneurship culture, some workers would bring innovative ideas to light.[97]

- Organisation

  Industry 4.0 brings not only change in production but also in business models. Traditional systems are adapted or replaced. Start-ups get the opportunity to work in the company's structure. Not only do the business models change, they change the whole corporate culture. Dynamic forms of organization facilitate the flexibilization of work organization in production. Opening up new markets promotes the awareness of the company. This will also attract new talents, of whom the company will benefit again. In addition to the new markets, this may result in international collaborations.[98]

- Conditions

  Politics is a driver that should not be underestimated in the Industry 4.0 sector. Funding in this area but also in similar areas accelerates the implementation of the digital factory. On the one hand, industries, that have left Europe as a production location due to wage levels

[95] Eckelt, 2016.
[96] Spöttl, 2017.
[97] Scott, 2018.
[98] Eckelt, 2016.

or other reasons, can be brought back. On the other hand, politicians can systematically promote new technologies through a variety of regulations. Since all of this primarily requires a lot of capital, the corresponding framework conditions must be created for this as well. The incentive to invest in research into new technologies should be aroused as well as the motivation to transfer technology. Investing in perhaps promising technologies requires the provision of venture capital. As new technologies are established, new test markets should be identified as well. This will show whether the developed products are suitable for the customer.[99]

[99] Lasi, Kemper, et al., 2014.

5 Industry 4.0

First of all, the question arises what is behind Industry 4.0 and where does it originate. What is the motivation for companies to change their actual business operations and implement Industry 4.0? In most cases, the operation is not ready for such drastic steps. So this would take a lot of time and requires will to spend money.[100] First, the term Industry 4.0 should be defined. It was mentioned for the first time in 2011 by the German Federal Ministry of Education and Research.[101] The term "Industry 4.0" belongs to a project in the high-tech strategy of the German government and is structured in four design principles, which should help companies to define their scenarios. The four points are interoperability, information transparency, technical assistance and decentralized decisions. To get a better understanding what these four words mean, they will be briefly introduced.[102]

Interoperability means, that every part of the production, people, machines, sensors and other devices can communicate with each other independently from the producer.[103]

Information transparency is defined as a virtual copy of the physical world that is fed with specific information from all the sensors out of the process chain. [104]

Technical assistance must be split up into two subgroups: First, assistance systems should support the human with their decision-making through visualizing the current state and second by supporting them doing their ordinary work.[105]

The meaning of decentralized decision-making is that the system can make its own decisions and perform on an automated level based on predefined parameters.[106]

5.1 Value drivers and industry 4.0 levers

According to research of McKinsey and Company, there are eight value drivers, which are essential for the topic Industry 4.0 (Figure 12 Value drivers).[107]

In the following, all value drivers but only the industry 4.0 lever, which are considered for this master thesis, are explained.

[100] Wischmann, Wangler, and Botthof, 2015.
[101] BMBF, 2011.
[102] Kang et al., 2016.
[103] Hermann, Pentek, and Otto, 2016.
[104] Hermann, Pentek, and Otto, 2016.
[105] Hermann, Pentek, and Otto, 2016.
[106] Lasi, Fettke, et al., 2014.
[107] Baur and Wee, 2016.

Figure 12 Value drivers[108]

The assignment of the levers to performance areas directs the focus on the concrete value creation and thus promotes the discussion of suitable individual concepts. Since the implementation is usually accompanied by interdisciplinary and comprehensive changes in the company and sometimes requires high investments, identified levers before implementation should be analyzed in more detail on their suitability for the company. In particular, potential risks and challenges with regard to existing processes, interdependencies between levers and their environment, technological as well as organizational and cultural implement ability of the levers and the financial investment burden of the 4.0 initiatives should be considered.[109]

5.1.1 Resource /process

Work, land, environment, and capital are the typical resources that are available for companies to accomplish their task. These factors are often referred to as production factors.[110] It is important to distinguish between exhaustible and non-exhaustible resources. A division into assets and liabilities, as it is done in business administration, also raises a very interesting picture of the subdivision of resources. Assets are people, know-how or patents, whereby liabilities are material or machines. All operational uses or factors of

[108] Baur and Wee, 2016.
[109] Proff et al., 2016.
[110] Prof. Dr. Voigt and Prof. Dr. Wohltmann, 2018.

production are freely available on the market, which can bring a competitive advantage to company assets.[111]

- Intelligent lots

  Digitization does not stop at the transport containers. Pallets are equipped with a wide variety of sensors. These make it possible to fulfil customer-specific requirements. By developing ever smaller sensors, it is possible to equip the transport containers with a variety of sensors. In addition to tracking pallets, the technology enables a variety of other applications. The sensors range from simple temperature sensors to acceleration sensors that measure the load or signal movements of the pallet, to CO2 probes and moisture meters. In combination, they convey the current environmental situation at all times, but also provide an overview of the history of a freight consignment. For communication and data transmission mostly LoRaWAN[112] networks are used. The development of self-powered systems, generating electricity through the movements of the transport containers, already enables autonomous operation in production.[113]
- Real-time yield optimization

  Yield Management is a variable pricing strategy based on understanding, anticipating, and influencing consumer behaviour to maximize revenue or profits from a fixed, time-limited resource.[114] A very interesting application in companies is real-time revenue optimization. All processes are continuously monitored and fluctuating prices per product are maintained depending on the data of the individual processes. This real-time data is also used to ensure transparency throughout the supply chain and improve overall performance.[115]

5.1.2 Asset utilization

Asset-utilization ratios are used to determine the profitability from inventory to accounts receivable, sales and total asset turnover. The higher the utilization ratio of any given asset is, the more profit makes the company.[116]

- Routing flexibility

  Routing flexibility stands for the capability to process parts on different machines when any faults occur. The product then goes through an alternative production route.[117] In addition, a distinction must be made between the potential and the current flexibility. The potential flexibility in production provides the possibility of an automatic change in the

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[111] Szczutkowski, 2015.
[112] Dias and Grilo, 2018.
[113] Amicis, 2018.
[114] Netessine and Shumsky, 2002.
[115] Zhong et al., 2017.
[116] Filbeck and Gorman, 2000.
[117] Seebacher, 2013.

production process in case of a disturbance.[118] The current alternative of production processes of products in the production system, determines the current routing flexibility.[119]

- Machine flexibility
  The machines flexibility is the ability of the machine to adapt to changing conditions.[120] It must be differentiated whether a machine falls under the single-purpose or multi-purpose machine category. Single-purpose machines are very special machines that can only fulfil one production task. Multi-purpose machines are much more flexible as they allow a wider range of different production steps to be processed. This means that they have a much higher efficiency and that fewer machines must be available at the same time.[121] A plant is considered to be more flexible, the less the unit costs change, if it deviates from the optimal operating point.[122]
- Remote monitoring and control
  The monitoring and control of machinery has changed significantly in the course of the fourth industrial revolution. In the past, everything had to be read directly at the machine, but nowadays it is possible to get the information from all over the world with the appropriate network structure. The machines must be equipped with appropriate sensors.[123] This allows machine conditions to be checked and monitored in real time. If corrective measures are required, the machine can also be acted upon from the outside. With these systems, it is possible to influence the production directly and thus significantly improve the quality of the parts. The rapid reaction to new conditions improves the overall process.[124]
- Predictive maintenance
  Preventive maintenance is concerned with a predictive maintenance trend designed to identify impending faults or the remaining life of technical equipment. With this method, maintenance measures can be initiated preventively and conditionally. This results in a more effective resource allocation.[125]
- Augmented reality for maintenance, repair and operations
  Augmented reality is a technology-based extension of the perceived environment. A wide variety of additional information is displayed in glasses, displays, tablets or smartphones.[126] This information is intended to help the worker accomplish the work

[118] Ghosh and Gaimon, 1992.
[119] Gupta and Goyal, 1989.
[120] Perovic, 2009.
[121] Gutenberg, 1951.
[122] Holz and Gaebler, 1985.
[123] Mielenz et al., 2007.
[124] Schleipen et al., 2010.
[125] Bink and Zschech, 2018.
[126] Tönnis, 2010.

task and thereby make it efficient. Classic examples in production would be machine data displayed in real time, possible disruptions announcing themselves or simple control of production. In terms of maintenance, this technology opens up a multitude of new application possibilities. Machine operators are guided through maintenance by the use of smart glasses. Standard work operation can be programmed in advance. Therefore, it is not necessary that a service technician come to the machine. For more complex problems, the technician can use the overlay display to guide the machine operator through maintenance and show exactly what needs to be done.[127]

5.1.3 Labour

The labour in the business sense, is plan and purposeful. This includes both physical and mental forms of work to produce goods or services. Work, too, is not excluded from the transformation of the fourth industrial revolution. The work is changing as much as the production processes through digitization. New systems and workflows play a key role here. One of the central topics is assistance systems. They should support the employee in his activities in the best possible way. The networking of workers with the machines, should lead to better cooperation, such as an increase in efficiency in production through parallel work of humans and robots. On the one hand, production processes that are automated bring the advantage that fewer workers are needed in production, but on the other hand, the demands placed on the operator increase. Decentralized control, which is usually achieved through digitization, also means that operators are less and less familiar with the actual processes. In the case of disorders that usually only occur in demanding and complex situations that humans have not caused, he is overwhelmed with the situation. Cyber-physical systems can help here. The new possibilities, in the collection and processing of process data, make it easier for the user to adapt to the new situation.[128]

- Human robot collaboration
  In the industrial production, there is an enormous competition for profitability. Labour intensive production is often outsourced to countries with lower labour costs. A large variety of variants for one product, limited the suitability for automating some assembly steps. Constant retooling makes this assembly unprofitable. The development of the new robots, which can work alongside the worker without any visible protective measures (fences, cages), makes it possible to advance the economy and flexibility of scalable automation to a new degree. The success of such a collaboration is only given if the human and the robot work productively. This type of cooperation is currently possible only for small parts, since it is quite clear to which weight classes these systems are

[127] Tönnis, 2010.
[128] Hartmann and Botthof, 2015.

allowed to operate.[129]

- Remote monitoring and control
  Under this point, two variants can be understood. On the one hand, if you take it literally. With systems to monitor the workers and if necessary put corrective measures. The second variant is much more interesting for this work. Here is a process, an automatically running workflow, monitored and controlled from anywhere. This method is not a new invention, but already established in many areas. In power generation, for example power station control, this method is already state of the art. In most production you are not here yet. Problems here are the varied work tasks and the great variance of products that are produced. If these problems are overcome, companies can increase production while reducing labour costs. The activities of the workers would be different from the actual work to machine care.[130]
- Performance management refers to the performance and increase in the workforce through appropriately installed framework conditions. It is therefore one of the most important human resource instruments and specifically promotes employee motivation. [131] In addition, performance management contributes significantly to achieving the strategic corporate goals. Also to be considered in connection with performance management and performance enhancement of the employees is the influence of the digital transformation on the work processes. The constant change of employees between project and day-to-day business as well as overarching areas of activity and responsibilities make it difficult for managers and department heads to keep track of the respective responsibilities and the respective workload. The result: lack of transparency, overloaded specialists and lack of opportunities for innovation and creativity.[132]

5.1.4 Inventories

Inventory is an accounting term. It means that goods are in different stages throw the production. Usually, there are three types of inventory: raw materials, work-in-progress, and finish goods. The differences of these three types are: raw material is the source material to produce the finished goods, while work-in-progress means that these goods are transformed from a source material into finished goods in production. Finished goods are those, which are available, to be sold. Today nearly, every business has a system installed so-called inventory management, to avoid that the inventory is too big or too small. If the stock, eider finished goods or work-in-process is too big for a long time it will result in costly storage. On the other hand, if the inventory is too small, the risk of losing out on potential sales and potential

[129] Markis and Sihn, 2016.
[130] Crane, 2007.
[131] Hammermann and Stettes, 2017.
[132] Utsch, 2018.

market share isn't beneficial either.[133]

- Batch size

  The batch size is referred to industrial engineering and in the production industry as the quantity that is produced in one production order and passes through the production as a closed unit (lot) without interruption by other orders.[134] The challenge for production planning is to determine the optimal lot size where unit costs are minimal. There are two factors against each other. From the manufacturing point of view, the highest possible number of the same products is significantly cheaper than frequently changing production. This significantly increases the storage costs, which leads to an additional capital commitment. The objective of companies, however, continues to go to batch size 1.[135] This means that every customer can order a tailored product to his needs. The challenge for the companies is to get the set-up costs and the lead time so far under control that these products can still be offered at a price suitable for the customer.[136]

5.1.5 Quality

The experience of the customer is one way to describe what quality is. Design specifications and manufacturing standards have a huge impact on the product quality. To fulfil all the expectations of the customer, quality is divided into four segments: quality planning, quality assurance, quality control and quality improvement. In combination these four elements leads to total quality management. The first step is quality planning. All the requirements where defined. Who will be the costumer, what are their needs and what tools are needed to achieve this?[137] Preventing mistakes or defects in manufacturing products is called quality assurance. Systematic measurements are installed to prevent any errors. There measurements are compared with a defined standard which should evident any mistakes. Quality control on the other hand has his focus on the output of the processes. Fulfilling the quality requirements is the only task they bother. Quality improvement is a systematic approach to eliminate or reduce waste, losses and rework in production processes. [138]

5.1.6 Supply /demand match

In the business world, supply and demand is one of the central themes. The markets are divided into two groups, potential buyer and seller. The potential buyer influences the demand. The supply is provided by the seller.[139] The supply is described by the quantity of a

[133] Chase, R.; Aquiline, N J; Jacobs, 1998.
[134] Dangelmaier, 2009.
[135] Srikanth and Umble, 1997.
[136] Castillo and Gazmuri, 2015.
[137] Nanda, 2016.
[138] P.R.G. Limited, 2015.
[139] Varian, 2003.

good a producer can produce at a given price. Demand is the amount consumers are willing to buy at a defined price. One of the hardest tasks is predicting the customers demand. Since this happens in most cases with a certain deviation, it is important to have the most flexible system in the entire process organization. This allows managers to react quickly to the new market situation. The goal is always to satisfy the desire of customers but not to create an oversupply in the market.[140]

- Data-driven design to value
  Data-driven design allows designers to get a better understanding of their products. For existing products, their design environment is linked to various tests.[141] For companies, it is very important to develop an understanding of their data. To help them understand it, they should use the Internet of Things. By the collaboration of different technologies, from the production to the design of the products, it is possible to realize a customized product in the production.[142]
- Data-driven demand prediction
  The use of historical data, which is available to a company to predict possible future sales volumes, seems relatively reasonable in the first step. Nevertheless, so many unpredictable factors play a role, that it is a very complex task. Calculation algorithms should help to accomplish this task.[143] Recognizing sales patterns of the past allows possible conclusions about the future. In addition to the internal data, external data must also be taken into account. This increases the probability of creating an even more accurate predictive model.[144]

5.1.7 Time to market

Normally it can take a long time from the first idea of a product to its actual launch. This period of time, which also includes development in the technical and logistical areas, is called time-to-market or TTM for short.[145] A very short time-to-market provides the companies a competitive advantage, especially for such as high-tech products. The manufacturer is the first to bring the product to the market and benefits from the high prices. Early adopters are able and willing to pay the high price and no competitor can undercut this. If the time-to-market is too long, competitors can already supply similar products or the product is already outdated.[146] There are several ways companies try to reach their optimal time-to-market strategy. Some of them have the strategy of pure speed, which means, they want to bring the

[140] Frazier, 1986.
[141] Lamy, 2018.
[142] Henrich, Kothari, and Makarova, 2012.
[143] Afrin, Nepal, and Monplaisir, 2018.
[144] Francis and Kusiak, 2017.
[145] Martel, 2018.
[146] Brem, 2008.

product on the market as quickly as possible. Fast-moving industries use this strategy very often but sometimes it results in failure or quality problems. A different approach is a more predictable schedule. Rather being the first on the market, delivering on schedule, for example for a special event like a trade show could be more valuable. Nowadays flexibility to make changes during the whole phases, from the idea to the lunch is the key to be successful. Often the requirements changes during the development of a product and without being too disruptive can be important.[147]

5.1.8 Services / after sales

The service deals with the customer before buying a product and the after sales with all the questions that arise after the purchase of a product. Since selling a product is only the first way to make money, it is important that the companies offer a good after sale. This shows the customer, not only that the company is willing to build a long-term relationship but also tries to generate a loyal customer base.[148]

5.2 Motivation for digitization

What is digitization? In the most original sense, it is the transformation of analogue information into digital formats. Sensors are used to measure analog values.[149] These supply the analog values to an analog-to-digital converter. It samples the voltage waveforms at defined intervals, determines the magnitude of the measurement at sample time, and translates the result to a digital value. As a rule, digital technology uses exclusively binary values which can only assume the two states 0 or 1. The binary information can be handled very well by processors.

Digitalization means that it is no longer just about a linear progression as in the past, that is, about pure optimization, but about the design of something new. Decisions will be made through digitization in predictable constellations, without human intervention. The systems, however, reach their limits in complex decisions. Here people have to contribute its experience to make the final decision. In this case, the systems provide the basis for the decision. Digitization offers many advantages over analogue processing of information. When the information is in digital form, it can be used, processed, reproduced, stored, and distributed using data processing systems. Due to the machine readability, this data can be read and processed much faster.[150]

A question that comes up, why is the digitization of production necessary at all? This question cannot be answered in such a general way. Digitization helps companies to identify

[147] Kahn, 2012.
[148] Krause, 2012.
[149] Litzel, 2017.
[150] Litzel, 2017.

and avert weaknesses in areas such as business model innovation, data and information management, customer knowledge, portfolio management, and manufacturing. With the help of the latest data analysis methods, you can handle the enormous amounts of data, and big data becomes smart data. For these systems to do their job, certain conditions are necessary. On the one hand, the corresponding data must be available and usable. Faulty, incomplete or out-of-date records often lead to these systems not being able to work. A uniform data format across several areas is often not found in practice. This makes an automatic analysis of the data very expensive or leads to each department having its own system in use. It should be in the interest of every business that the collaboration of the departments should be based on clean data. The more companies know about themselves, their products and their customers, the easier they can gain a competitive advantage.[151]

Digitalization, Internet of Things (IoT), big data, augmented reality and assistance systems increase the complexity and scope of the technology portfolio to be controlled. New providers appear with a myriad of new programs and solutions to meet the needs of businesses. Due to the different providers, the projects can become very demanding. In the future this will require interdisciplinary skills of the executives. The change of the existing systems, ERP, CRM, MES or PLM will go on to be adapted to the company's needs. The new emerging systems, from digitization, are also adapted to the needs of companies. Only those who manage to accomplish these tasks in the best possible way for the company, can exploit the full potential of the systems.[152]

The Internet of Things is a collective term that combines technologies, infrastructure and the information society. This makes it possible for physical and virtual objects to communicate and work together. By using processors and sensors on the machines and components, the system is able to communicate with each other via networks.[153]

The IoT can be set equal to a network in which smart objects are integrated. They can use the network to exchange information with each other via M2M (Machine-to-Machine) communication. So that there are no confusions in the network, each smart object is provided with a unique, assignable Internet address. The control of these networks has changed compared to the conventional Internet. So far, the user has provided the input. This is done by the IoT independently. It fetches the necessary information directly from the machines or products.[154]

The aim of this network is to merge the boundaries between the real and the virtual worlds. Thus, each item is able to communicate information about the IoT via its current state. Such

[151] Riedel, 2017.
[152] Plass, 2017.
[153] Gabler, 2016.
[154] Jesse, 2016.

information serves the end user in manufacturing to substantially improve usability. This information makes it much easier to plan your wait, as the machine dictates when it's the best time to do it.[155]

5.3 Thirteen design factors for industry 4.0

The results of the demarcation of the benchmarking that has been done in the previous chapter (4.5 Focus area of benchmarking), are considered in this section. The studies show that there are two main topics that influence Industry 4.0. On the one hand, these are the sphere of influence of the environment and on the other hand is the design field (Figure 13 Thirteen design factors for industry 4.0). The environment describes the future framework conditions that will prevail. The key factors are only indirectly influenced by the Industry 4.0 economy. The direct influence takes place via the design field. For this reason, only these are discussed here.[156]

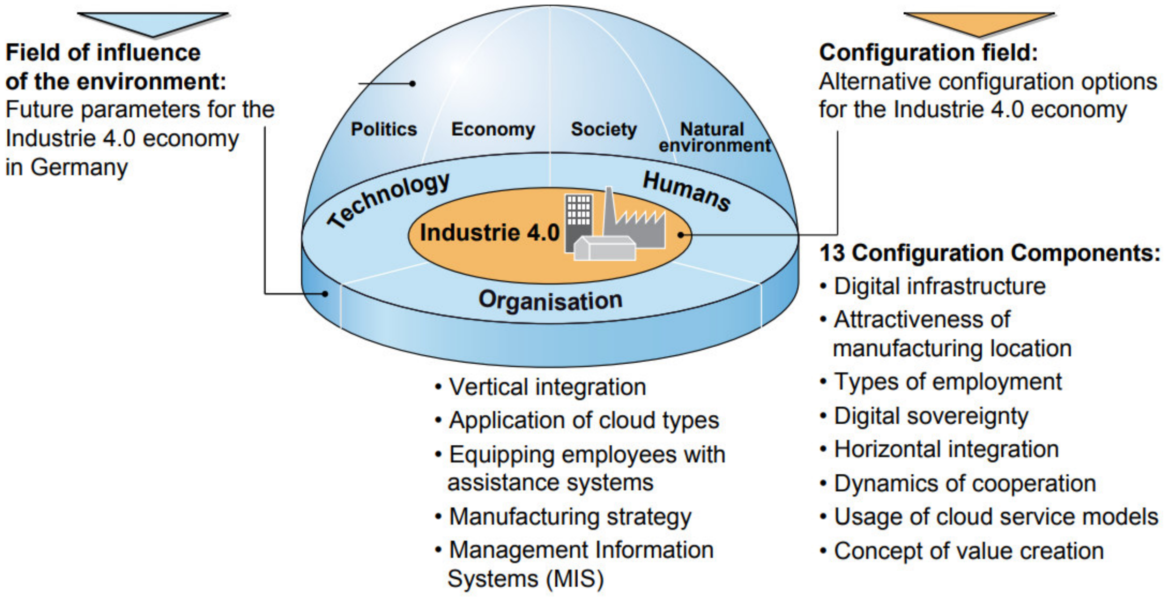


Figure 13 Thirteen design factors for industry 4.0[157]

In order not to lose track of these 13 design factors, they are subdivided into three subgroups: politics and society, industry and finally business. The individual points can be assigned as follows:

[155] Mattern and Flörkemeier, 2010.
[156] Eckelt, 2016.
[157] J. GAUSEMEIER, 2016; Eckelt, 2016.

