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Analysis of an Austrian motorbike-components-production

Simulation and evaluation of different assembly-systems against the background of increasing demand of motorbike-components.

Master Thesis

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STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

date

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Acknowledgement

The masters thesis is representing not only the formal end point, but also the highlight of a masters programme. Having the opportunity to write this thesis in collaboration with a company that is the market leader in a growing and important segment has been a true privilege. Therefore I want to thank the board of WP as well as my mentor and friend Mr. Dipl.Ing. (FH) Harald Edlinger of WP for giving me the opportunity to write a thesis in such an interesting field of research and in such a supportive environment.

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A very rewarding, but at times also challenging path has led to this thesis. I would not have been able to walk it alone and am highly grateful to the people who were there all along the way, and beyond. I would like to thank my parents, Dipl.-Päd. Gabriele Steinbacher and Dipl.-Ing. Gottfried Steinbacher, who have supported me in my endeavors my whole life. I am thankful to my sister, Dr. Karoline Steinbacher, who has always been a role model for me and I greatly appreciate her advice, also in academic matters. My girlfriend, partner and best friend, Melanie Rupp, has been a crucial emotional support in writing this masters thesis and I am very grateful for her, being there every day and for her constant support despite finalizing her own diploma thesis.

Completing this masters thesis has been one of the most rewarding, interesting and valuable experiences for me yet and I am thankful to all those who have made it possible.

Abstract

Due to increasing demand of motorbike components the Tier-1 supplier WP Performance Systems has to handle a higher production output by a constant price pressure. Based on historical reasons motorbike suspension systems are the core products of WP. A growth in demand is mainly forecasted in the onroad-segment. Therefore the focus of this thesis is on the evaluation of different concepts for increasing the output of the onroad-fork assembly line.

To gain experience on the research topic and the scientific approach for these kinds of problems, a literature research has to be carried out. Possible production strategies and material flow concepts as well as methods for analyzing are described in the theory part.

In the next step an in-depth investigation of the “status quo” points out what the benchmark of the current state-production is as well as what are the problems of the current solution. It is obvious that only a correct and comprehensive analysis of the status quo can serve as a basis for a benchmarking analysis of the possible future state.

With these gained data different concepts to meet the requirements on the future production system were developed. Each of these concepts was then simulated with discrete-event-simulation software in order to evaluate the performance. The results of the simulation yield to an automation approach.

Beside the performance, the costs are an important factor by deciding a change in the production process. For a comparison in terms of costs a cost function is plotted over a period of 10 years. This function includes the investment costs as well as the additional annual labor costs. The cost analysis pointed out, that concept 3 as well as concept 4 amortize in the period of 5 years or less. Therefore the decision depends on the willingness to make a bigger investment with a longer time period to amortize in order to save money in the future.

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1 Introduction

1.1 The WP AG

Next to the KTM AG and the Pankl Racing Systems AG, the WP AG (henceforth called WP) is part of the KTM Industries AG as shown in Figure 1.1. The WP AG is holding 100% of the WP Performance Systems GmbH shares. The headquarters of the KTM Industries AG is located is Wels, Upper Austria. All companies of the KTM Industries AG are specialists in delivering high performance as well as high quality products. The headquarters of WP is located in Munderfing, Upper Austria. The main production facilities as well as management and administration are located at the headquarters. WP produces cooling systems at another production facility in Dalian, China. Other branch offices of WP for distributing and servicing their products are located in the Netherlands and in the US.

As one of the leading Tier-1[1] supplier in the racing-, street- and offroad-motorbike industry WP Performance Systems has to deal with an expected rise in sales of 100% until the year 2020. Responsible for this high growth is for the most part the biggest customer and sister company of WP Performance Systems, Europe´s biggest motorcycle manufacturer KTM. According to market researchers of KTM this rising demand is only due to developments in onroad market, in contrast to the already saturated offroad market.

To manage this challenge, WP´s Head of Industrial Engineering, DI (FH) Harald Edlinger asked me to carry out an investigation of how a redesign of the onroad-suspension assembly area could look like. A holistic point of view in terms of layout, manufacturing processes, material flow and also demand of workforce was needed. This investigation is a substantial part of my Master Thesis. In order to provide a sound academic framework to the survey, the Master Thesis was supervised by Univ. Proj.-Ass. Ing. Mag. Daniel Tinello at the Institute of Logistics Engineering at Graz University of Technology.