Politics and society:

1. Digital infrastructure
2. Attractiveness of the production site
3. Employment
4. Digital sovereignty

Branch of industry

5. Horizontal integration
6. Dynamics of cooperation
7. Use of cloud service models
8. Value creation concepts

Business:

9. Vertical integration
10. Use of cloud types
11. Equipment of employees with assistance systems
12. Production strategy
13. Management information system

1. The digital infrastructure is a sub-point of the information and communication infrastructure. It includes the basic technical facilities that ensure the generation, processing, distribution and retrieval of digital data. Currently, efforts are made to push ahead with the wideband Internet expansion. The goal is to cover as much as possible using fibre-optic cable as well as the current mobile radio standard. Usually, a locally buildout is more likely. Economic centres and important transport hubs are preferably developed and the rural regions are retrofitted with a great delay.[158]

2. The attractiveness of the production site is very much determined by the external considerations. Factors such as the perception of productivity as well as the prevailing conditions play a role. These are differentiated into hard and soft factors. Taxes, subsidies, tariffs and transport costs are hard factors. Educational offers and recreational opportunities, on the other hand, are soft factors.[159]

3. The employment relationship will also change as part of the Industry 4.0 revolution. In doing so, the normal employment relationship will be abandon and companies move

[158] Möller, 2016.
[159] Baldassarre, Ricciardi, and Campo, 2017.

towards new employment relationships. An example would be “body leasing”. To cope with production peaks workers are only needed for a very short time in one location. Working hours, locations and work content of the employees in the production are adapted to the pronounced volatility in the market situation and the resulting production conditions.[160,161]

4. Self-determined action and decision-making mark a sovereign system. From this definition, digital systems are capable of self-determined action and decision-making in the digital space. There are currently three subdivisions of systems: outsourced, sovereign and self-sufficient systems. Third-party systems are characterized by the fact that the provider dictates everything. With sovereign systems, the decision lies by the customer. This determines which provider the customer trusts and which system is used. In the case of an autarchic system, everything is developed and determined by the user. This offers the best protection but also brings significant disadvantages, as for example: complex and costly, development and maintenance.[162]

5. Ensuring the interaction between information processing and functional levels is called horizontal integration in production technology. This is not limited to local productions but it includes cross-company value networks. Horizontal integration is possible in three variants: minimum, partial and full integration. The effort is enormous in order to bring such systems to work, companies are afraid to expand the system used. Following the motto: "never touch a running system". Under the aspect of partial integration, only those areas of production are upgraded where the potential for efficiency and productivity increase is possible. Full integration requires the formation of cross-company value networks. There should be a continuous information chain from the supplier to the customer. These systems must have a high degree of security, reliability and confidentiality.[163]

6. Collaboration is a liaison of two or more parties that seek to accomplish the same goal or activity together. The form, frequency of contact and the duration of the collaboration characterize the dynamics of cooperation. With long-term value-added partners, both operational and strategic advantages can be achieved. The cooperation is based on complementary competences of the partners. There is little incentive to acquire the know-how of the partner. The other access to cooperation is so-called ad hoc alliances.

[160] Eckelt, 2016.
[161] Botthof and Hartmann, 2015.
[162] Gausemeir and Klocke, 2016.
[163] Botthof and Hartmann, 2015.

Companies are organized on service platforms. The know-how transfer is high because the services provided are disclosed. This allows to exchange service partners quickly.[164]

7. Cloud service models are services offered through the Internet. In doing so, IT services are offered, used and billed as required. This is possible for defined products via standardized interfaces. The spectrum of the offer ranges from information technology to platforms and software.[165]

8. The value creation concept defines how the value proposition towards the customer is fulfilled. The interplay of internal and external resources and capabilities in the value chain is used to create value. The value creation concept is differentiated into three types: system head, intelligent production service provider and holistic value creation. Many companies are classified in the category system header. In doing so, the focus is on differentiating oneself from others. Thereby, the largest value creation potential is generated in the field of research, development, design, marketing and production. Simple work is outsourced. Intelligent production service provider in combination with Industry 4.0 causes a resurgence of domestic production. The construction of networking intelligent manufacturing systems enable high quality and low production costs at the level of low-wage countries. The holistic value creation approach is the combination of creative value networks and production locations. The merging of services and contributions, leads to the creation of new innovative business models. Traditional strengths in manufacturing and development combined with innovative business models enable companies to take global leadership.[166,167]

9. In the field of production and automation technology, vertical integration means the linking of IT systems at all hierarchical levels. Linking all levels includes: actuators, sensors, steering-, manufacturing-, operating- and corporate planning. With integrated systems companies try to reach the full benefit potential over all hierarchy level. Existing systems are replaced or updated. The compatibility of the interfaces of the different levels is coordinated accordingly. Most companies shy away from the enormous effort involved in continuous networking. That is why mostly isolated solutions arise. Only areas where a significant benefit can be identified are networked. Networking actor and sensor levels are the basis for plant optimization. Meanwhile, so-called Cyber Physical Systems (CPS) have prevailed. These can learn from changing operating conditions and adapt accordingly.

[164] Wang et al., 2016.
[165] Oztemel and Gursev, 2018.
[166] Bieger and Reinhold, 2011.
[167] Kang et al., 2016; Zillmann and Wilk, 2016.

Communication takes place over all levels via the Internet.[168]

10. The "cloud" is a technology that provides IT resources dynamically over the Internet. The payment of such systems usually takes place according to flexible payment systems. This results in service-based business models. The investment cost for the benefits of information technology can be saved, because only the operational costs are incurred for such systems. Trust in cloud systems is still very low. Therefore, companies often use their own cloud in their networks. They want to protect their know-how from everyone. This method is also less elastic because users often generate peak load. Companies rely on public cloud service providers. These have a high elasticity and are relatively cheap because of the large number of users. The protection of know-how is much more important in such variants. This is usually ensured by effective access restrictions or state-of-the-art encryption technology. The combination of private and public cloud is called hybrid cloud. The advantages of both systems are combined in one. The sensitive data is stored on the private and the less sensitive data on the public cloud. This significantly relieves the company networks. Some companies do not trust cloud solutions yet. Here, all data is stored locally on servers. The reasons are: incalculable data protection risks and worldwide different legal regulations.[169]

11. Assistance systems in production range from power assistance to mobile expert systems. The workers are networking with the machines and other resources, thereby they are obtaining production-relevant information. By providing them in real time, they make a significant contribution to decision-making. The worker who is using data glasses in the production is called Augmented Operator. His decision-making base is enhanced by overlaying a virtual view of the real factory. To ensure that these systems are working, there must be complete trust in the technology and security of the data. The education and training of employees to use these systems is essential for companies. Most companies are slowly starting to equip individual departments with this new technology. Reasons for the slow integration are concerns about privacy and security risks. Therefore, a corresponding balance between effort and risk effect is made for each department. The third option, that some companies take, is to avoid such systems. At the same time, corporate privacy concerns are too great. Serious industrial espionage and sabotage attacks on international corporations, in the past, have encouraged the reluctance of such systems. Therefore, corporations usually use these systems only selectively in the productions.[170]

[168] Botthof and Hartmann, 2015; Eckelt, 2016.
[169] Oztemel and Gursev, 2018.
[170] Niehaus, 2014.

12. A number of coordinated decisions in the areas of production and production processes are included in ZAHN's production strategy. The production task describes the type and quantity of services. Decisions about the production structure relate to plant locations, capacities and infrastructure. The production process describes logistics and relationships with suppliers. In the “local for local” production strategy, the plants are set up close to the customers. This allows the local market to be adequately served. Short-term changes to the mark can be dealt with well by the proximity. Short delivery times and reduced storage costs are another side effect of this production strategy. The second production strategy, which is also often used, is “local for global”. Companies move away from the customer and look for production sites with the best conditions. From there, the global market is served. Reasons for such strategies are local tax rates, construction, energy costs and legal certainty.[171,172]

13. In order to have decision-relevant data at hand, management information systems are introduced. These help executives gather, aggregate and analyze information and data. Such systems increase the transparency in planning and reporting, which in turn is the basis for controlling interventions. Business Intelligence systems are automatic management information systems. These bring the information together and prepare it according to the business requirement. This will always ensure data consistency. Meanwhile, companies move away from pure business intelligence systems and combines them with big data architecture. Due to the networking anyway, very large amounts of data are created, these provide the management with new decision-making bases. Big data analytics are integrated into corporate governance processes.[173]

[171] Laqua and Wey, 2012.
[172] Zahn, 1988.
[173] Weber et al., 2014; BITKOM, 2015.

6 Business Process Model and Notation

The term "Business Process Model and Notation" is to be understood as a graphical specification language in business informatics and process management. This standard was developed by the Object Management Group (OMG) [174] and has since been maintained by this organization. The goal was to standardize the different languages for business process modelling, thus providing a single, standardized language for describing business processes.[175]

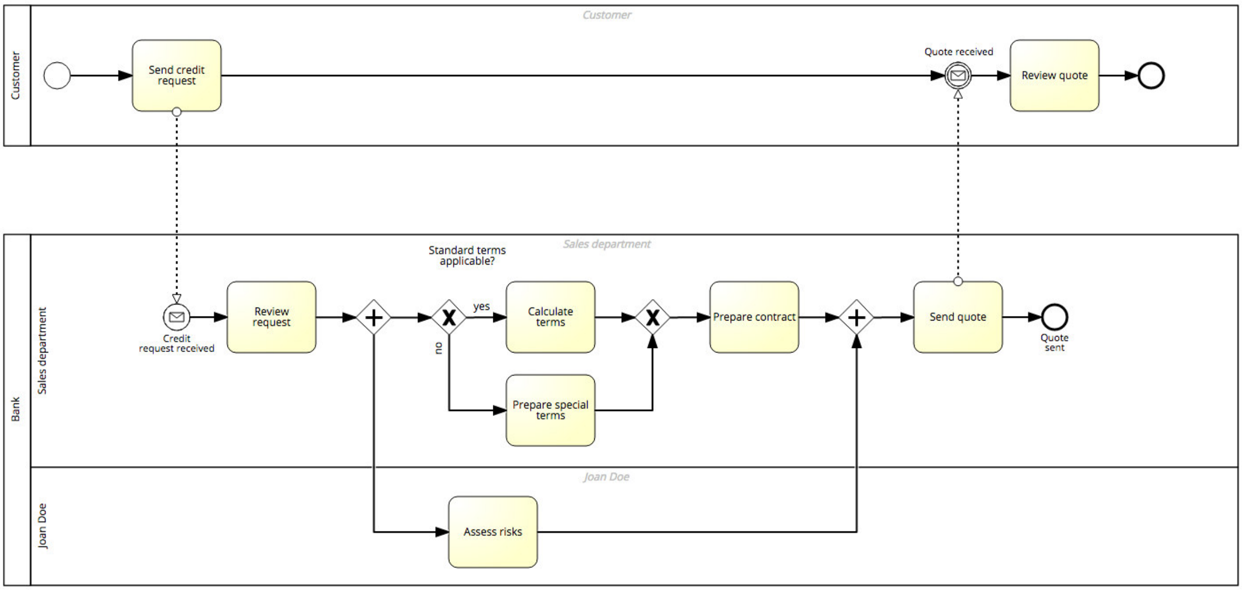


Figure 14 BPMN pools and lanes[176]

Business process diagrams are at the centre of business process modelling (Figure 14 BPMN pools and lanes). A business process diagram is reminiscent of classic flowcharts, with a number of special objects for describing business processes (Table 1 BPMN symbols).

- flow objects
  Flow objects describe the processes of business processes. It describes activities, events and connectors. Activities are tasks that must be performed by a particular organ (company, people, etc.). The result is always the beginning or the end of an activity or process. Decision alternatives are modelled via connectors in the process flow.[177]
- connection objects
  Between the flow objects, the relationships to each other with connection objects are described. Sequence flow, message flow and associations are connection objects. The

[174] Soley, 2012.
[175] Fettke, 2008.
[176] Kampik, 2016.
[177] Owen and Raj, 2004.

temporal sequences are described by means of a sequence flow. Communication between different process participants is ensured via the message flow. Associations are used to provide additional information for flow objects.[178]

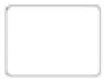
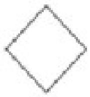
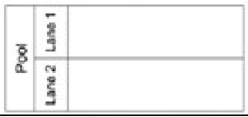
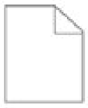
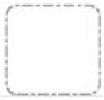
- swim lanes

  To arrange flow objects in different groups, swim lanes are used. Swim lanes are divided into two groups: pools and lanes. Pools are used to describe a completed process that runs in an organization. Lanes are used to group activities within different functional areas of a company. Sequence flows only connect activities within a pool while the message flow connects only activities of different pools.[179]
- artifacts

  Context-specific features are described with artifacts. They can consist of data objects, groups and annotations. Data objects describe the data needed or generated for processing activities. For analysis or documentation purposes, groups are formed. Annotations make it possible to attach certain additional information to individual processes.[180]

[178] White, 2004.
[179] OMG, 2006.
[180] Ateetanan et al., 2017.

Table 1 BPMN symbols[181]

focus	concept	explanation	symbol
flow objects	activity	task that needs to be done in a company	
	event	defined time that indicates the beginning or end of an activity or process	
	gateway	Decision alternatives in the course of a process	
connecting object	sequence flow	Run sequence between activities	
	message flow	Communication channel for messages between activities	
	association	Connection between flow objects and additional information	
swim lane	Pool	Summary of all activities typically performed by a company	
	Lane	Distribution of all activities of a pool into different areas	
artifact	data object	Information needed or generated when editing activities	
	group	graphical summary of various objects in the process diagram	
	annotation	additional verbal additions to the process diagram	

181 Fettke, 2008.

7 General description of the current situation

This chapter is divided into two sections. The first shows the product and its execution. In the second part, the three individual departments are presented in more detail.

7.1 Product variants

In its basic form, the crane consists of three components: mounting plate, articulated arm and push arm. Since these are usually loading cranes, they are attached to a vehicle. For this, a separate mounting plate (Figure 15 Loading crane on a truck) is necessary. This is mounted either at the rear end of the vehicle or between the cab and the loading area. This component is recognizable by the extendable hydraulic supports. The articulated arm (Figure 15 Loading crane on a truck) is the assembly that is connected to the mounting plate including the part of the crane that allows bending. The push arm (Figure 15 Loading crane on a truck) on the other side enables the extension of the arm to reach a greater range.

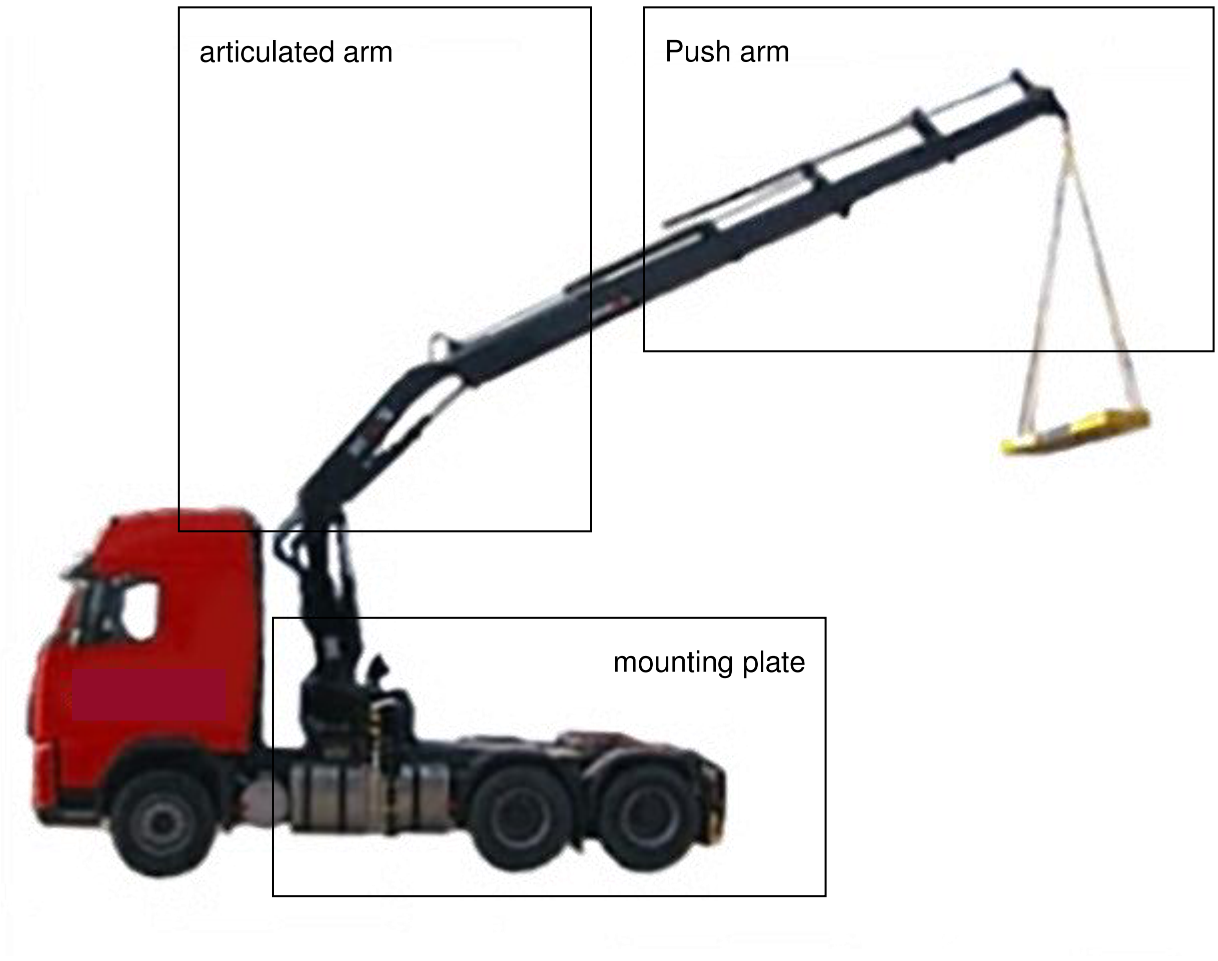


Figure 15 Loading crane on a truck[182]

[182] Lehmann, 2018.

Additional bending arms (Figure 16 Additional bending arm) are components, which allow a further bending of the crane to extend its range and enable even more flexibility.

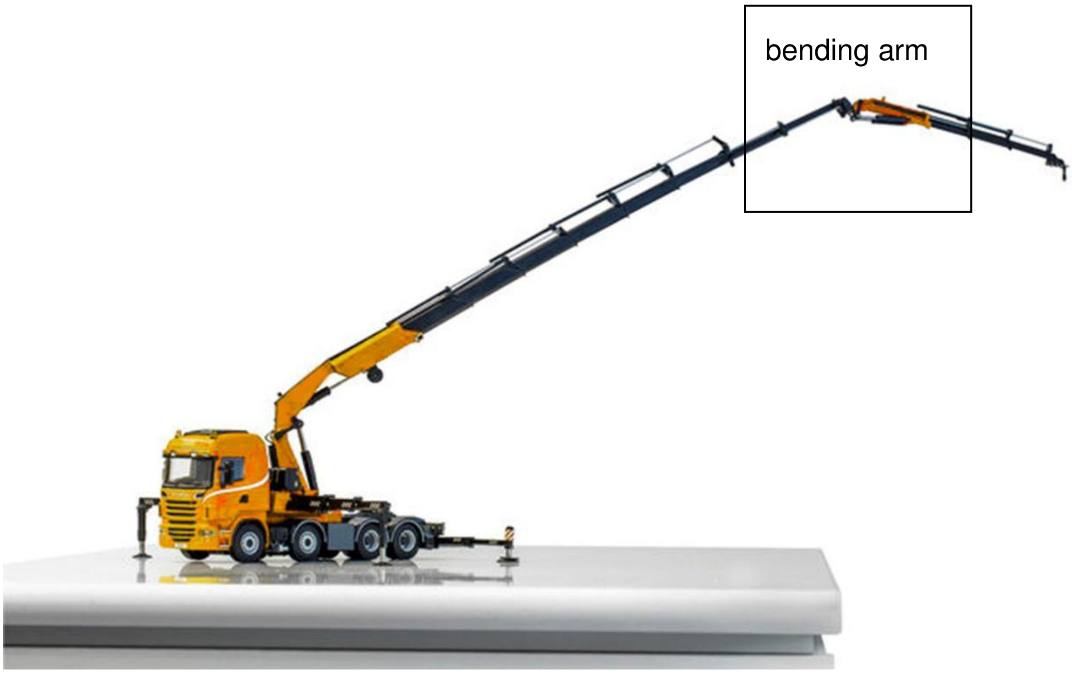


Figure 16 Additional bending arm[183]

7.2 Production areas

For a better overview, the following description is divided into three parts. This subdivision is based on the three departments in steel construction. In the following illustration (Figure 17 Layout sheet metal production) three areas are marked in colour. The red area is the small part production, the violet area the push-arm production and the magenta coloured area is the articulated arm production.

183 Küppers, 2013.

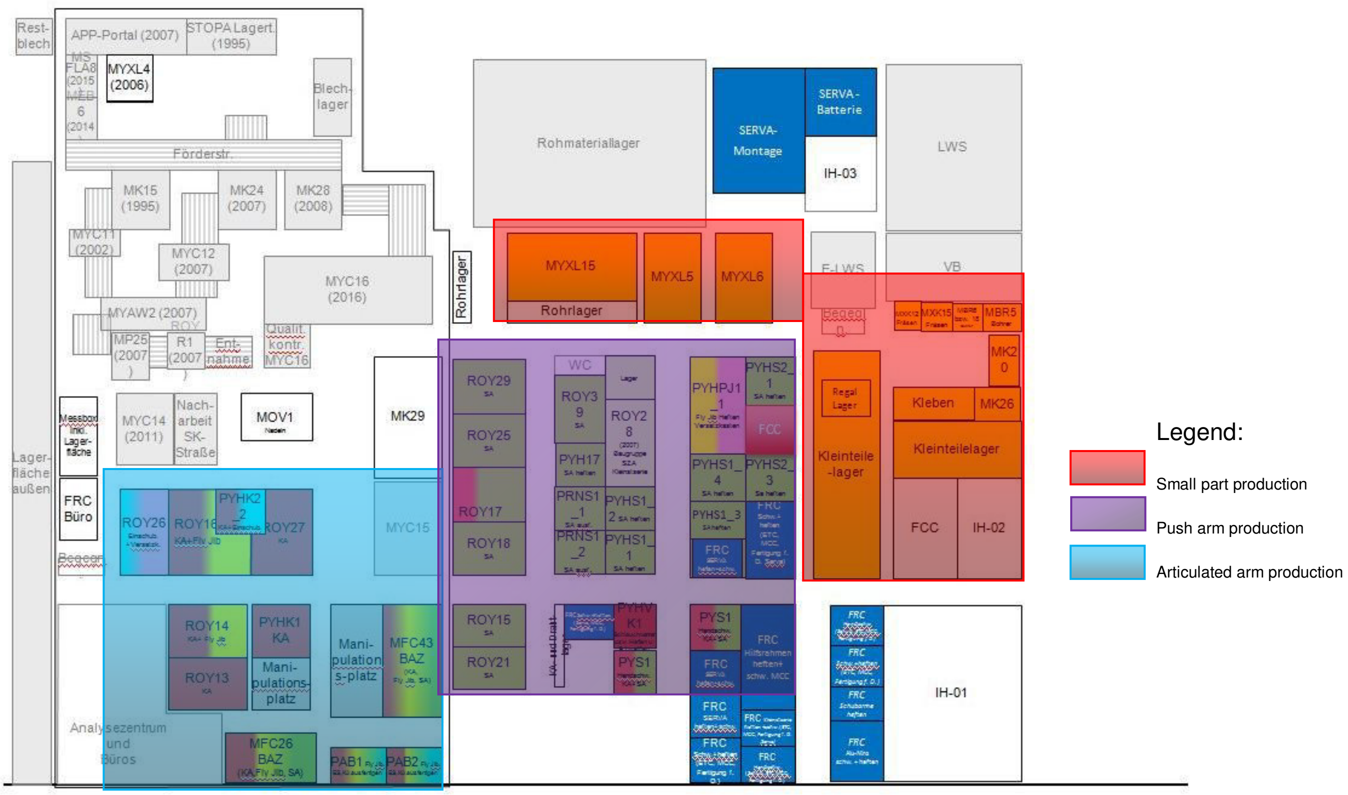


Figure 17 Layout sheet metal production

7.2.1 Small part production

The small parts area consist of parts necessary for push arms and articulated arms as illustrated in Figure 17 Layout sheet metal production. Small parts are cut out of the steel plates and then attached to the push and articulated arms. The small parts production consists of a total of nine machines, three lasers, two milling cutters, two drills and two edging machines. There are eight different variants of how the components are either further processed or stored directly. The most common variant, that applies to 43% of the orders, undergoes at least one processing. The second most common variant, 41% of the orders, directly transports the orders from the laser to the small parts warehouse.

In order to start the production, a corresponding order must be placed in the enterprise resource planning system. After this has been done, the raw material store and the interleaver are informed about the material and arrangement that must be provided. The interleaver creates an optimal cross-sectional image so that the steel plates can be cut efficiently and waste production is minimised. The cutting template of the interleaver is then passed on to one of the three laser cutters. After the steel plates have been cut into the appropriate solutions, the components are transported accordingly. The small parts warehouse and small parts production are self-controlling system. The warehouse operates with a kanban system.

When the preparer prepares the required parts for an order, they are removed from the small parts warehouse. If a certain minimum stock is undershot, new production orders are automatically made for the missing parts. This results in a self-controlling process. In addition to the small parts warehouse there is a second warehouse, which stores only order related parts. These parts spend a short time in the warehouse because they are specially made for orders that are processed at a defined time.

7.2.2 Push arm production

The push arm production is located in the second, purple area (Figure 17 Layout sheet metal production). It consists of three staple boxes, eight welding boxes and two rework stations. In addition to the actual push arm production it also includes a subdivision for push cylinder linkage. Here, some small parts are manufactured to articulation points, welded with special welding robots and then stored in the small parts warehouse under a new part number. At the beginning of the process of main push arm production, the necessary small parts, which have been prepared by the preparer, are brought to the staple boxes. Here, templates are used to staple the small parts on the push arms. In the next step, the push arms are transported to the welding boxes which happens via two different manufacturing processes. One is a manual welding box and the second is an autonomous welding robot. The distribution key between the two shows that 98% of the push arms are handled by robotic welding and only 2% by manual welding. 72% of the welded push arms then receive a direct surface treatment in the cathodic dip coating. The remaining 28% of the components are either reworked in the push arm-reworking department or in the machining centre before they receive the surface treatment.

7.2.3 Articulated arm production

In the third, magenta coloured area (Figure 17 Layout sheet metal production), the articulated arms (Figure 15 Loading crane on a truck) and the fly jibs (Figure 16 Additional bending arm) are made. The department consists of two staple boxes, five welding robots, two machining centres, and one final workstation. The process of producing the articulated arms is very similar to the push arm production. First, the small parts are stapled, then welded. Subsequently, most of the parts are reworked to the desired specification in the machining centre. The last step before the cathodic dip painting is the final workstation, where the product is checked and individualised. Customer-specific requests are executed, for example winches or additional lamps are attached.

7.3 Information flow

While the previous sections mainly dealt with the material flow through production, the focus of the next few chapters is placed on the information flow and the control of the processes. As already mentioned above, the entire process of small parts production and warehousing is a self-controlling system. After the parts have been cut out, they are directly placed on transport scales and provided with a data sheet of paper. All the other workstations, through which the material has to pass are noted on this sheet. If they are sent directly into the small parts warehouse or to one of the processing machines, it is also noted. The paper serves to identify the parts and to ensure production tracking.

The ERP system informs the preparer about the parts that should be removed from the small parts warehouse. These are in turn pre-sorted (order-specific) on suitable transport vehicles. After this, they are transported to the appropriate stapling boxes. Since not all parts are produced by the company, the preparer combines them there. The transport of the load carriers takes place in the factory hall by means of a forklift truck. A special software, a production app, was developed to control and coordinate these transports. In the first versions of the app, the stapler could use a computer to tell the forklift driver which order to deliver next. Since the workers always chose the more pleasant jobs, as they made more orders and earned more, the system had to be changed. Now the app ensures a fair distribution of orders.

For the processes involving the staplers to the final production, the production apps, *SAP Control Centre* and *Go & See* are available to the employees. These three electronic resource management tools provide employees with the necessary information to facilitate their workflow and streamline the order processing.

The cathodic dip painting (KTL) is the final part of the production chain that is considered in this case. Here, the finished components are subjected to a surface protection against corrosion. This step also closes the circle of information. The KTL returns all necessary information to the ERP system to complete the process chain.

8 Gaining data and results from the value stream and material flow

This chapter presents the results of the material flow and the value stream analysis. In the following, the collected data will be discussed.

8.1 Gaining data

The task of entering values in the value stream map, was possible with the table provides by the company (Figure 18 Process overview map). This was checked and approved in the course of a workshop. Since this image (Figure 18 Process overview map) only offers an overview, the individual entries are described in detail. The following detailed description refers only to the small part laser (KT Laser), where the calculation is the same for every other process.

Process Overview map

Value Stream /KPIs	Processes	KT Laser	KT Fräsen	KT Bohren	KT Kanten	Rüster	SZA ROY	Schubarm Heften	Knickarm Heften	Fly-JIB Heften	Knickarm ROY	Schubarm ROY	SA Handschweißen	KA Handschweißen	Schubarm Nacharbe	BAZ	PAB
Databoxes																	
KPI	**Unit**																
Shifts	*Shifts/day*	2.3	2	2	2	3	3	2.8	3	2.5	3	3	3	3	3	2	2
shift lengths	*hours/shift*	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
planned breaks / shift	*min/shift*	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
POT	*min/day*	952.20	828.00	828.00	828.00	1242.00	1242.00	1159.20	1242.00	1035.00	1242.00	1242.00	1242.00	1242.00	1242.00	828.00	828.00
working days	*WD/week*	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
working weeks	*weeks/year*	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
working days	*WD/year*	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230
overtime (last 12 month)	*min*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average daily demand	*Pieces*	3690	173	476	1244		68	205	41	9	49	203	2	14	63	57	60
Setup time	*min*	1.565	3.06	4.92	3.498		17.496557	13.8253	19.654	19.36	15.8344	13.4658	12.1524	12.1524	4.89827	20.5328	
Number of different parts	*# of types*																
Number of Resources	*amount*	3	2	2	2		1	6	3	2	5	6	1.5	1.5	2	2	1
Target time/Pcs/Resource	*min*	0.54	1.74	1.29	0.43		11.17	22.61	52.20	152.00	72.65	24.20	30.60	30.60	26.02	24.87	11.00
		32.16	104.24	77.46	25.60	0.00	670.26	1356.88	3132.00	9120.00	4359.22	1451.95	1835.80	1835.80	1561.40	1492.47	659.72
Time per part (CT)	*min*	0.18	0.87	0.65	0.21	#DIV/0!	11.17	3.77	17.40	76.00	14.53	4.03	20.40	20.40	13.01	12.44	11.00
Takt Time	*min/Piece*	0.26	4.79	1.74	0.67	#DIV/0!	18.26	5.65	30.29	115.00	25.35	6.12	621.00	621.00	19.71	14.53	13.80
		15.48	287.17	104.37	39.94	#DIV/0!	1095.88	339.28	1817.56	6900.00	1520.82	367.09	37260.00	37260.00	1182.86	871.58	828.00
Target OEE	*%*	69%	18%	37%	32%	#DIV/0!	61%	67%	57%	66%	57%	66%	3%	3%	66%	86%	80%
OEE last 12 month	*%*																
Target time/Pcs/Resource	*sec*	32.16	104.24	77.46	25.60	0.00	670.26	1356.88	3132.00	9120.00	4359.22	1451.95	1835.80	1835.80	1561.40	1492.47	659.72
Time per part (CT)	*sec*	10.72	52.12	38.73	12.80	#DIV/0!	670.26	226.15	1044.00	4560.00	871.84	241.99	1223.87	1223.87	780.70	746.24	659.72
Takt Time	*sec/piece*	15.48	287.17	104.37	39.94	#DIV/0!	1095.88	339.28	1817.56	6900.00	1520.82	367.09	37260.00	37260.00	1182.86	871.58	828.00

Figure 18 Process overview map

The necessary data for the calculation of the Target OEE are on the left side of the table, under the heading Value Stream / KPIs.

The company defines the OEE in another way. In their calculation, only the availability factor comes to bear. Performance and quality are only considered, if there are too many deviations from the target OEE. This value is used to check whether the production works according to the specifications. If a corresponding deviation is detected, the corresponding causes are determined. The company divides the losses into four categories: change over, quality losses, technical losses and organizational losses.

$$Company\ OEE = \frac{Net\ Production\ Time}{Planned\ Operating\ Time}\ [\%]$$

The upper left area, the first rows of the table (Figure 18 Process overview map), displays data about the working hours to calculate the potential working time. The POT is calculated for all processes according to their shift models. The formula for this is:

$$POT = (shift\ lenghts * 60 - planned\ breaks) * \ shifts\ \left[\frac{min}{day}\right]$$

$$POT = (7.7 * 60 - 48) * 2.3 = 952.20\ \left[\frac{min}{day}\right]$$

Then, the calculation of the working days per year follows:

$$working\ days\ total = workings\ days * weeks\ \left[\frac{Days}{Year}\right]$$

The annual average of parts that should be produced is derived from the table (Figure 19 SAP abstract), which was also used for the material flow calculation. The values in this table are historical values. The setup time can also be found in the SAP table (Figure 19 SAP abstract).

material	name	work place	setup time	unit	machine time	unit	annual demand 400	standart time	setup time II
Part 004887	Product A	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004888	Product B	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004889	Product B	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004890	Product B	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004891	Product B	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004892	Product C	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004893	Product C	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004894	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004895	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004896	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004897	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004898	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004899	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004900	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004901	Product D	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004902	Product E	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004903	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004904	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004905	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004906	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004907	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004908	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004909	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004910	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
Part 004911	Product F	MYXL5	0.024	STD	0.252	STD	0.000	0	0
				Minimum:	**0.000**		848,683.000	75816.15	22141.04
				Maximum:	**10.000**			0.089334	0.026089
								5.360033	**1.565322**
Zeilenbeschriftungen	**Summe von Jahresbedarf 400**						3690		
MYXL15	241								
MYXL5	659002								
MYXL6	189440								
Gesamtergebnis	**848683**								

Figure 19 SAP abstract

The figure 17 is an excerpt from the SAP table (Figure 19 SAP abstract). This excerpt is limited to the three small parts laser. If the annual demand is divided by the working days, a daily demand of 3690 parts results. According to the formula, the set-up time is here also:

$$Setup\ Time = \frac{Setup\ Time\ II}{Annual\ Demand\ 400} * 60\ [min]$$

The target time is the time the work may take to produce one of the parts.

$$Target\ Time/Pcs/Resource = \frac{Standard\ Time}{Annual\ Demand\ 400} * 60\ [min]$$

The cycle time of the corresponding processes is calculated by dividing Target Time / Pcs / Resource by the resource.

The tact time of the processes is also calculated by dividing POT by average daily demand. In addition, to conclude those, the target OEE is calculated from the cycle time by the tact time.

As only the first quarter of the year, was considered for the master thesis, new lists had to be created with SAP corresponding to this period. The lists look the same as the ones already listed above (Figure 19 SAP abstract). Since they summarized all the machines of a process, they had to be broken down into individual machines by a simple filter. The following picture (Figure 20 Summary of machine groups) shows a short excerpt.

machine name SAP	annual demand 400	daily demand	sum daily demand	name
MYXL 5	659002	2865	3690	KT Laser
MYXL 6	189440	824		
MYXL 15	241	1		
MXK 12	39646	172	173	KT Milling
MXK 15	247	1		
MBR 5	109530	476	476	KT Drilling
MK 16	48059	209	1244	KT Edging
MK 20	238080	1035		

Figure 20 Summary of machine groups

The quantities for each machine or workstation were known, so it had to be deduced how the materials were moving through production. There is no automatic system for this, therefore the data had to be read out using a pivot table.

name	MBR 5	MK 20	MK 26	MXK12	MXK15	MYXL15	MYXL5	MYXL6	overall result
Product A							1		1
Product A							2		2
Product A							2		2
Product A							2		2
Product A							2		2
Product A		1					1		2
Product A		1					1		2
Product A								1	1
Product B				2				2	4
Product B				2				2	4
Product B		2					2		4
Product B		2					2		4
Product B				2			2		4
Product B								4	4
Product B				2			2		4
Product B							2		2
Product C	1			1			1		3
Product C				1			1		2

Figure 21 Pivot table

As can be seen in this picture (Figure 21 Pivot table), the name was used for this purpose. This consideration focuses on the small part production, from the lasers to the small parts warehouse. The first five order lines reveal that the parts produced only occur with MYXL5. This means that the parts were cut out by the laser and then put into stock immediately, without any additional processing. Line six, or the order 0370-60106, displays two entries – one with the MYXL5 and then with MK20. In this case, the part was cut out with the laser and then brought to the edges before it was stored. The following Sankey diagram (Figure 22 Material flow) shows the result of small part manufacturing, applying this method to all products and all eligible machines.

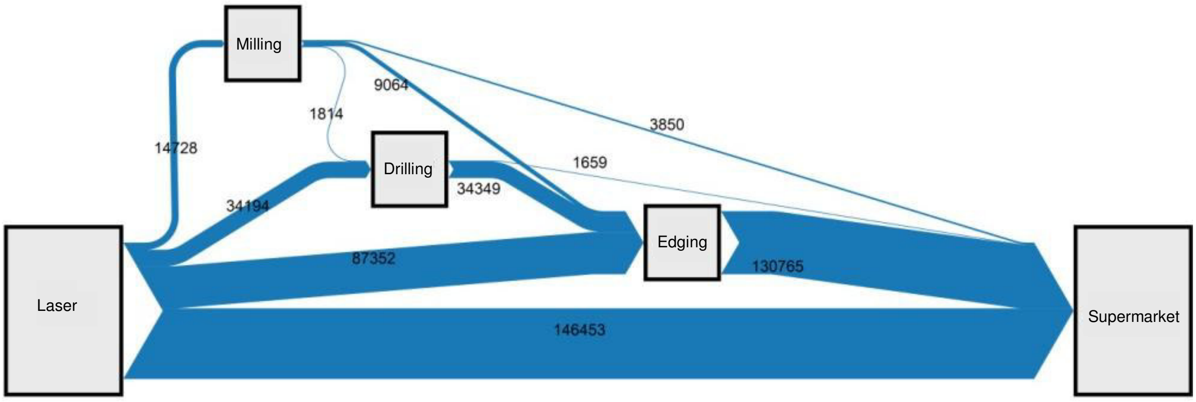


Figure 22 Material flow small part production

8.2 Results from the value stream

To give a structured overview, the previous chapter described how the data was obtained. Now the results are analyzed and interpreted. The analysis will be divided into three separate subchapters, according to the departments.

8.2.1 Results from small parts production

The OEE of the four processes clearly identifies milling as the process with the greatest optimization potential of this department. A theoretical OEE of 18% is crucial for this. In relation to how many parts are processed in this step, however, the results differ. Therefore, a brief outline of the process steps in this department is necessary. The sequence for the material, if it passes through all for machining processes are, laser, milling, drilling, edging and bearing. It is not possible for the parts to go through the production in a different order. Sometimes, however, not all production processes are necessary for each part. This means that there are eight different variations of how the party can be processed in the small parts production.

- Laser -> Supermarket
- Laser -> Milling -> Supermarket
- Laser -> Milling -> Drilling -> Supermarket
- Laser -> Milling -> Bohren -> Kanten -> Supermarket
- Laser -> Drilling -> Edging -> Supermarket
- Laser -> Milling -> Edging -> Supermarket
- Laser -> Drilling -> Supermarket
- Laser -> Edging -> Supermarket

Now, of course, the material flow of the small part production need to be outlined. The illustration shown above (Figure 22 Material flow small part production) depicts the actual material flow through the department. The lowest bar, laser -> supermarket, emerges as the most common variant.

The table 2 (Table 2 Order numbers), does not show the items but the orders listed. 41% of all orders, which corresponds to 146,453 parts, were transported directly from the laser to the supermarket. The most common variant, including 43% of the orders undergoes at least one processing step. The 43% correspond to a volume of 136,274 shares. Interestingly, the 3,234 orders contain fewer parts than the 3,098 orders. This is because different quantities are required in an order.

Table 2 Order numbers

direct	1st machining	2nd machining	3rd machining	4th machining	total
3.098	3.234	1.132	44	3	7.511
41%	43%	15%	1%	0%	100%

One significant finding while examining this method was the impossibility to determine how the parts actually went through production. An example should illustrate this better. Parts that have been milled, and are supposed to be drilled in the next step and then transported to the supermarket cannot be clearly assigned. 1814 parts are transported from milling to drilling and again only 1659 parts from drilling to the supermarket. The tracking fails in between. It is impossible to determine how many of the 1659 parts that were drilled came from the milling. Some could have also come from the laser, for example. The paths through the production step are not clearly traceable. An intermixing of different parts occurs, because the laser also supplies parts for drilling. This requires a deeper analysis. Even if the processes on the individual machines are broken down the processes on the individual machines, this kind of data processing is ineffective.

Referring once again to the OEE data, it becomes evident that if milling is left out, edging, which has a much higher meaning to the production, also exhibits a relatively low OEE. The higher significance is determined by the quantities that run through the production processes. 31% of the parts that are produced are processed in milling.

The following table (Table 3 OEE summary small part production) lists the OEE values again. In addition, the quantities that are processed daily are listed. Furthermore, the average OEE and weighted is calculated. For the weighting, the unit per day were used.

Table 3 OEE summary small part production

unit per day	OEE	process
3690	69%	KT laser
173	18%	KT milling
476	37%	KT drilling
1244	32%	KT edging
Σ 5583		
average OEE	39%	
weighted average OEE	56%	

8.2.2 Results from the push arm production

The only process loop occurs in the push arm production (see Figure 23 push arm production sankey). The parts are prepared and then transported to thrust cylinder linkage where the appropriate brackets for the cylinder are mounted. A welding robot designed for this purpose, handles of this task. Thereafter, the finished parts are returned to the supermarket and stored until their use. Provided with new identification numbers, these parts are then re-equipped, if necessary, and brought to the appropriate stapling stations.

In the push arm production there are three stapling stations, which are quite different, depending on the quantities that are processed. As illustrated in the diagram (Figure 23 push arm production sankey), two of the three stapling places were busy with about 3000 pieces, while the third stapling place worked about 10100 pieces in the same period.

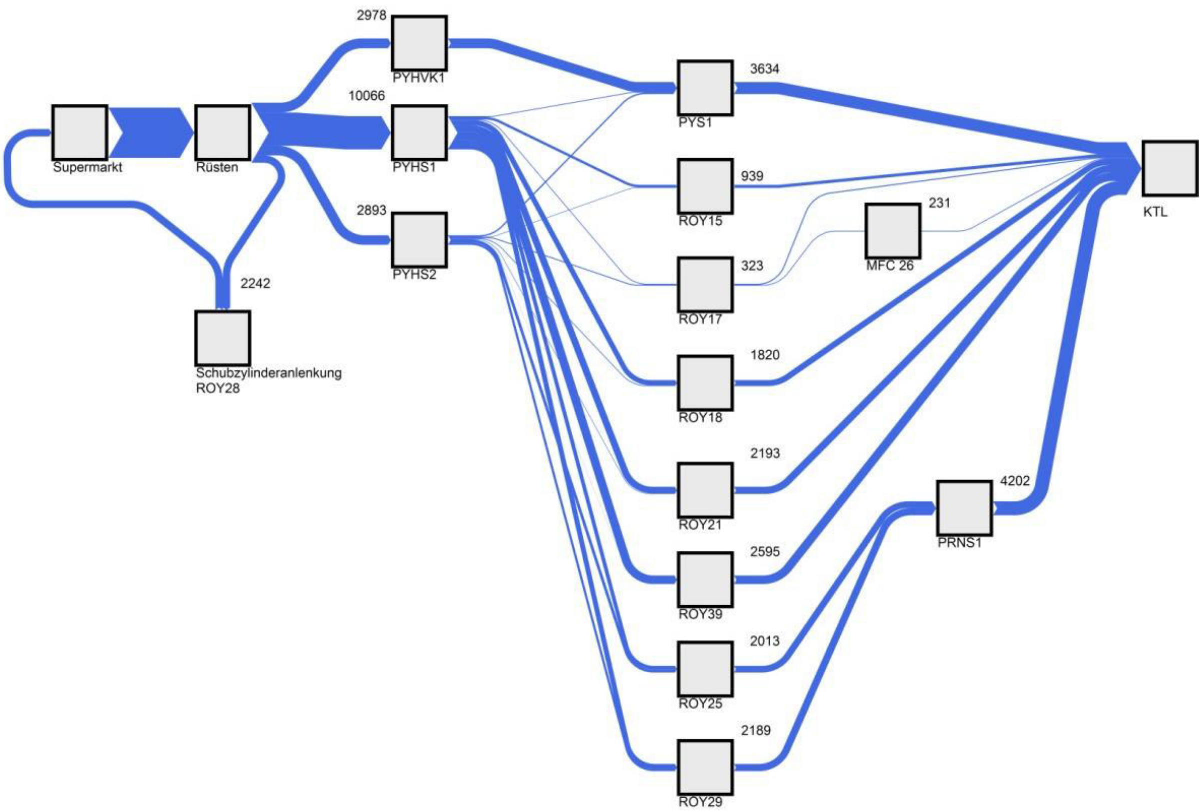


Figure 23 push arm production sankey

This apparent imbalance is due to the fact that the stapling station PYHVK1 only provides material for the manual welding stations. The other two setup stations serve both: all the welding robots and the manual welding station. Nevertheless, the question arises, why PYHS1 has processed 3.4 times the amount of parts in the same period. On a closer examination, it turns out that the PYHS2 mainly deals with parts that are special or over lengths and custom-made. This explains the significant divergence.

Furthermore, it is noticeable that there are different tendencies in the distribution of the material. Different stapling jobs deliver to different welding boxes. For example, the PYHS1 loads the welding robots 18, 21, 25, 29 and 39 more often than the manual workstation or the robots 15 and 17. The second staple box PYHS2, distributes the most material by far to robots ROY 25 and 29. Expressed in percentages these two robots process 55% of the parts that go through the staple box.

After considering the total numbers of welding robots and manual workstations it becomes evident that the fluctuation is not all that big. The bandwidth ranges from about 554 to 3634, the average being around 2000 pieces. Robot Roy 17 is definitely the one with the lowest numbers, as it is often used for new experiments, which explains the low number of processed parts.

Two further process steps, need to be mentioned here: the MFC 26 and PRNS 1. Process PRNS 1 is where the push arms get there finishing touches. This step is not necessary for all products. Noticeably, only two out of seven welding robots send this material. In this process step, various jobs are carried out, such as removing the welding spatter or customer-specific adjustments. Machining on MFC 26 is the only process executed by both, the push arm and the articulated arm. The available resources are shared. The share of 16% in the total number of pieces is only very small. In this process step the push arms are mechanically reworked.

The table (Figure 18 Process overview map) shows, that almost all process steps have a similarly high theoretical OEE. It ranges from 61% to 67%, which is very realistic and reflects the manufacturing possibilities. In this consideration, the machining centre and the manual welding were taken out. The machine centre would correct the result slightly upwards and the manual welding would decrease the percentage massively. In addition, the machining centre actually belongs to the articulated arm production and is therefore considered in the next chapter (8.2.3 Results from articulated arm production).

The OEE value for hand welding reveals massive problems. An OEE of 3% would point out, that there are some problems with this particular process. After a closer look, the table with the OEE values (Figure 18 Process overview map) contained a mistake in the quantities of the daily manufactured products. If the values are extrapolated (Figure 18 Process overview map) to the period considered, only a value of 1040 pieces emerges. But examining the tables (Figure 19 SAP abstract) with the actual quantities that have been produced exposes that more than three times as much have been processed, namely 3634. If this is now calculated back in the appropriate ratio then the OEE increases from 3% to 11% (Table 4 OEE summary push arm production). However, this value, which results from a possible working time of 1242 minutes in which only seven products are processed is still not a good.

Table 4 OEE summary push arm production

push arm production

unit per day	OEE	process
68	61%	SZA Roy
205	67%	stapling
203	66%	ROY
7	11%	hand welding
63	66%	finishing process
Σ 546		
average OEE	54%	
weighted average OEE	65%	

8.2.3 Results from articulated arm production

The articulated arm production is the smallest of the three departments. Since many cranes can bend only once, the articulated arms, in comparison to the push arms, manage significantly smaller quantities. Put into figures, the department is about five times smaller in numbers than the push arm production.

Nevertheless, the basic structure is relatively similar to the push arm production. Again, production involves stapling by hand or robot, welding for post-processing and the paint shop as a final stage. Three stapling workstations are available for the articulated arm, two of which are combined into one. This is also recognizable in the quantity of the parts that are processed. The PYHK 1 has about twice as much flow as the PYHK 2. The Fly-Jib staple is an extra point in the table (Figure 18 Process overview map) that is also integrated in the PYHK1.

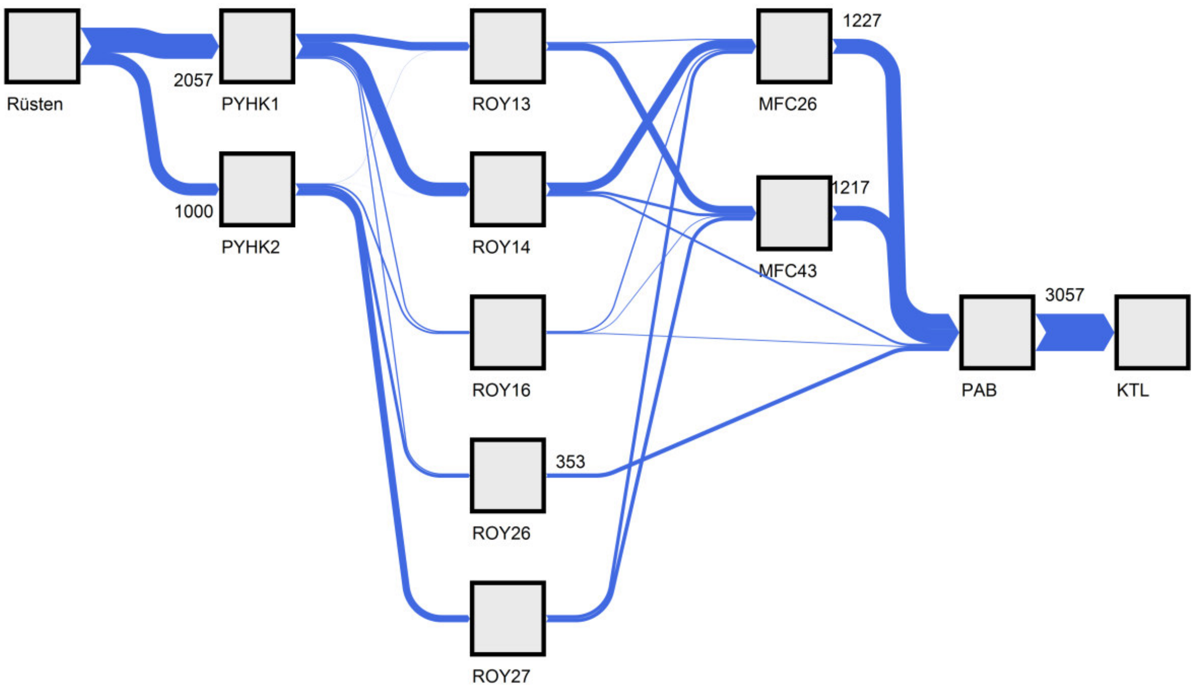


Figure 24 articulated arm production sankey

What stands out immediately is that the stapler boxes only deliver to certain welding robots (Figure 24 articulated arm production sankey). The intermixing of parts, as seen in the push arm, is much less extensive. Thus, 89% of the parts of PYHK 1 go to the two welding robots ROY 13 and 14. The second staple box supplies all robots but two of them carry a very small proportion (Figure 48 Material flow articulated arm part 3). This leads to the conclusion that PYHK 1 operates robots 13 and 14 and PYHK 2 operates robots 26 and 27 and both equally serve the welding robot 16.

After the robots processing, two machining centres are set up directly. 80% of all parts are additionally processed on one of the two machines. The welding robot 26 constitutes another anomaly, since it does not transport its parts to one of the machining centres but directly to the final process step.

In this case, the OEE values, are quite high: the lowest starts at 57% for stapling and robot welding and the highest ends at 86% in the machining centre (Table 5 OEE summary articulated arm production).

Table 5 OEE summary articulated arm production

articulated arm production

unit per day	OEE	process
41	57%	stapling
9	66%	Fly-Jib stapling
49	57%	ROY
49	80%	hand welding
57	86%	BAZ
60	80%	PAB
Σ 265		
average OEE	71%	
weighted average OEE	73%	

8.2.4 Comparison of the OEE values

Comparing the three departments, the articulated arm achieves the best result by far. This calculation (Table 6 Average OEE calculation) determines the mean value.

Table 6 Average OEE calculation

small part production

unit per day	OEE	process
3690	69%	KT laser
173	18%	KT milling
476	37%	KT drilling
1244	32%	KT edging
Σ 5583		
average OEE	39%	
weighted average OEE	56%	

push arm production

unit per day	OEE	process
68	61%	SZA Roy
205	67%	stapling
203	66%	ROY
7	11%	hand welding
63	66%	finishing process
Σ 546		
average OEE	54%	
weighted average OEE	65%	

articulated arm production

unit per day	OEE	process
41	57%	stapling
9	66%	Fly-Jib stapling
49	57%	ROY
49	80%	hand welding
57	86%	BAZ
60	80%	PAB
Σ 265		
average OEE	71%	
weighted average OEE	73%	

total OEE from average OEE:	55%
total OEE from weighted average OEE:	58%

Calculating the weighted mean with the production quantities demonstrates that the three productions are not so far apart. Nevertheless, the articulated arm production is still 8% more efficient than the push arm production and 17% more efficient than the small parts production.

9 Industry 4.0 visualization tools for the production

Based on the current state the company wants to keep up with the times and constantly improve its processes, the following part of the Master's thesis presents some of the aids that could be considered. The construction of a network for digital communication is the basic prerequisite for any of these systems to work. This also helps shape the path of communication from traditional to digital. The networking of the factory and the new communication options allow numerous efficiency and rationalization potentials to be exploited.[184] The new networking not only brings about an increase in the communication between the employees but also a massive increase in the workforce and the machines. This information provision is contributed by mobile assistance systems that are able to share the necessary information with the workers. This is called hybridization.[185]

The distinction in automation research is that it divides how much the human being can intervene in the system. The levels of automation [186] play a key role here. As a result, assistance systems can be distinguished with regard to their support performance and their level of automation. The rapid technological development of recent years has enabled the even more powerful computer to be deployed, bringing the assistance systems to unprecedented levels of computing and performance. It is a so-called technology push, which has however begun in the business-to-consumer (B2C) market. With a certain delay, these technologies are also used on an industrial scale. The late use can be attributed to the lack of suitability of the terminals regarding running time, robustness, and compatibility. A considerable share of the development contributes to the game industry. In the process, technologies are developed that provide the most efficient image processing possible, which in return is used in industry in augmented reality and other image processing systems.[187]

However, there is an almost infinite amount of different tools, technologies and application fields. A method for filtering this information overload has to be established. In the area of creativity technology, a morphological box is suitable for such cases. This method makes it quite handy to create a suitable solution for each case.[188]

[184] Niehaus, 2014.
[185] Rammert, Schulz-Schaeffer, and Ingo, 2002.
[186] Cummings and Bruni, 2009.
[187] Ziegler, 2017.
[188] Schawel and Billing, 2014.

Table 7 morphological box for assistance systems [189]

characteristic	attribute					
device	tablet	glasses	smartwatch	shop floor management board	Pc	other
target group	employees without persoraal responsibility		team leader		senior staff	
field od use	maintenance	assembly		logistic	other	
qualification requirements	none	admission	certified training		retraining	
system connection	none		local		databases	
data preparation	audiovisual	audio		graphic		haptic
support services	information	consultation	instruction	inervention documentation		
interaction	monologically		dialogue		with external	
adaptability	yes			no		
use	once		continuous	selectively	periodically	
control funktion	none		result		execution/ process	
performance documentation	yes			no		
learning support	none		further information		know query	

As can be seen in the table (Table 7 morphological box for assistance systems), this has already been tailored to the application of this master's thesis. On the left side are the properties that contribute to the solution of the question or problem. It should be ensured that these properties are independent from each other. In the corresponding line, the different forms are listed. For a better understanding of this approach, this should be explained by an example. In the first line can be seen that the property on the left, is what it has to fulfil. The line then shows the different forms that the device can accept.

Now it is important to find the best solution for the specific application. The green line has been chosen as an example for a solution. In the selected variant, an assistance system for maintenance of a machine tool should be found. Glasses were chosen, in order to have the hands free for work. This allows receiving information while hands are free to perform the activity. The system must have the properties to access the appropriate database to provide the operator with the important information for maintenance. If it then needs the experience of another expert or the manufacturer of the machine to eliminate the problem, communication medium, sound and image is necessary. The expert can give the worker precise instructions on how to do the job.

The next section discusses each visualization device.

- Tablets

  Smart tablets (Figure 25 Smart tablet in production) used in the industry differ significantly from consumer devices. The biggest advantage of such a device is the flexible positioning of the device. So far, mostly fixed IT solutions have been used. The main use of tablets in

[189] Niehaus, 2014.

production is the better illustration of production data. In the meantime, the systems are so flexible that they can represent their own "system landscape" for each worker. Thus, the workers only get the information they really need. This mobility allows the machine to be controlled via radio technology from different locations. The ergonomics can be significantly increased in this way. Another positive aspect of such a system in manufacturing is that you can move to a paperless manufacturing. However, the use of such systems also presents some challenges in the production environment. The use of these systems must be very intuitive and ergonomic. The operators must be able to use and apply the systems without much effort. The identification of the operating elements is a key challenge. Since these systems do not have a physical connection and usually have multiple interfaces, it is important to find an automatic configuration approach.[190]

Figure 25 Smart tablet in production[191]

- Glasses

  Smart glasses (Figure 26 Smart glasses) use either augmented reality or virtual reality technology to provide their information back to the worker. These have the task of making complex processes easier and more manageable. The worker can display additional information on work steps during processing. These ranges from specifications such as parts to be machined, welding order or other operations as well as construction plans. The worker can respond to questions so quickly without wasting time. Another major application is the control of the work steps. The built-in camera controls the individual work steps of the worker and would inform the worker if a wrong step would made. Another field of application of this technology is in the maintenance of machines. Here, a specialist can give the worker supportive work instructions without having to come

[190] Schmitt and Zühlke, 2013.
[191] Simplify, 2018.

personally to the machine. Therefore, ways and costs can be saved. An added benefit of this technology is that the worker has his hands free to work.[192]

Figure 26 Smart glasses[193]

- Smart watch

  Smart watches (Figure 27 Smart watch) are watches that allow additional processing of data. Currently, workers on machines have to get their information manually. The information ranges from work preparation, follow-up orders to maintenance plans. If a fault occurs in a machine, so far the worker has been informed about the signal tower on the machine about it. By means of the vibration alarm in the watch these disturbances are noticed much earlier and thus a longer machine downtime can be avoided. The worker can be given specific work processes at defined times without forgetting them. The classic example where the application of such systems already works very well is in logistics. Information about the locations of the products to be transported is transmitted to the worker on the device. Thus, the employee is spared the search of the goods. Such measures increase efficiency in production and logistics with the wearable.[194]

[192] Meiners, 2015.
[193] DAQRI, 2018.
[194] Schmitt and Zühlke, 2013.

Figure 27 Smart watch[195]

- Shop floor management board

  A shop floor management board (Figure 28 Shop floor management board) is an instrument in the production to visualize certain key figures. Usually, the desired key figures are graphically processed and thus enable the workers to be informed about the current production at a glance. This invention is by no means new, but with the accompanying digitization, this instrument takes on a new meaning. The connection to the ERP system makes it possible to respond more quickly to a changing operating state. In order to allow an attachment first, a certain preliminary work is needed. To have no media breaks in the system, a uniform system is needed, which records the key figures on the machines. The benefits of digitizing the shop floor is that manual data entry is replaced by automated systems. Today, the systems are able to draw from the collected data, not only conclusions about the production but also to process it. This can be a significant time saving to generate the previous systems. Another possibility is that the communication does not go in one direction only. This allows to control the production via this system additionally. Employees can actively intervene in production via the connection to the ERP system.[196]

[195] Mills, 2018.
[196] de Leeuw and van den Berg, 2011.

Figure 28 Shop floor management board[197]

- Industry PC
  The classic PC in manufacturing is still the most common method of providing information to the worker. These devices must withstand the harsh industrial environment compared to office computers. Their tasks range from process visualization, controlling robots to industrial automation. In addition, the classical tasks directly at the work place, like the information supply fulfil these computers. Their advantage is that they are relatively cheap and require little computing power. Therefore, computers that are mass produced can be used. Many companies are reluctant to replace this proven method of providing employees with the necessary information with a new system.

It turned out that three topics are of special interest for the company. This includes retrofitting, automated guided vehicles and wearable.

9.1 Retrofitting

The first of three topics covered is retrofitting. Retrofitting is a method to integrate older machines that do not yet have various communication interfaces (TCP / IP, WLAN, Profibus, OPC, etc.) by additional sensors in an existing network. The company defines which information a machine has to deliver and how to get that data with as little effort as possible. With this option, older machines that fulfil their function perfectly, can be easily integrated into the modern machine park. By integrating the machines, a more accurate picture of

[197] Bosch, 2018.

production can be gained and current production data can be displayed more easily.[198]

9.1.1 Examples for retrofitting

Since it has already been described what retrofit is, this section presents examples of providers. The first product is from a start-up, Oden Technology from the US. They have set themselves the task of developing a device that picks up the measured values using inexpensive and accessible components. The device, a Raspberry Pi, is connected to the machine and picks up the corresponding values at the programmable logic controller (PLC). These measurements are wirelessly sent to the "cloud" and processed there. There, the customer can then retrieve his data and use the appropriate analysis tool. Oden Technology offers not only data trackers but also a complete package from data collection to processing.[199]

Other manufacturers also offer solutions that provide the companies with degree of freedom. Weidmüller is a manufacturer of different electronic connectivity. These too have recognized the mark that brings the retrofitting with it. The company provides system solutions especially for "older" machines using the PLCs. We put an adapter on the existing PLC which makes it possible to use a new PLC. These are all network capable and thus allow the integration of the machines in the machine network.[200]

The Fraunhofer Institute has also developed a solution for retrofit. The "vbox" aim is not to replace the older but still very well functioning machines just because of the lack of network capability. Machine control requirements have changed dramatically over the last few years. Thus, the integration into intelligent manufacturing networks with analogue machines is impossible.[201]

9.2 Automated guided vehicles

The second part deals with autonomous transport systems. Specifically with automated guided vehicles systems (AGVS). Such a system is by definition an in-house, floor-bound conveyor system, which is automatically controlled. The main task is to bring material in a company from A to B but no people. Another criterion which facilitates a classification of the systems, whether the system is free-wheeling or has defined routes. Since the production layout is a subject of constant change, only free-moving systems are considered. The previous system is based on the conventional system of material handling by means of a forklift, which in contrast to an AGV, has some disadvantages. The processes become much more transparent through organized material and information flow. A more precise

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198 Austin-Morgen and Wilkins, 2016.
199 Technologies, 2017.
200 Weidmüller, 2016.
201 Fraunhofer, 2016.

calculation of the transport routes leads to easier compliance with the time specifications. The commitment to personnel in intralogistics can be reduced by means of an AGV, which in turn leads to a reduction in personnel costs.[202]

9.2.1 Examples for automated guided vehicles

The first example should be the winner of last year's IFOY Award. The TORsten from TORWEGGE, could secure this title with its new design and its excellent characteristics. It offers a variety of platform options. The navigation of the vehicles can be fully autonomous as well as manual. Fully autonomous operation uses robust Adaptive Monte-Carlo localization. The various sensors used in the platform are used to determine the position in the workshop based on the given layout [203]. Since an unrestricted production process is a prerequisite for efficient production, the system is able to operate in a 24-hour service. The TORsten is suitable for weight ranges of one to three tons.[204]

The second example is also an IFOY winner. The FTS WEASEL from SSI SCHAEFER is a product specially developed for the retrofitting of existing warehouses. The insert is only suitable for small parts. The transport weight of 35 kilograms is the limiting factor. Due to the markings, located at the bottom (line), the investment costs are lower. Since this system has a very limited field of application, it will not be considered further.[205]

The well-known manufacturer KUKA also introduces a potential AGV, the KMP 1500. KUKA's approach is to move away from rigid and inflexible transportation routes to intelligent and autonomous vehicles. The platform offers enormous potential for expansion. Thanks to the company's own robot arms, the platform can expand its field of application in addition to the transport tasks. The transport vehicle can become a mobile work platform. The product is always positioned accordingly for the work step. After completion of the work, the product on the platform moves independently to the next processing step.[206]

9.3 Wearable

The third part deals with portable aids, wearables. These are small devices that the worker carries directly on the body. Mostly, this technology can be found in the form of watches, tablets or glasses and these should support the employee in his day-to-day business so much that, on the one hand, the quality and, on the other hand, the efficiency of the individual processes increase. Typical areas of application of this technology are in maintenance and servicing, quality assurance and logistics. The five primary uses include

[202] Part, 2009.
[203] Dellaert et al.; Thrun, Burgard, and Fox, 2005.
[204] TORWEGGE, 2017.
[205] Schäfer, 2016.
[206] KUKA, 2017.

assist, document, support, list and pick.[207]

Under the aspect of assisting is to understand that this system provides held when the employee is in situation where questions can arise. Be it in production processes, troubleshooting and repair or simply providing the installation instructions. With these measures, the employee can be helped directly without great delay and thus increase the work performance.[208]

Nearly every process is documented to ensure complete tracking of products through production. One-step towards paperless production is to solve the documentation about the corresponding wearable. Small scanners can read both RFID and barcodes and read out all necessary information for the particular product.[209]

In case of malfunctions or failures of a machine, the worker and his suitable wearable can react quickly to the new situation. The specialist technician does not have to go to a defective machine, but can give the employees on-site instructions directly via live images to ensure a quick repair. In this way, the expensive travel coasts of the service technician fall away, if the failure is not in production hall. Since adjusting the machine does not add value and therefore add only losses, there are already systems where the product "tells" the machine what to do. This requires a central database, where all work schedules are located and the machine selects the right schedule for the right product.[210]

Time is one of the most decisive factors in logistics today. Having the product in a defined location at a defined time is crucial to avoid delays in production. Picking is used very heavily in logistics. Mostly the warehouse operator is placed on the digital image with the appropriate additional information by means of data glasses. This information can be possible routes, storage locations or work processes.[211]

9.3.1 Examples for wearables

Wearables are the products that workers will hardly ever get around in the future. Smartphones have created the basis for such systems. They have already reduced a major inhibition threshold and made it possible to use it in production.

Meta has built a similar variant of the Hololens by Mircosoft. This variant are augmented reality (AR) glasses, which has a huge field of application. Wearing them, it's possible to view and test new projects in the virtual world. Realistic scenarios can be played through and errors can be detected in advance. Other uses of the glasses are the monitoring of

[207] Plutz et al., 2016.
[208] Bauernhansl, ten Hompel, and Vogel-Heuser, 2014.
[209] Hinkka and Tätilä, 2013.
[210] Chiarini, 2013; Ghobadian et al., 2018.
[211] van Dorp, 2002.

production for example. A virtual tour through the production is possible and getting the current production data on the corresponding machines. This significantly influences the production control and enables decentralized control.[212]

Oculavis has developed an assistance system for the logistics sector. AR glasses serve as an information system that helps the worker to search for and pick goods. The glasses show the worker on clearly visible arrows, where the products are which should be selected. In the next step it is possible to calculate the exact quantities. The technical term for this system is pick-by-vision. The right application at the company would be the small parts warehouse.[213]

ProGlove takes a different approach. In this case, the worker do not have glasses but a glove on. It is provided with a scanner on the back of the hand, which can fulfil different tasks. From picking, quality controls, track & trace and assembling, this glove can be used anywhere. The system scans 1D / 2D barcodes on the products or carriers. This ensures accurate traceability through production.[214]

[212] Meta, 2016.
[213] oculavis, 2016.
[214] ProGlove, 2016.

10 Concept development

The main aim of this thesis – creating a concept that allows the use of the operations data - is presented in this chapter.

The tasks of the overall concept should be to better control or eliminate the three main problems. The three problems in the manufacturing are: production control, quality issues and missing manufacturing data. How should the concept solve these three problems?

The production control is to be done via the OEE. Since this is composed of several components, it is possible to cover a wider range of production. If a change in the OEE is registered, it is not easy to say where the problem lies. This requires a closer analysis of the three factors. The three factors, availability, performance and quality, provide an indication of the following areas. Availability allows conclusions about machine availability. Changed cycle times can be read in the performance index. This may occur due to lack of labour or unavailable material. Defective parts or reworking of products can be read in the quality factor.

In order to find quality problems in the production, it is important that the traceability of the product is present. Thus, the source of the quality problems can be found and fight the cause. Another aspect of tracking is the possibility of material flow analysis. This enables a more efficient design of the future production layout. Connections in production can be visualized and therefore it is easier to recognize.

A missing database of current production data prevents the new production layouts from being tailored to the needs. Since such possible connections cannot be seen and this can lead to inefficient layouts. It would also be possible to simulate future scenarios based on the current production data. Fluctuations in production or the production of new products would also be simulated in advance and, if possible, identified any mistakes early on.

Like every concept, it starts with a definition of the requirements. It needs to be limited to the three topics value stream map, material tracking, and OEE tracker.

10.1 Catalog of requirements

The company has specific requirements for the framework conditions and tasks that the concept must fulfil. These are outlined in the following section.

- Value Stream
  The main task of the value stream map is to display all the data needed, live or as averages values from the SAP. A live display is needed to examine the current process and the average to evaluate the shift's performance. In addition, the program should be compatible with Mircosoft VISIO. Since VISIO is an independent program by Mircosoft,

the value stream program must run as add-on. VISIO is already available to the company Group as a software solution, which reduces he costs because no new software has to be purchased. This master's thesis only examines the sheet metal production of one of the plants in Austria, therefore, the software's expandability is a prerequisite. The system must be able to process data from different production sites and permit the merging of several production sites (multi site capability). As a detailed report about the processes is necessary, the so-called key performance indicator (KPIs) must be calculable individually for each. Another very important requirement is the easy implementation for the solution. The company expects the implementation to be effortless and the desired result easily attainable. The term “out of the box” is very common in this context.

- Material tracking

  The requirements for the material tracking system are more complex. Currently, tracking of parts is not possible due to machining and high production volumes. Therefore, the system must track the load carrier to get the tracking information. The system has to be a modular system in order to adapt to constantly changing influences. Changing influences are for example new or alternating products or a changing production layout. To obtain an overview and complete traceability, the system has to provide real-time tracking. Thus, it is possible to control the exact location and storage of working equipment during the entire production. The material tracking systems should be reliable and serve the company over a certain period. Using an existing database, the system should be able to simulate future scenarios. This includes changes in the layout as well as changing production volumes. It should further detect the visible paths and specify the optimal path for material handling. The system should always indicate the fastest route through the shop floor, depending on all inner and outer circumstances. An open interface for third-party integration is needed as well. Through this interface, it should be possible to control an automated guided vehicle transport system (AGVS).

  The system needs to navigate independently through the production hall. This means that it must work operate with minimum expenditure. As already mentioned in the value stream, a ready-to-use application is desired.

  The information gained from the analysis, about the requirements of the systems, shows that some criteria are no longer relevant. These are explained below. The modular system, which is a requirement for the system, is no longer included in the criteria, because all the systems considered were 100% compliant. The tracking systems are designed to be supplemented with appropriate modules or extensions at any time. The biggest challenge for these systems is the ability to simulate past material tracking values and then redeploy them in a new layout. Most providers of such systems have developed a solution purely for tracking materials on the shop floor. These systems can track anything from actual products to load carriers or humans. The trackers have an enormous field of application. In the future, the possibility of all-encompassing tracking could become very interesting for companies in this field. To give just one example, it would significantly facilitate checking if all employees had been evacuated in case of emergency. These systems could also help to determine the last location of every employee, which gives the emergency services a considerable advantage.

- OEE Tracker

  The OEE Tracker has to be able to send its data directly and with a simple transfer to SAP. Furthermore, the data transmitted to SAP need to be processed in a way that is compatible with the value stream software package. Generating data must be possible with both types of workplaces, automatic and manual. This function is important because production includes processes ranging from manual workstations up to fully automatic welding robots. Therefore, the user-interface should be adaptable to all kinds of workstations. Since not only highly modern welding robots with corresponding interfaces for data extraction are in production, the system must enable a connection with older machines. In the industrial world, this is called retrofit capabilities. Like the other two systems, this should also be one in which the company can draw on corresponding experience from other projects implemented by the provider.

10.2 Selection of the components

As soon as the requirements were clarified, the selection of the necessary components for the implementation of the concept began. At first, it was necessary get an overview of the vast field of providers to determine the current industrial state. Since the market is currently flooded with providers that offers similar solutions, a decision model was necessary for the selection. The company often uses a pair wise comparison for their decisions, this was also used here. In order to be make a more informed statement, the comparison was additionally combined with a utility value analysis. The method that was used to decide which OEE Tracker and which Material Flow Tracker would fit the concept, will be briefly explained below.

The pair wise comparison is a method to evaluate alternatives. In cooperation with a value analysis, the decision-making thus becomes methodologically comprehensible. This is useful to avoid making decisions based on intuition alone. The results of this technique show which component fulfils the requirements best.[215]

[215] Behnke and Behnke, 2006.

then / more important	criterion 1	criterion 2	criterion 3	criterion 4	criterion 5	criterion 6	criterion 7	criterion 8	criterion 9	criterion 10	total	%
criterion 1		1	1	1	1	1	1	1	1	1	9	28.13%
criterion 2			1	1	1	1	0	0	1	1	6	18.75%
criterion 3				1	1	0	0	1	1	0	4	12.50%
criterion 4					1	1	0	1	0	0	3	9.38%
criterion 5						1	0	1	1	0	3	9.38%
criterion 6							1	1	1	1	4	12.50%
criterion 7								1	0	0	1	3.13%
criterion 8									1	0	1	3.13%
criterion 9										1	1	3.13%
criterion 10											0	0.00%
											checksum	100.00%

Figure 29 Pair wise comparison [216]

Before comparing different solutions, the appropriate criteria should be defined in a collective creative process, brainstorming, for example. It is important to ensure that the widest possible range is covered to avoid limiting the scope. The first step is to devise a criteria matrix (Figure 29 Pair wise comparison). Two criteria are respectively compared with each other. The next step is to decide which of the two is more important. If the criterion in the row is more important than the one in the column, this criterion is rated with 1. Respectively, the criterion in the column, that is rated as less important gets a 0. When every single criterion has been rated, the sum of the single rows, which reflects the significance of the criterion is calculated on the right side. To ensure comprehension, the weights are given in percent. These values additionally serve as the basis for the utility value analysis.[217]

The utility analysis then is devised in another table (Figure 30 Utility analysis). The individual criteria are evaluated against the alternatives available for selection. The evaluation is also performed in a number system ranging from 0 to 10.[218]

[216] Rolosixmeich, 2013.
[217] Behnke and Behnke, 2006.
[218] Müller-Benedict, 2006.

		product 1		product 2		product 3		product 4	
	weighting factor	weithing of the product	utility value	weithing of the product	utility value	weithing of the product	utility value	weithing of the product	utility value
criterion 1	28.13%	10	2.81	10	2.81	7	1.97	3	0.84
criterion 2	18.75%	4	0.75	10	1.88	8	1.5	5	0.94
criterion 3	12.50%	3	0.38	3	0.38	3	0.38	3	0.38
criterion 4	9.38%	7	0.66	4	0.38	3	0.28	4	0.38
criterion 5	9.38%	8	0.75	8	0.75	7	0.66	8	0.75
criterion 6	12.50%	4	0.5	9	1.13	9	1.13	4	0.5
criterion 7	3.13%	7	0.22	2	0.06	1	0.03	1	0.03
criterion 8	3.13%	9	0.28	3	0.09	3	0.09	3	0.09
criterion 9	3.13%	8	0.25	1	0.03	0	0	1	0.03
criterion 10	0.00%	8	0	1	0	3	0	1	0
	sum		6.59		7.50		6.03		3.94

Figure 30 Utility analysis[219]

The better an alternative meets a criterion, the higher its rating will be. After all alternatives have been evaluated, the ratings are multiplied by the percentages or weighting factors from the pair wise comparison. Adding up the values of an alternative results in a final value that used to make a decision. Consequently the alternative with the highest value is the best solution to solve the problem.[220]

10.2.1 OEE tracker

After the theoretical introduction to the subject of pair wise comparison, the described, practice-oriented application needs to be applied. First, I set the decision criteria, then I started the evaluation from my perspective. Unfortunately, I received no feedback from the company regarding their opinion, so I had to use my own values.

In a real decision-making process this task would affect the whole company and it would be imperative to involve several people.

[219] Rolosixmelch, 2016.
[220] Haasis, 1996.

	manual or/and automatic data collection	third party integration	real-time performance feedback	stand alone / complete solution	browser- based application	wired or wireless network	multi-site	implement time	rent / permanent	machine / manual workstation	costs	Σ	weighting factor	ranking
manual or/and automatic data collection		0	1	1	1	1	1	1	1	1	1	9	16	2
third party integration	1		1	1	1	1	1	1	1	1	1	10	18	1
real-time performance feedback	0	0		1	1	1	1	1	1	0	0	6	11	4
stand alone / complete solution	0	0	0		0	1	0	0	1	0	0	2	4	9
browser- based application	0	0	0	1		1	0	0	1	0	0	3	5	8
wired or wireless network	0	0	0	0	0		0	0	0	0	0	0	0	11
multi-site	0	0	0	1	1	1		0	1	0	0	4	7	7
implement time	0	0	0	1	1	1	1		1	0	1	6	11	4
rent / permanent	0	0	0	0	0	1	0	0		0	0	1	2	10
machine / manual workstation	0	0	1	1	1	1	1	1	1		1	8	15	3
costs	0	0	1	1	1	1	1	0	1	0		6	11	4
												55	100	

Figure 31 Pair wise comparison

As illustrated in the table (Figure 31 Pair wise comparison), a few more requirements have been added to the ones mentioned in the chapter above (10.1 Catalog of requirements). The most important feature of a new software, according to this review, is its capability to integrate and be integrated other software packages.

The analysis shows that there are three main criteria. The other eight remaining criteria have proven to be less important. As already mentioned, beside tracking, the most important task of the OEE tracking is third party integration. Second most important is the assurance that the requested data can be generated both automatically and manually. The flexible adaptation of the system to the different workstation configurations ranks right after automatic data collection.

Based on these evaluation criteria, the five products listed in the following table (Figure 32 Data box OEE tracker) where chosen. In the process, the properties of the providers where completed in the table to use them in the value analysis.

	Perform OEE	Datafox MDE OEE	EasyOEE	ShopFloorConnect	FacktoryM1ner
manual or/and automatic data collection	manual & automatic	manual & automatic	manual & automatic	manual & automatic	manual & automatic
third party integration	✔	✔	x	✔	✔
real-time performance feedback	✔	~	✔	x	✔
stand alone / complete solution	stand alone	complete solution	stand alone	complete solution	stand alone
browser- based application	✔	x	✔	x	✔
wired or wireless network	wired & wireless	wired & wireless	wired	wired	wired & wireless
multi-site	✔	✔	x	x	✔
implement time	10 weeks	around 6 months	weeks	weeks	weeks
rent / permanent	permanent	permanent	rent	permanent	rent
machine / manual workstation	machine/manual	machine/manual	machine	machine	machine/manual
Costs	~	~	390 €/month	~	49 €/machine

Figure 32 Data box OEE tracker

The result are five products, three of them are permanent installations: Perfom OEE, Datafox MDE OEE, and ShopFloorConnect. The other two are on loan: EasyOEE and FacktoryM1ner. EasyOEE was included into this selection, because the company had already worked with it. The objective was to show that there could be more appropriate solutions for the OEE tracking. The only thing that distorts the result is that it was not possible to determine the exact costs for the permanently installed OEE trackers. The pricing strategy of the providers consists of selling complete packages that include training and extensive support.

One criterion property may need further explanation. “Stand alone / complete solution” means stand-alone systems are systems that are completely self-contained and do not use infrastructure, be it networks, servers or anything like that. In addition, all products that are marked as stand alone can only be accessed via an Internet or intranet-enabled browser.

The evaluation of the software packages is explained by describing the distribution of the points of the product with the highest value (Figure 33 Result OEE tracker). The first criterion that should be applied to the properties of PerformOEE is the automatic and manual capture of the required data. The supplier is able to provide three states of data collection: automatically, manually and a combination of both, which gave them the best value compared to the others. Since it is possible to connect to the SAP system using standard interfaces, the full score is reached. Regarding real-time performance feedback, the package was also able to reach the maximum point score because the data is permanently analyzed and, according to the manufacturer, predicts imminent losses. In the category “stand alone” the system only reached six points because it is a closed one. It does not allow working independently on changing tasks. The provider is completely in charge and thus one is restricted to this one system. As it is a closed system, direct access to the system is also heavily regulated. Advantage of this variant are that the data can be accessed worldwide via open internet access. However, this features constitutes a vulnerability at the same time. Phishing is an indistinguishable threat and a part of industrial espionage. Since all systems can be both wired and wireless, this category does not affect the results and was taken out of the calculation by its factor. Nearly every supplier offers multi-site data tracking, therefore the same points where given the system, which fulfil the requirements. In terms of implementation time, the overall winner ranks only second to last, because the other systems usually work on a rental basis, which reduces the implementation time. PerformOEE supports both manual and machine workstations, therefore the system got nine points.

evaluation criteria	weighting factor	Perform OEE	utility value 1	Datafox MDE OEE	utility value 2	ShopFloorConnect	utility value 3	FacktoryM1ner	utility value 4	EasyOEE	utility value 5
manual or/and automatic data collection	9.00	8	72.00	8	72.00	8	72.00	8	72.00	8	72.00
third party integration	10.00	10	100.00	10	100.00	10	100.00	10	100.00	2	20.00
real-time performance feedback	6.00	8	48.00	3	18.00	3	18.00	8	48.00	8	48.00
stand alone / complete solution	2.00	6	12.00	4	8.00	4	8.00	6	12.00	6	12.00
browser- based application	3.00	7	21.00	3	9.00	4	12.00	7	21.00	7	21.00
wired or wireless network	0.00	7	0.00	7	0.00	4	0.00	7	0.00	4	0.00
multi-site	4.00	8	32.00	8	32.00	2	8.00	6	24.00	2	8.00
implement time	6.00	7	42.00	3	18.00	7	42.00	6	36.00	7	42.00
rent / permanent	1.00	5	5.00	5	5.00	5	5.00	5	5.00	5	5.00
machine / manual workstation	8.00	9	72.00	9	72.00	6	48.00	9	72.00	6	48.00
costs	6.00	4	24.00	3	18.00	3	18.00	6	36.00	4	24.00
			428.00		352.00		331.00		426.00		300.00
			1		3		4		2		5

Figure 33 Result OEE tracker

10.2.2 Material Tracker

The comparison further showed (Figure 34 Pair wise comparison material tracker) that all software solutions already include the analysis function. The systems not only record the completed transports, but can also reference them in future recommendations on material transport efficiency. The easiest way to do this is to avoid empty runs and unnecessary ways. The company also anticipates the prospect of autonomous transport systems in addition to or instead of a forklift. This had to be taken into account as well. However, all these systems work by means of a transmitter that is not mounted directly on the material but on the load carrier. As already mentioned, a direct tracking of the material is currently not possible.

The issue of connectivity and reception needs to be considered as well. The connection of the tracker to the system has to work at all times and without interference. However, there are some factor that could impair the connectivity of the systems. Most of the production halls are made of metal and other radio networks are installed that could provoke interferences. Therefore, the type of connection must be chosen wisely so that an appropriate adaptation to the environment is possible.

	in & outdoor	accuracy	expandable	SAP integration	active or passive sensor	real-time-tracking	rent / permanent	connection	Σ	weighting factor	ranking
in & outdoor		0	0	0	1	0	1	1	3	8.8	6
accuracy	1		0	0	1	0	1	1	4	11.8	4
expandable	1	1		0	1	1	2	2	7	19.1	2
SAP integration	1	1	1		2	1	2	2	9	25.0	1
active or passive sensor	0	0	1	0		1	1	1	4	10.3	5
real-time-tracking	1	1	1	0	0		2	2	6	17.6	3
rent / permanent	0	0	1	0	0	0		1	2	5.9	7
connection	0	0	1	0	0	0	0		1	1.5	8
									34	100	

Figure 34 Pair wise comparison material tracker

As with the OEE Tracker, integration into SAP takes first place in terms of necessary requirements for the software. SAP also function as the central data storage space for the material tracking software. All the data generated with the tracking system should be stored in SAP. That is the only place where everyone has access. The second most important requirement is expandability. This concerns not only should the addition of a new tracker but the expandability of the system. While only a specific part of production is considered in this thesis, an extension to subsequent production areas needs to be considered as well. This criterion is similar to the modular structure of the system, which is purely an extension.

	Kinexon	blik - Logistics	deTAGtive
in & outdoor	in & outdoor	indoor	in & outdoor
accuracy	under 10 cm	under 50cm	~ 1m
expandable	easy	easy	easy
SAP integration	✔	✔	✔
active or passive sensor	active	active	active
real-time-tracking	✔	✔	✔
rent / permanent	permanent	rent	permanent
connection	wifi	wifi	bluetooth

Figure 35 Data box material tracker

In order to cover a variety of solutions in the decisions making process, I decided to compare these three providers. All types of systems, from a very well-known to a start-up system are represented. deTAGtive is well-known, blik the start-up and Kinexon is situated somewhere in between (Figure 35 Data box material tracker).

As in the previous example, I would like to explain my rating based on the winner (Figure 36 Result material tracker). The results in the selection of the three are very similar, which speaks for three very good systems. The first criterion that had to be evaluated was the possibility to use the system outside of the production hall. This will become partially relevant as soon as several production halls and locations are integrated into the system. External influences should not limit the system. Two of the three systems offer this feature, which is why they have received a much better rating here. The system’s accuracy is not the deciding factor for its implementation. Since the trolleys moving production parts around the hall are large objects, their location does not have to be determined by a few centimetres. Kinexon mastered this anyway, so it scored the best. Expandability is an easy task for all systems.

Adding a new station as well as expanding to a new area is a basic function. Similarly, passing the generated data to SAP is no challenge for all three.

All packages are equipped with appropriate interfaces and protocols. One thing that the three systems have in common is that they all have an active sensor. This means, compared to a passive sensor, the tracker itself emits pulses and the receivers determine its position by means of triangulation. This has the significant advantage that continuous tracking of its position is possible. Not only does the tracker determine start and finish point but the actual transport route. This is necessary for the analysis of the infrastructure, which is why only active systems have been considered. The active sensor is complemented with a real-time tracking possibility. Without the former, the second would not be possible, which is why all three have achieved the same score here. The next criterion in the list is “rent” or “permanent solution”. Two of the three are marketed conventionally as permanent installation in the production hall. Blik goes another way here. The start-up charges only a certain amount per transmitter, but nothing for the installation or the rest of the components. On the one hand, this allows a greater flexibility, but on the other hand, the whole concept of the start-up also presents risks. The likelihood that this company will not succeed in establishing itself on the market is much higher compared to the possibility of well-known companies suddenly going bankrupt. The last requirement “connection” is fulfilled by all systems. They all have a wireless connection. However, two systems offer much better range and stability with a 2.4 GHz wireless LAN concept while deTAGtive operates with Bluetooth. This implies that a higher number of receivers must be installed, which in turn drives up the costs of the purchase.

evaluation criteria	weighting factor	Kinexon	utility value 1	blik - Logistics	utility value 2	deTAGtive	utility value 3
in & outdoor	8.8	8	70.59	6	52.94	8	70.59
accuracy	11.8	9	105.88	7	82.35	5	58.82
expandable	19.1	8	152.94	8	152.94	8	152.94
SAP integration	25.0	7	175.00	8	200.00	8	200.00
active or passive sensor	10.3	8	82.35	8	82.35	8	82.35
real-time-tracking	17.6	8	141.18	8	141.18	8	141.18
rent / permanent	5.9	7	41.18	6	35.29	7	41.18
connection	1.5	8	11.76	8	11.76	6	8.82
			780.88		758.82		755.88
			1		2		3

Figure 36 Result material tracker

10.3 Business Process Model and Notation

For a better understanding how these systems interlock a Business Process Model and Notation (BPMN) has been created. The Business Process Model and Notation is set up with six swim lanes. Defined as follows:

- SAP (inkl. Leistand) – the complete control and storage of data generated by the different trackers is located here.
- OEE – Tracker – ensures time tracking at the machine or at the manual workstation
- VASCO – is the software that represents the value stream and imports the current live data
- Interleaver – creates the patterns on the raw steel plates
- Task – all producing activities are summarized here
- Kinexon – is responsible for the material tracking

To produce a new product, it has to be registered as a task in SAP. While the necessary measures are taken, the task is sent to the interleaver and the raw material store at the same time. The interleaver creates the cutting layout using the incoming information. Meanwhile the warehouse provides the raw material for the lasers.

Then, the laser is fed (Figure 37 BPMN Task) with the appropriate raw material from the warehouse and receives the cutting layout from the interleaver.

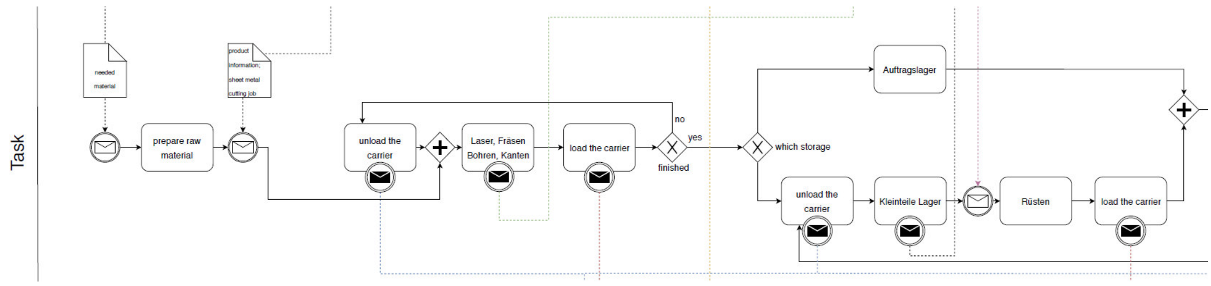

Figure 37 BPMN Task

As soon as the production process starts, an event is triggered (Figure 38 BPMN OEE Tracker). This tells the tracker to switch from its idle process to the tracking function. The time is captured as the process takes place. At the end of the process the time value for the corresponding product is stored in SAP, uniquely assignable. This procedure is the same for every step of the process.

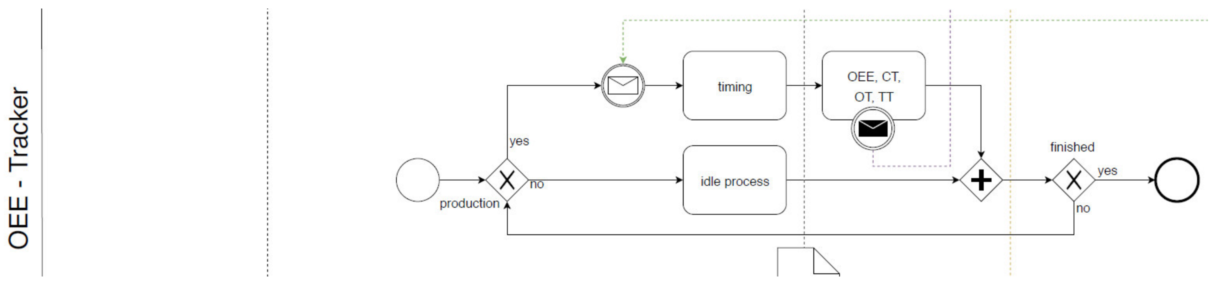

Figure 38 BPMN OEE Tracker

VASCO (Figure 39 BPMN VASCO) can then access the stored OEE data in SAP and display it in the relevant process's data boxes in the value stream.

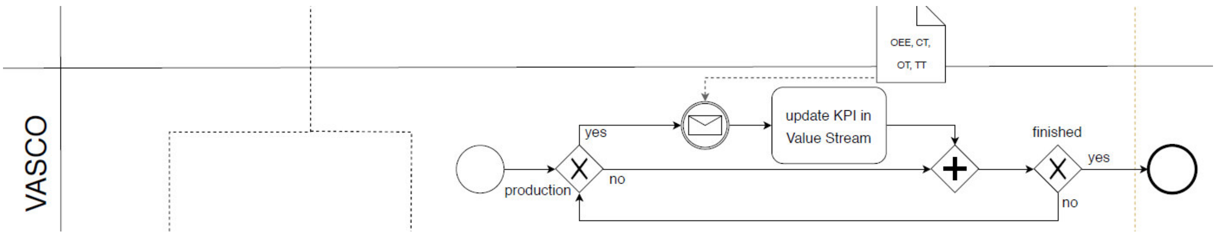

Figure 39 BPMN VASCO

The material tracking software (Figure 40 BPMN kinexon) starts tracking the material from the moment the product is placed on the load carrier after the processing task. Not only the product but also the unique identification number is saved. The tracking ends, when the part is removed from the load carrier before it is processed in the next step. The covered distance and the additionally gained data, such as the time required for this distance, are in return sent to SAP and centrally managed there.

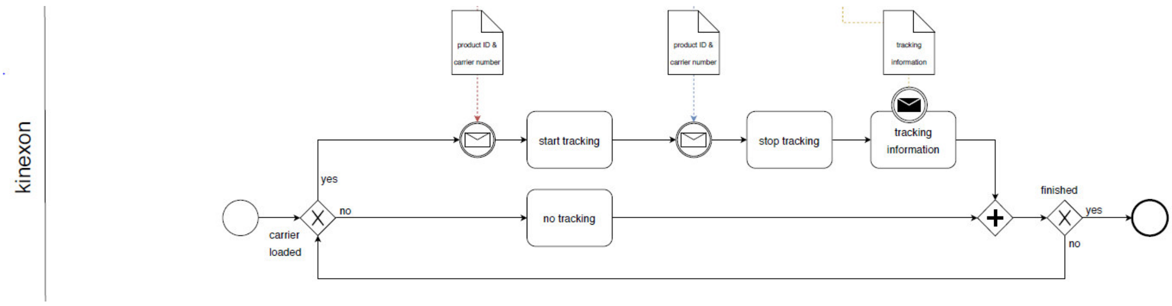

Figure 40 BPMN kinexon

These were only extracts from the whole picture that showed the individual functions of the different systems. It is nevertheless important to consider the processes in their entirety.

The communication between the swim lanes is one of the central points of a BPMN. They show how the individuals users/participants exchange information with each other and what they should contain. Since each system works independently, their interfaces are crucial. In this project, it was decided that the SAP becomes the designated hub. This significantly simplified the choice of products. Since SAP is a very common ERP system, support software providers adapt their products accordingly.

The structure of the BPMN is very similar to the value stream. Apart from the three new components, all previously used process steps are recognizable. In order not to over-size the model, some processes have been summarized. The process itself is always the same. To ensure that the summary does not overlook any process steps, they were wrapped in a loop.

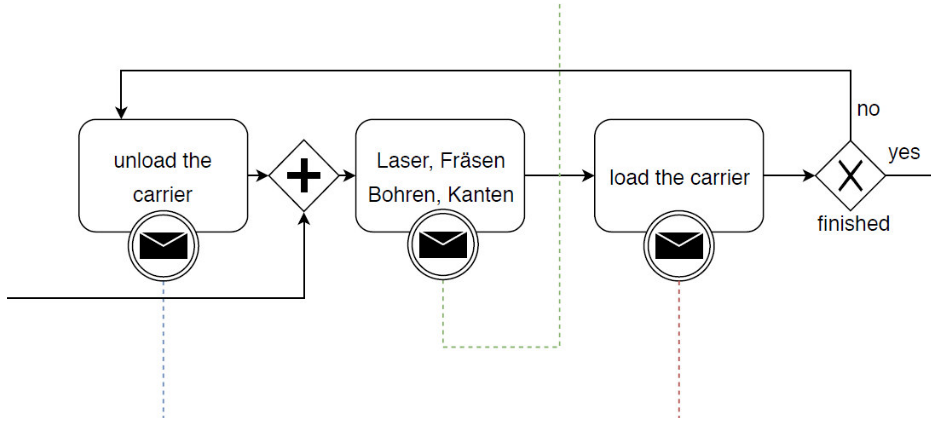

Figure 41 BPMN small parts production

Every part starts with the laser (Figure 41 BPMN small parts production). The raw material is directly transported into the laser with the forklift truck. The step "unloading the load carrier" is skipped. After that, the loop repeats itself, depending on how many processing steps are necessary. In the diagram (Figure 41 BPMN small parts production), three differently coloured dashed lines, move away from a letter symbol. The letter symbol initiates an event taking place. The blue line triggers the event in the tracking software, that tracking should be stopped. The red one, by contrast, causes the software to start timing. The green line means that the OEE Tracker should take the time. Since the OEE is dose not just track start and end time, but also other factors such as setup procedures, malfunctions must be taken into account. This information is specified in a corresponding interface and stored as additional information in SAP. After the small parts production, it has to be decided to which of the two warehouses the materials are transported (Figure 42 BPMN part storage). When the products enter the small parts store, they are removed from the load carrier, which in return stops the tracking. The information is delivered to SAP so that the stock level can be checked. In return, when the preparer is commissioned to provide material for a job, carriers are loaded, which starts the track. If the parts produced from the small parts production are order-related, they remain on their load carrier, since they only need to stay in the warehouse to wait for their transport to the next process step.

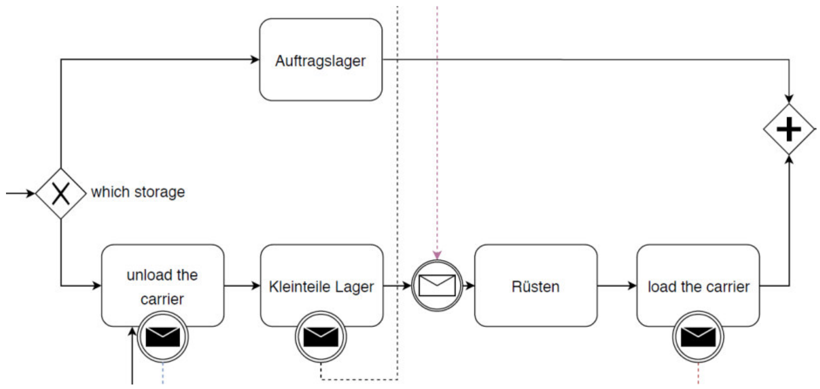

Figure 42 BPMN part storage

At the first decision-gateway, one production flow leads to the push cylinder linkage. The finished linkage is delivered back to the small part warehouse. Subsequently, the different stapling processes decides whether the material is transported to manual or robot welding. Then a separation between push and articulated arm occurs. The lower process strand is the push arm and the upper one is the articulated arm. This is possible, because certain process steps can only be assigned to one of the two. The last step is the transport of the finished products to the KTL. Here, the information that the production is finished (Figure 43 BPMN push arm- and articulated arm), is sent to SAP.

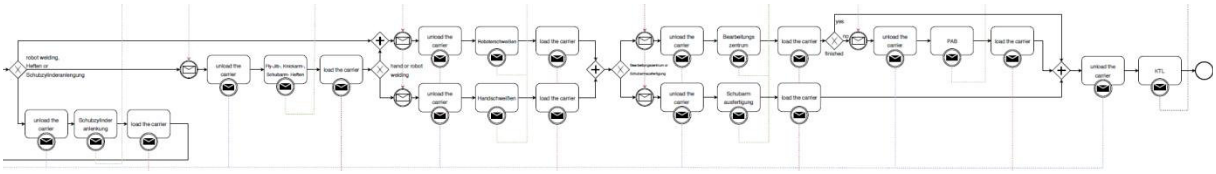

Figure 43 BPMN push arm- and articulated arm

11 Summary and Conclusion

The company has recognized that Industry 4.0 is the future. To be able to be competitive, the company has to become more effective in their production to reduce their product costs. So far, some projects have been tested. This led to a veritable collection of island projects. Now the decision was made to create a overall concept for the sheet metal department in the factory. The value stream, the OEE and the material flow should be covered.

To get an overview of what the actual state was, the company wanted a benchmark comparison. This turns out to be the biggest challenge of the thesis. The ambition was to compare the production of the company with competitors that are in the same industrial field. Unfortunately, it was impossible to get information from other companies therefore, together with the company responsible, we decided to modify this chapter and present an internet research for this topic instead. At the beginning, different countries were compared with each other, but also the leading companies in the supply of Industry 4.0 equipment. Out of the benchmarking the 13 design factors were developed that every company should consider.

The second major topic of this master's thesis is a more detailed analysis of the value stream at the production plant in Austria. In doing so, a platform was found that was able to cope with the current and future scenarios. However, the current state had to be recorded and displayed in the correct form.

At the beginning of the thesis, the production layout had to be rebuilt on paper, because the layout had changed and doesn’t fit to data I have received. The observation period was from 01.01.2017 to 01.04.2017. This means re-establishing the "original" condition with the process supervisors. Possible improvements were derived from the created value stream. In the future, it should also be possible to simulate changed production layouts and to test them under real circumstances. Another subhead of this topic is the collection of the OEE. To date, the OEE was only known in a theoretical form. This, as it turned out in this master's thesis, was not always correct either. A system was found that anables automatic detection of the value. The challenge for this system is to cope with the different workstations. There is everything from manual workstations and semi-automatic to fully autonomous welding robots.

Material flow, like the benchmark comparison, was also a very complex task. The company had already undertaken some activities in this regard. The aim was to use RFID chips to track material flows through production directly on the product. This failed due to the mechanical processing effects and the enormous quantities. A positive side effect would be a clear traceability not only through production but also in the further product life cycle. Since this option was no longer attractive, so therefore the automotive industry served as a source of inspiration. They have a very proven system in use, which cloud handle the task. Not the products but the load carriers are tracked. With this option, the material can be tracked in production. The products are transported through the production hall anyway with appropriate transport vehicles, so this variant would need an additional work step. . An additional practical and economical reason to use such a variant is that no additional processing steps are necessary to attach the tags. The research showed that only systems with active sensors should be used. These allow a permanent tracking and a much lower installation effort (significantly fewer receivers necessary). Another task of this system is the integration of automated guided vehicles. A possible future scenario envisages the integration of such transport solutions.

Since they are only standalone systems so far, a platform had to be found for communication. As the company relies on SAP as ERP system, this lends to use this system as platform. SAP is the interface and location of the data accessed by the material tracker, the OEE tracker and the value stream. How the three systems do that, was illustrated in a BPMN diagram.

The basic idea in the field of Industry 4.0 and digitization to develop further is a very good one. In order to stay the leading company in crane manufacturing in the future, it will be necessary to make production much more efficient. With a weighted total OEE of just 58% there is still a lot of potential. The previous approach to improvement measures did not allow a increase in efficiency. So far, the improvements have only been limited to individual process steps, finding for every process step its own measure. It lacked the overview or an overall project which takes care of the many small problems and sums the up. Only then meaningful increases in efficiency would be realized.

The fact that the company is dealing with the subject of Industry 4.0 shows that they perceive the potentials and that they want to continue to be world market leaders they are. In order to be able to continue to produce in Europe, waste in production has to be reduced to a minimum. This makes it possible to reduce further production costs and to outperform competitors. To reach the desired level, an considerable amount of money and time has to be invested. Coordination in a central location is very important. As a result, significant additional costs can be avoided since some projects do not have to be developed twice. Likewise, the experiences of the different projects come together in one place.

The outcome of the concept should be to get a better overview of the production. The concept enables all production data that is relevant to be stored and managed in one central location. The acquisition of the necessary production data would make the analysis work much easier via the automatic system. This also makes it possible to intervene in production in a controlling manner. Emerging problems in the production can be found better and fix the cause quickly. The problem can no longer be pushed on to subsequent processes, as it immediately identifies in the key figures which process is the cause. Building on this concept, it should also be possible in the future to plan new production layouts and to simulate this with the software solutions. The motivation is that it is possible to develop the most efficient layout for production. With at layout the waste in the production can be avoided with little effort. An additional integration of other production sites could lead to the digital capture and mapping of the entire production chain. Thus, the production can be controlled even more precise and enable a much more accurate planning of the production steps.

The topic was chosen with great foresight and covered a very large and essential area of production. The objective to compare with other companies in a benchmark comparison could not be achieved. The reasons for this were, on the one hand, lack of authority and the willingness of companies to cooperate. Since this is one of the most important areas for the company, it would be necessary to deal intensively with the topic from the company side and to enter into long-term cooperation in order to obtain meaningful results. To turn the idea into a functioning system, there are still a lot of work to invest.

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Appendix

In addition to the already shown graphics in the thesis, this is a summary of all the generated graphics. These were necessary for the preparation of the master thesis. The first graphic is the current value stream, with all its data from production. This is followed by material flows for the three departments. The first graphic is always the entire material flow of the department. The other graphics are the more detailed subdivisions of the material flow to the individual workplaces.

The numbers that are always there by the arrows, provide information about the quantities of material that is transported between the individual processes. There are differences in the numbers between the small parts production and the other two departments. This can be explained by the fact that in the small parts production each part is counted. In comparison orders are counted in the other two departments. This means that an articulated arm consists of many individual parts but is only counted as one in the material flow. This also applies to the push arm production in the same sense.

The last two material flow charts show the total material flow combined across all three departments. In the first (Figure 53 Material flow complete part 1), the base of the line width is the same, which is why the articulated arm production and push arm production have vanishingly thin lines. In the other diagram (Figure 54 Material flow complete part 2), there are two reference bases for the line width. On the one hand the small parts production and on the other hand the push arm and articulated arm production. This was created so that the material flow can be better visualized.

The last two pages of the appendix contain the complete BPMN (Figure 55 BPMN Part 1, Figure 56 BPMN Part 2). Only small cutouts were shown in the running text, which could lead to some confusion. Therefore, the whole model, with all its elements is shown here. Unfortunately, due to its size, it had to be split into two pages.

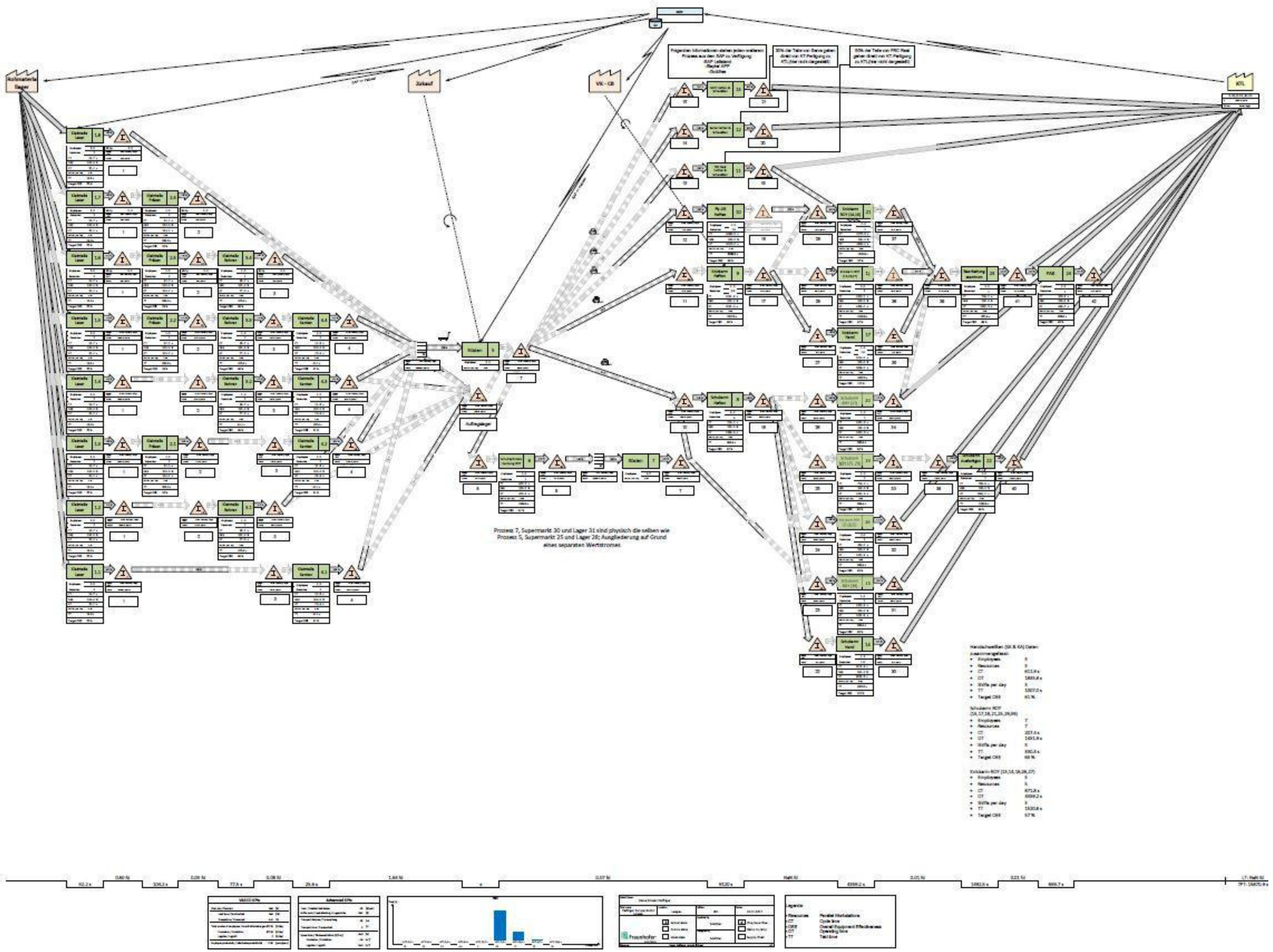

Figure 44 Vale stream current situation

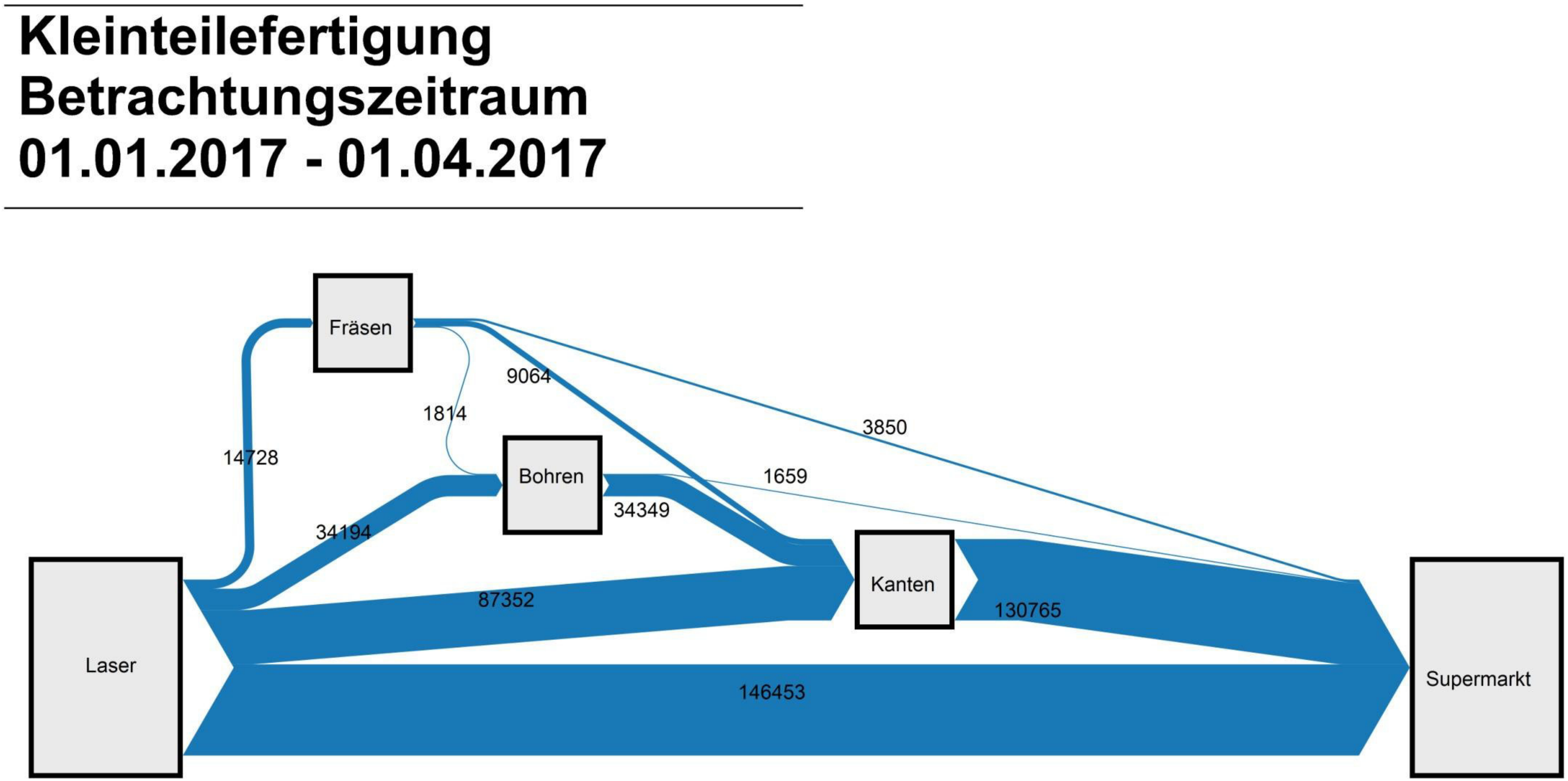

Figure 45 Material flow small part production

Knickarmfertigung Betrachtungszeitraum 01.01.2017 - 01.04.2017

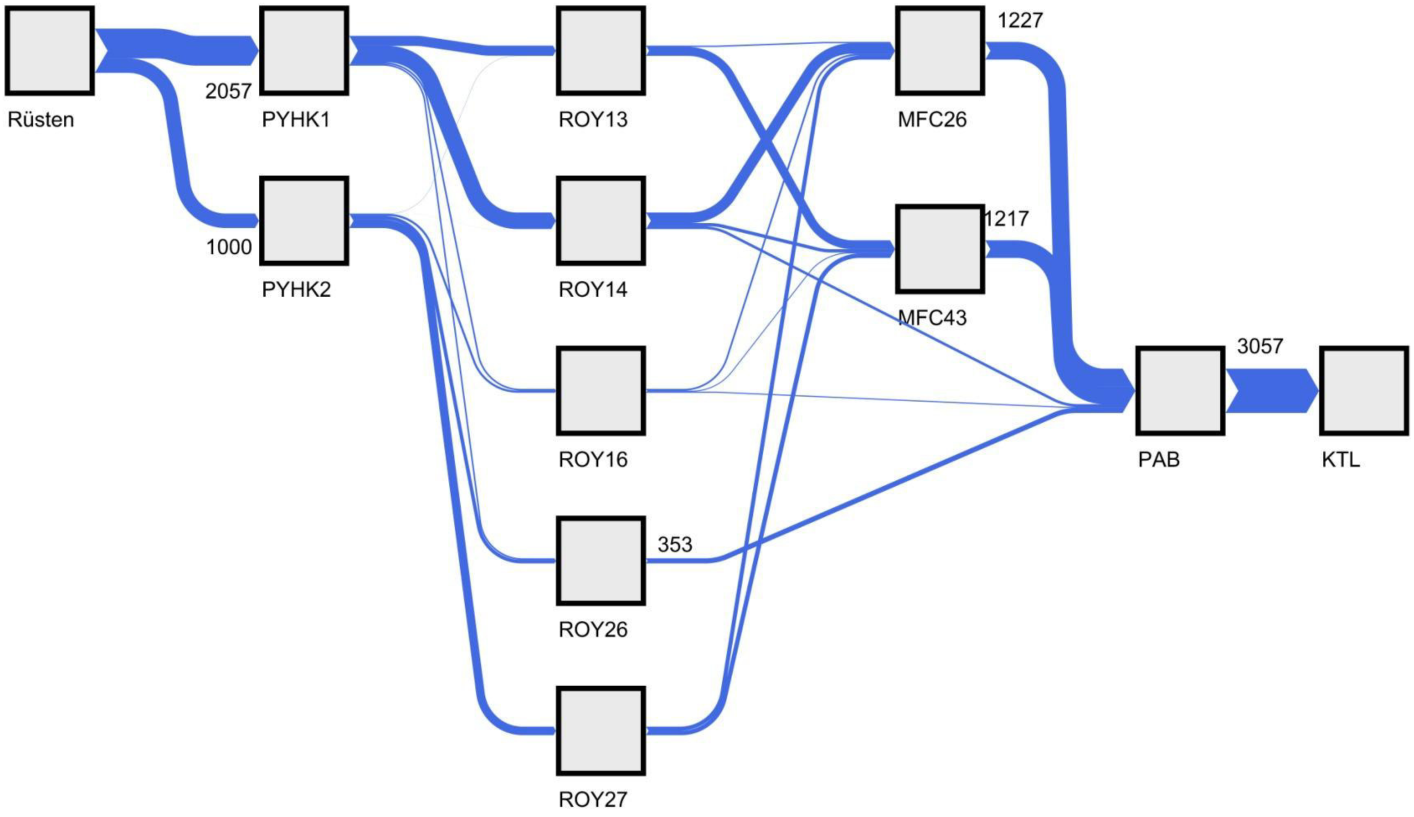

Figure 46 Material flow articulated arm part 1

Knickarmfertigung
Betrachtungszeitraum
01.01.2017 - 01.04.2017

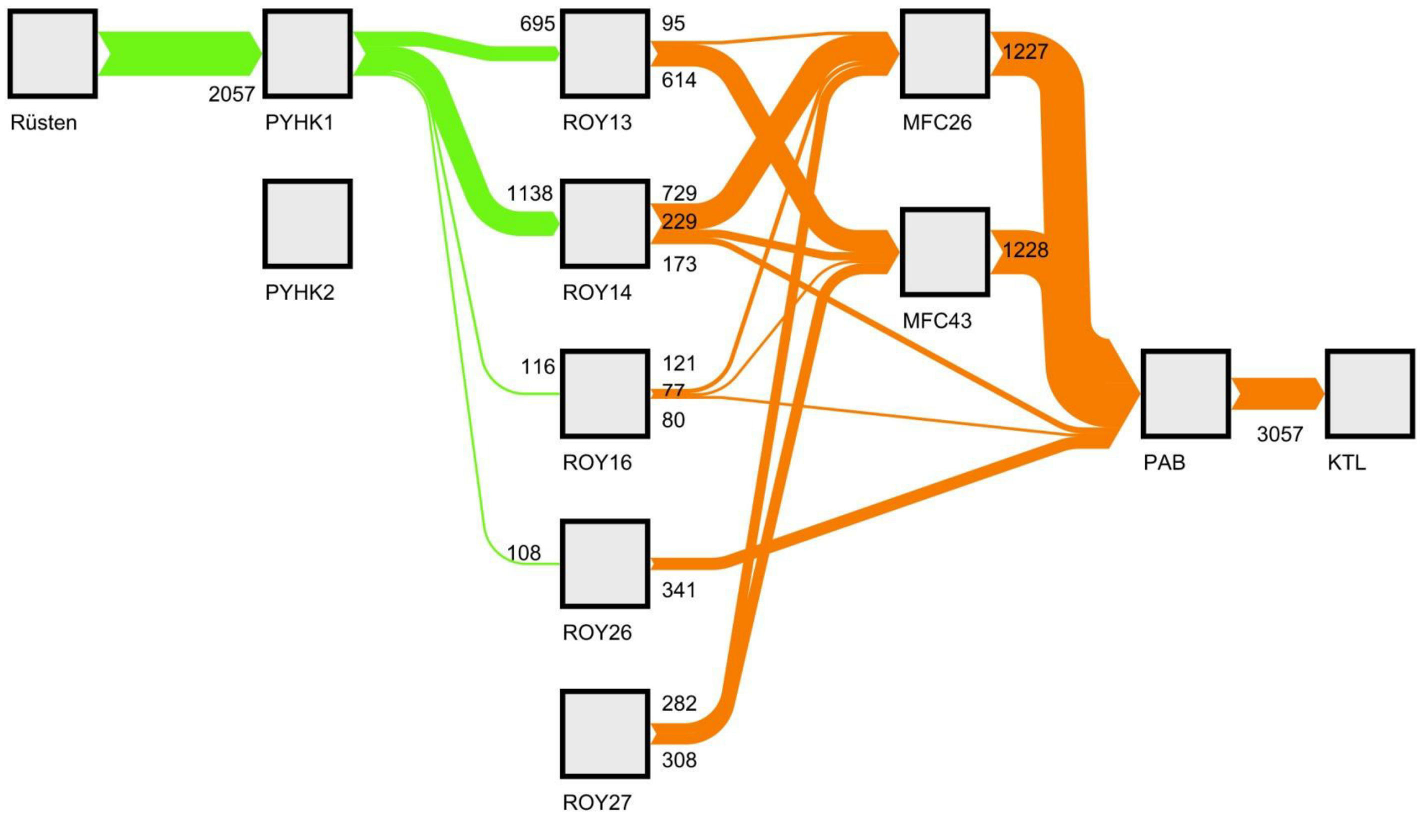

Figure 47 Material flow articulated arm part 2

Knickarmfertigung Betrachtungszeitraum 01.01.2017 - 01.04.2017

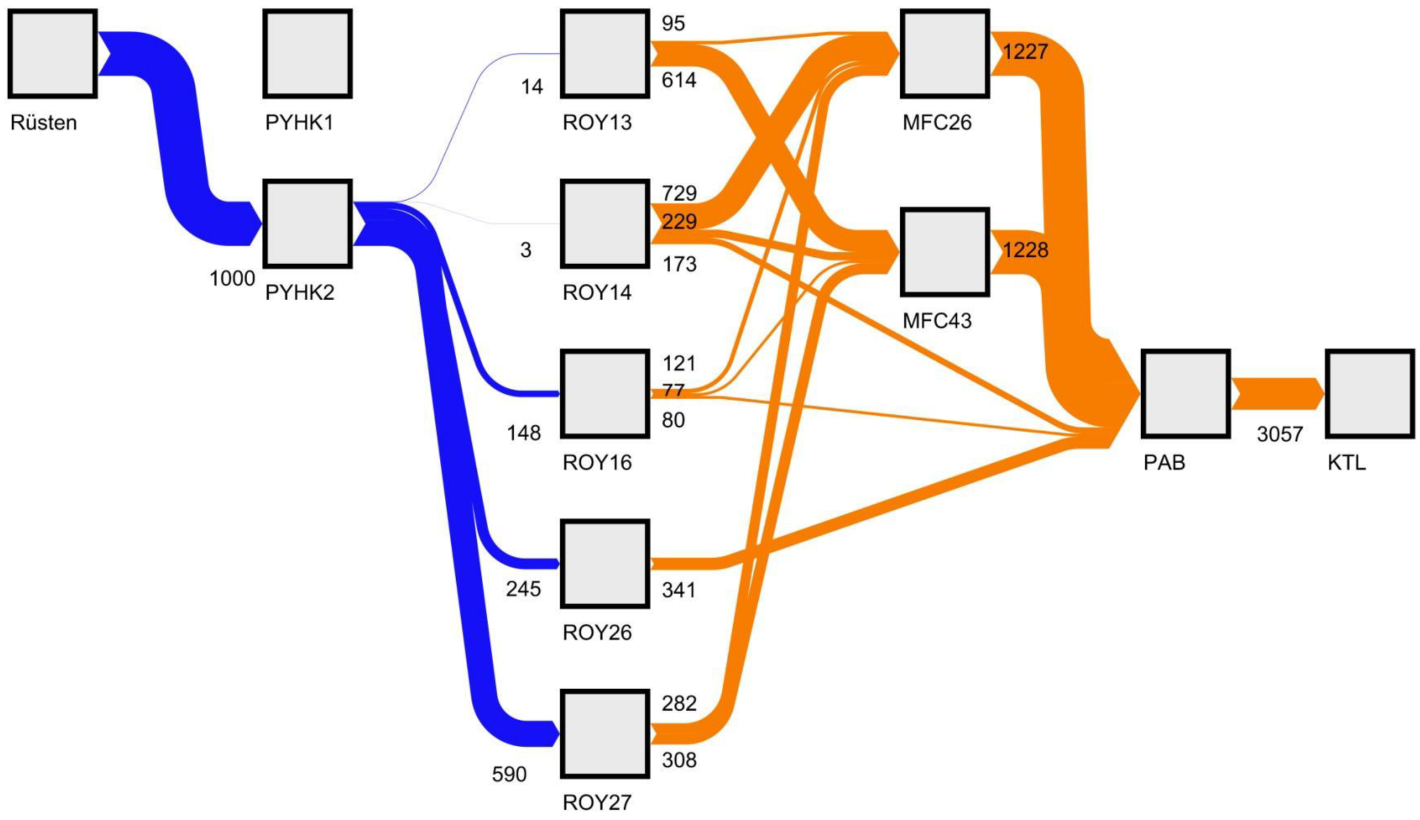

Figure 48 Material flow articulated arm part 3

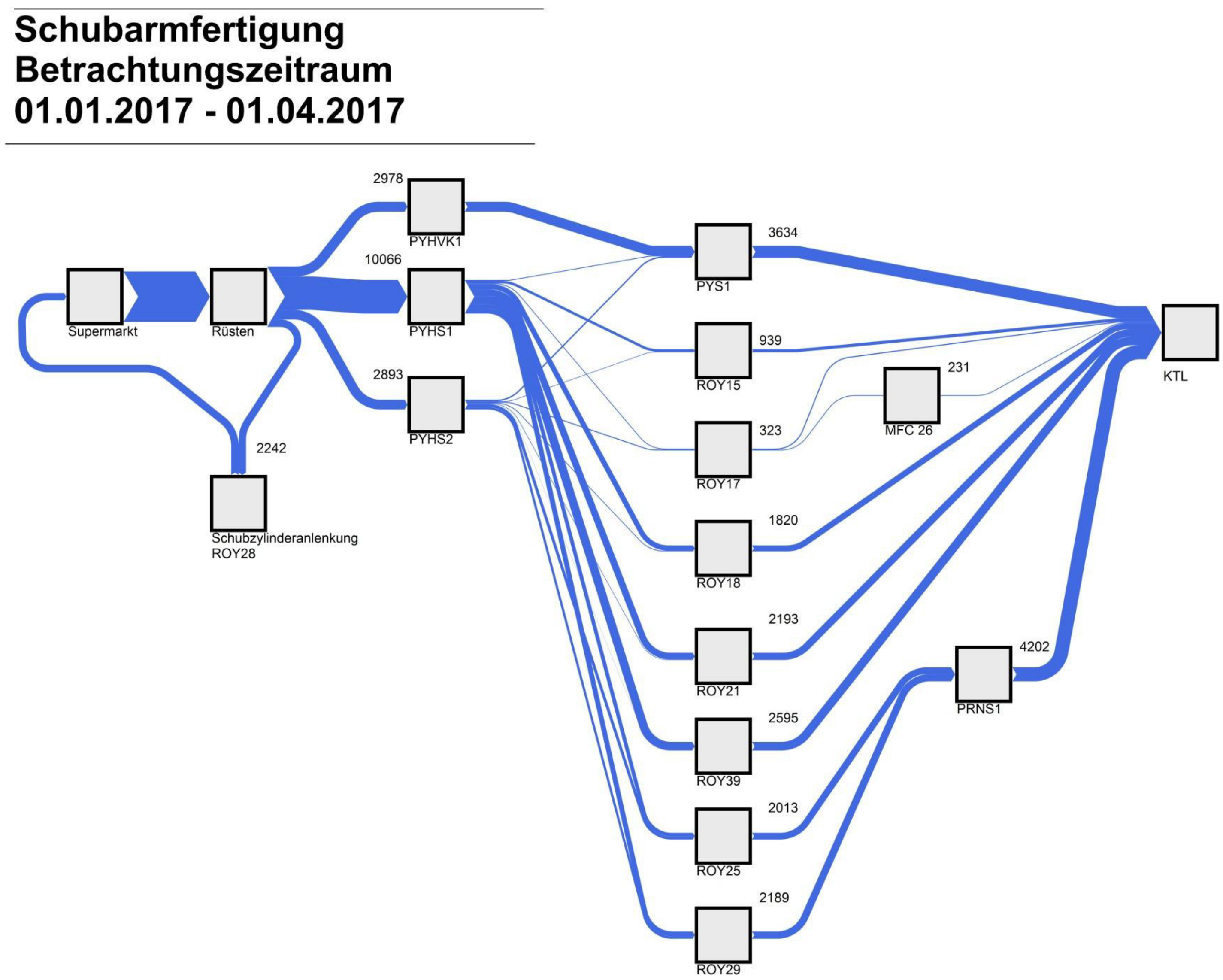

Figure 49 Material flow push arm part 1

Schubarmfertigung
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01.01.2017 - 01.04.2017

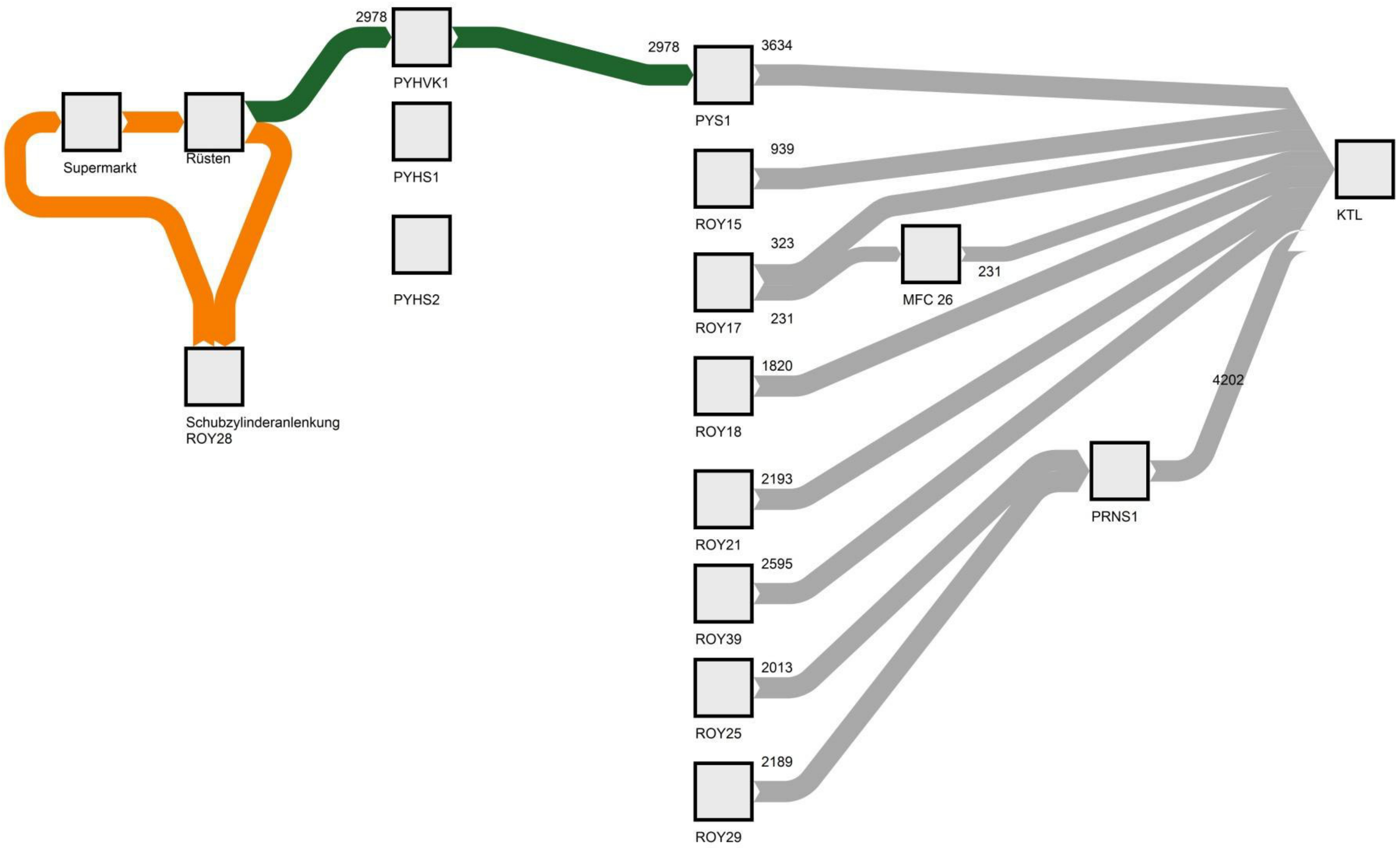

Figure 50 Material flow push arm part 2

Schubarmfertigung
Betrachtungszeitraum
01.01.2017 - 01.04.2017

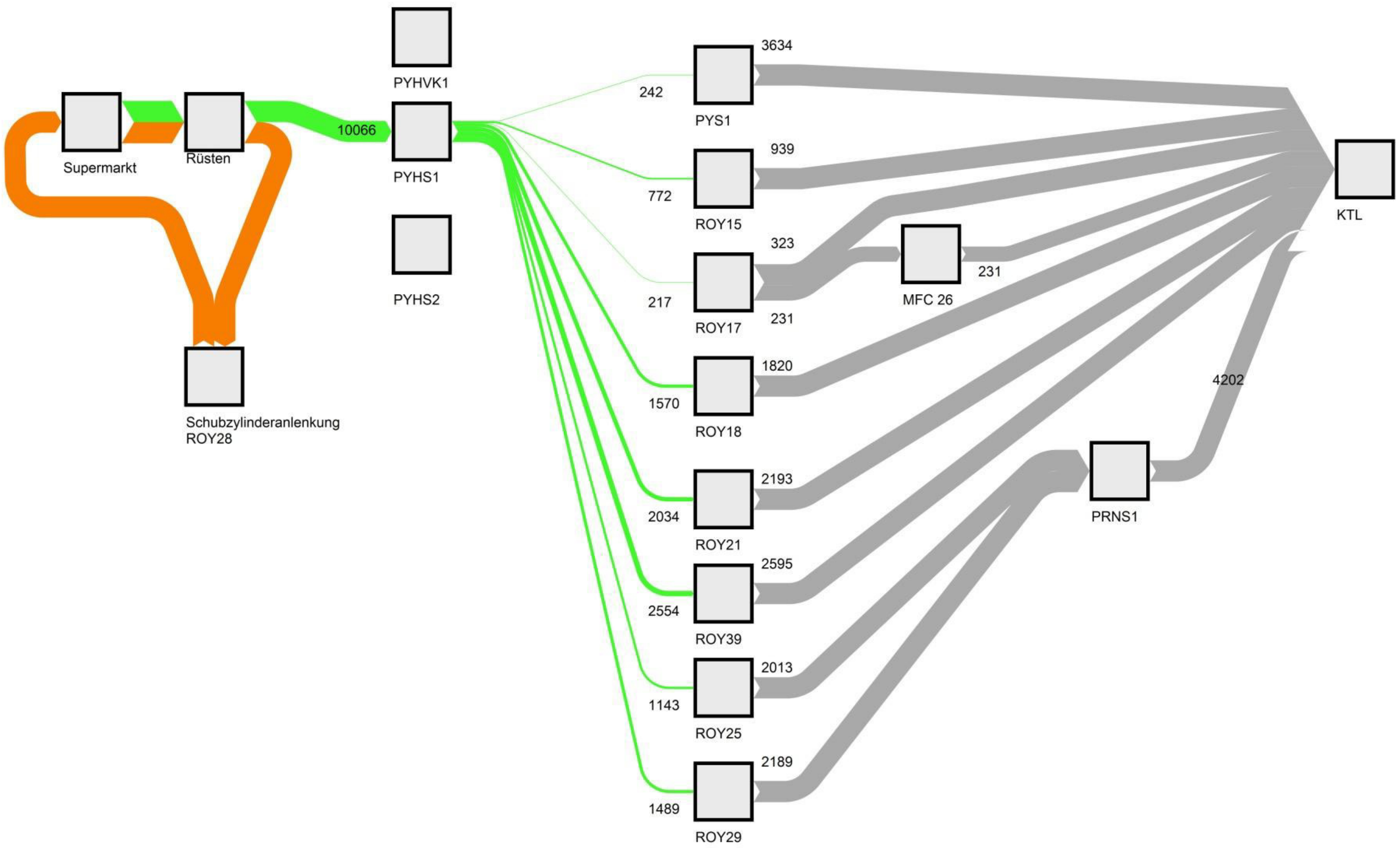

Figure 51 Material flow push arm part 3

Schubarmfertigung
Betrachtungszeitraum
01.01.2017 - 01.04.2017

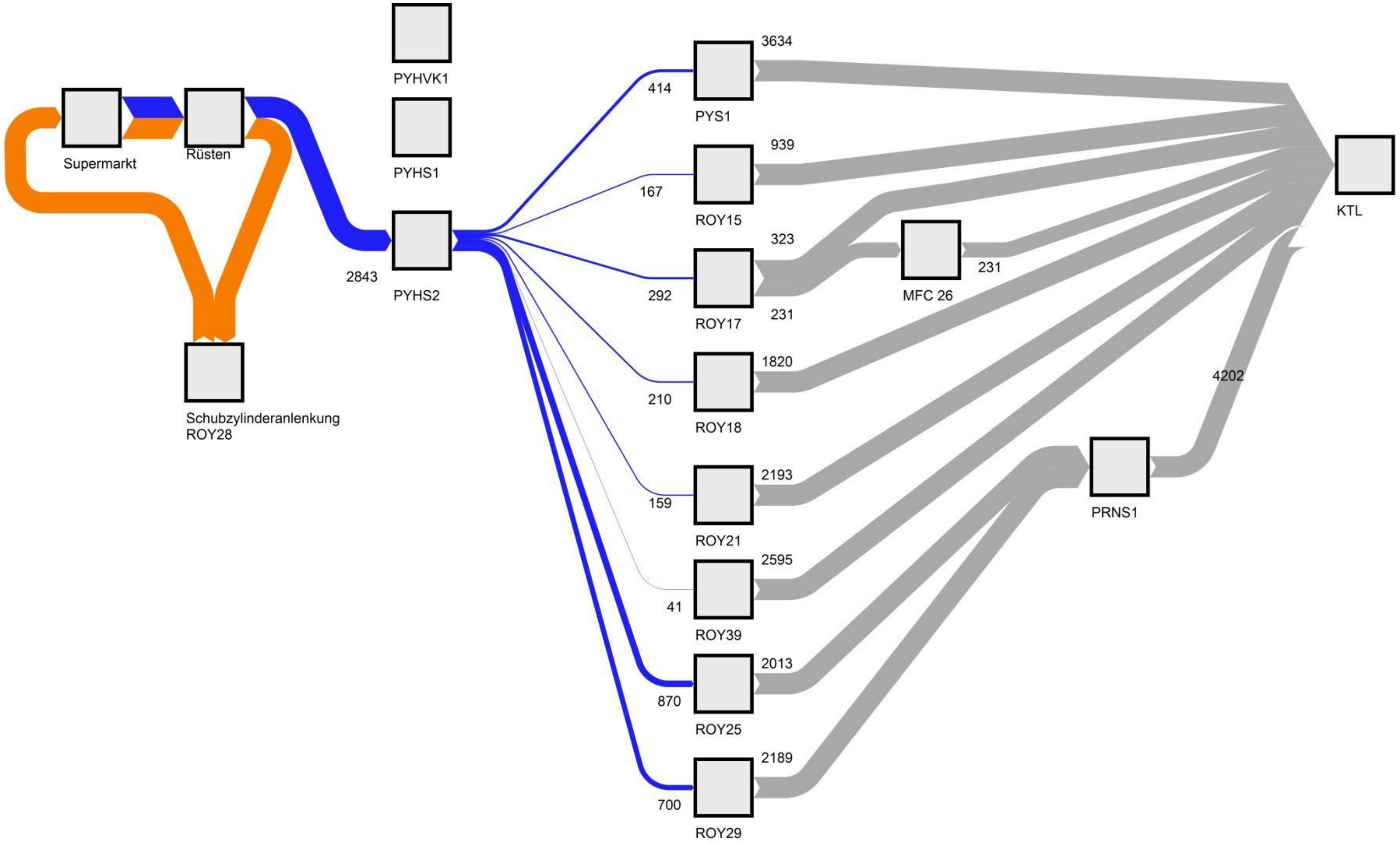

Figure 52 Material flow push arm part 4

Materialflow Palfinger
Betrachtungszeitraum
01.01.2017 - 01.04.2017

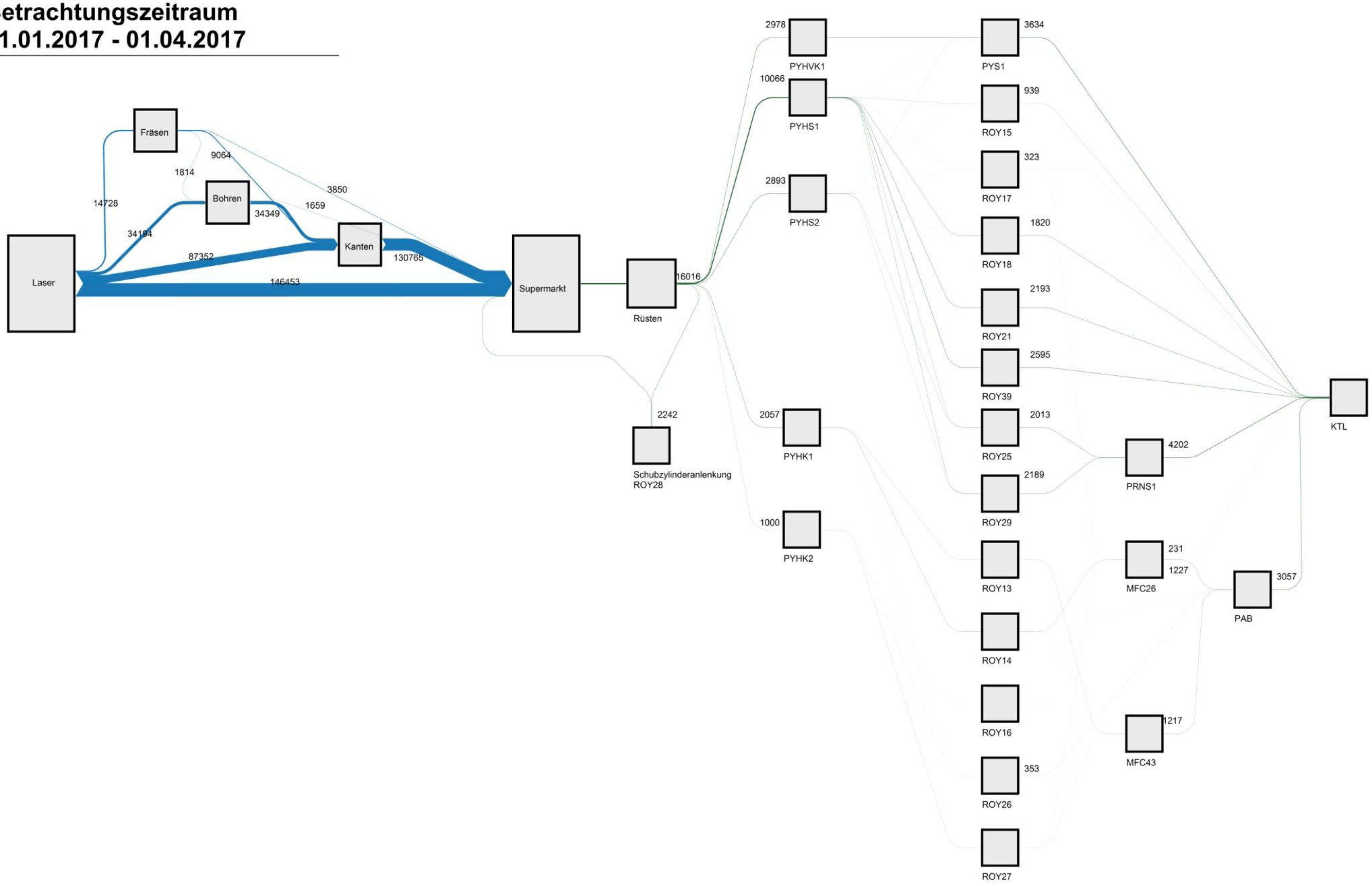

Figure 53 Material flow complete part 1

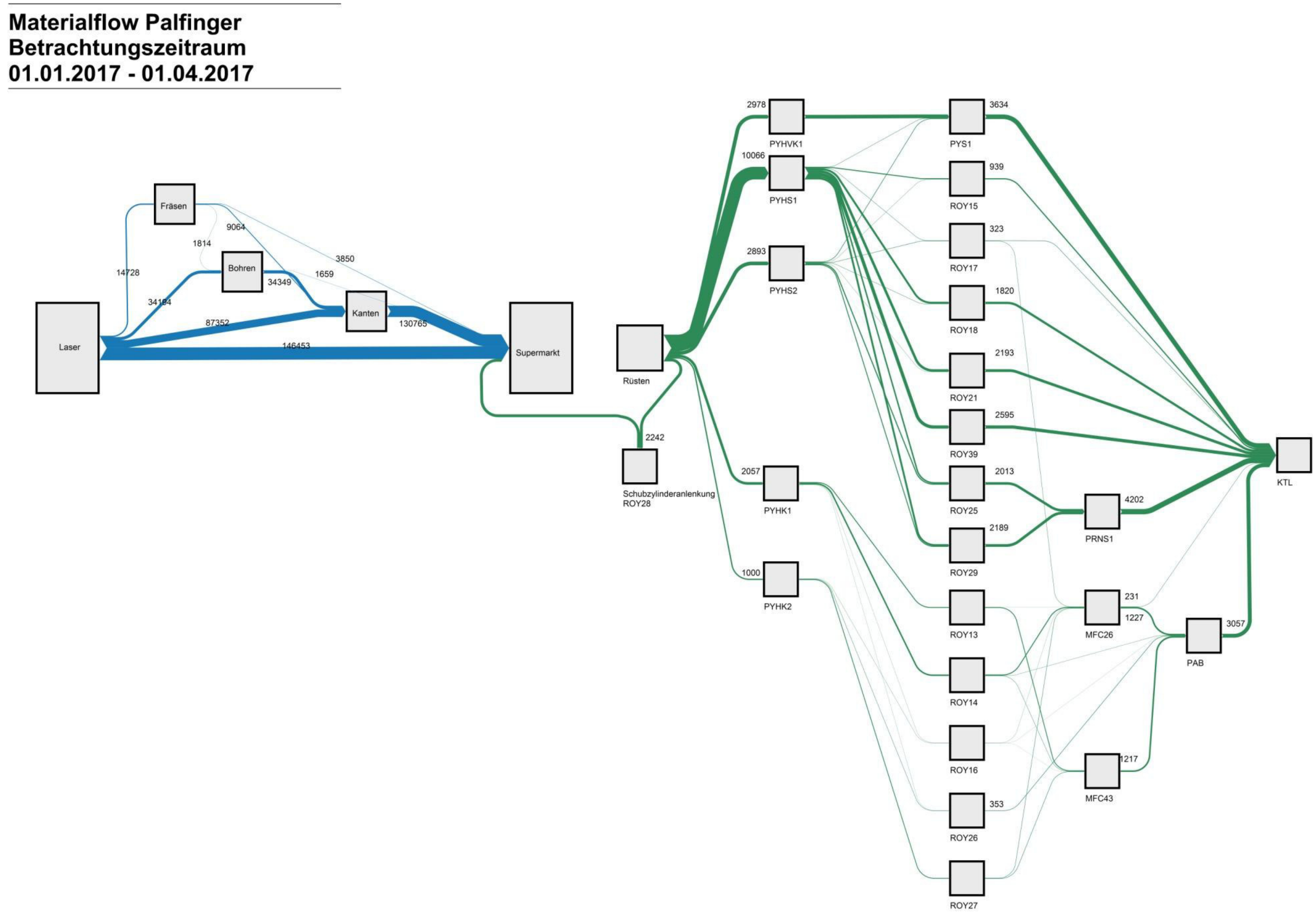

Figure 54 Material flow complete part 2

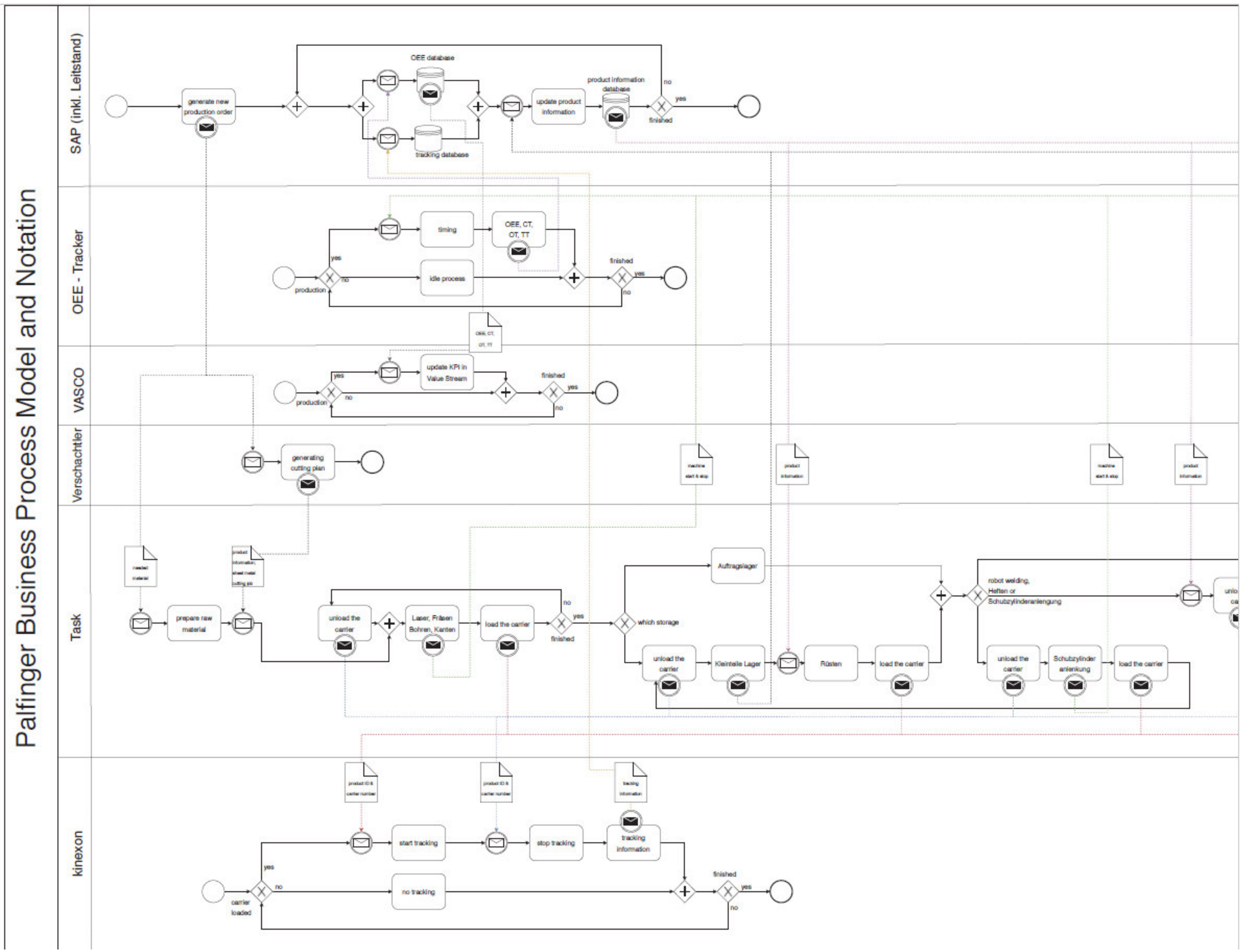

Figure 55 BPMN Part 1

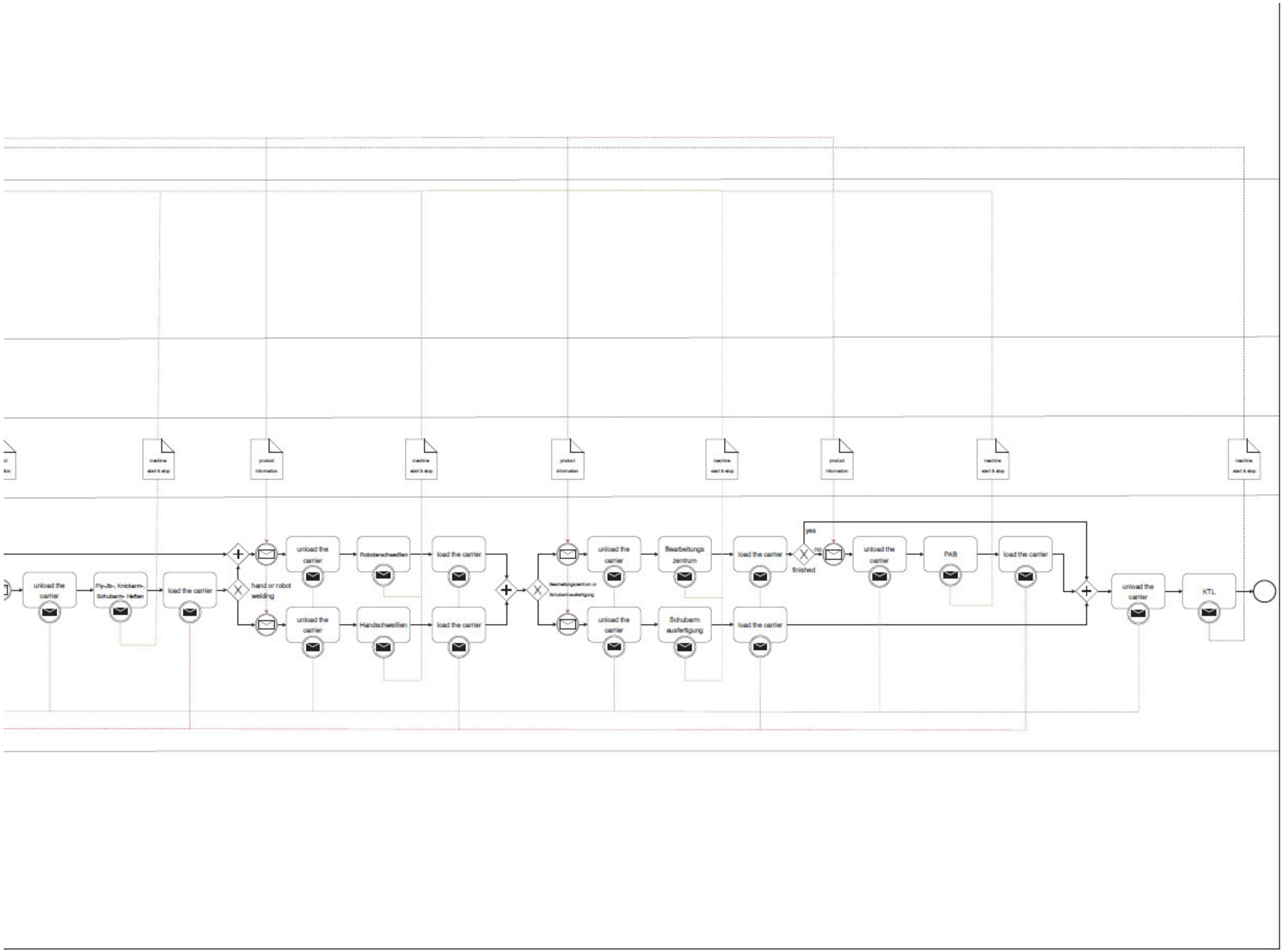

Figure 56 BPMN Part 2