[1] According to the Supply pyramid a Tier 1 supplier delivers to the Original Equipment Manufacturer (OEM) directly. A Tier 2 supplier delivers to the Tier 1 supplier and so forth. ([HoHe11], p. 353)

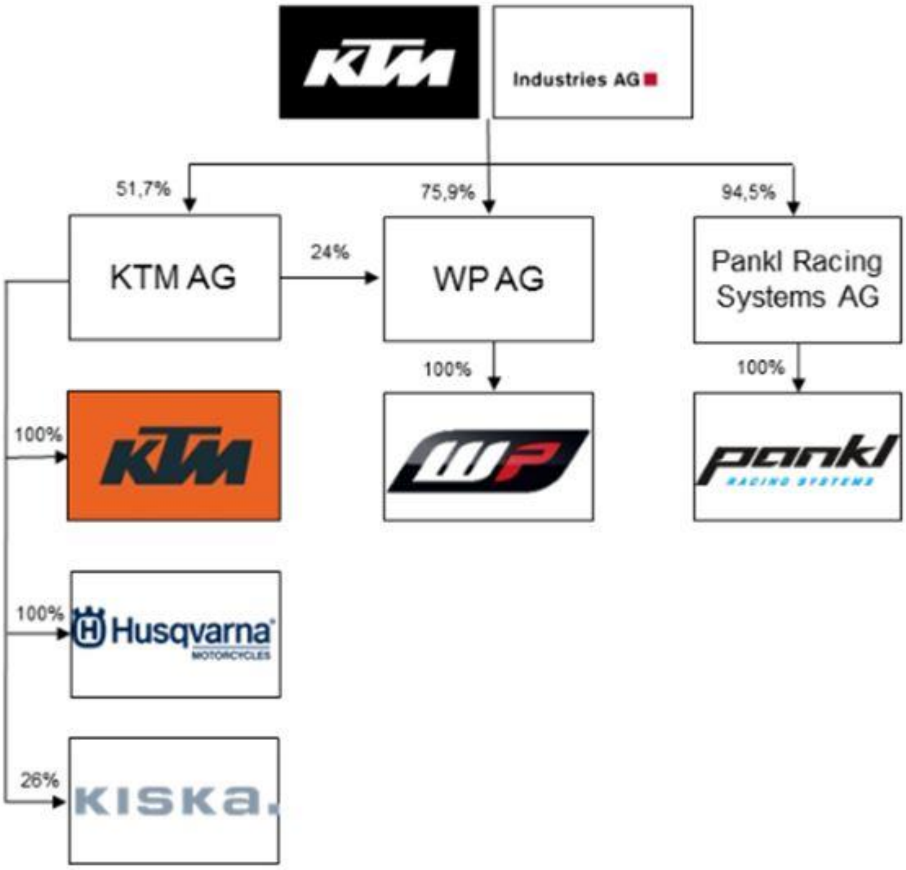


Figure 1.1: Organigram of KTM Industries AG[2]

WP itself is a supplier of different components for the automotive industry with a focus on the 2-wheel segment. The group is divided into two segments and further into four divisions related to their four product groups, these are shown in

Table 1.1

Since 2016 WP no longer has its own R&D department. This department was transferred to the sister company KTM. This strategic change was made to enable WP to focus on its core competence of manufacturing products with a high quality and short customer lead time. Nevertheless due to the strong connection between WP and the R&D department of KTM, WP is also involved in the whole design process of their products. In Figure 1.2 a typical onroad-motorbike fork is shown. The focus of this thesis is on the assembly of this type of products.

[2]Source: http://www.ktm-industries.at/index.php/unternehmen/organigramm, 06.03.2017

Figure 1.2: WP-Fork for onroad-motorbikes[3]

Table 1.1: Segments and Divisions of WP

SEGMENT	DIVISON	PRODUCTS	ANNUAL REVENUE in 2015
Chassis Components	Suspension	Forks, Shocks and Steering Dampers	119.951 k€
	Frame	Main Frames, Rear Frames and Frame Components	
Engine Components	Radiator	Water and Oil Coolers	43.588 k€
	Exhaust	4- and 2- Stroke Exhaust Manifolds, Pre-Silencers, Silencers,	

[3] source: WP AG

1.2 Problem Definition

As mentioned earlier, WP delivers different kinds of products for different segments in the automotive sector. As shown in
Table 1.1, the segment of chassis components is about three times bigger in terms of revenue then the engine components segment. Due to the large share of revenue and the great complexity of these types of products, in combination with a forecasted increase in demand of about 100%, the board of WP decided to investigate how this expected growth in the chassis components segment can be handled. The expected rise in sales is forecasted to the biggest part for the onroad-suspension products, therefore the focus of this thesis will be on this product category.

To gain experience on the research topic and the scientific approach for these kinds of problems, a literature research has to be carried out. In the next step an in-depth investigation of the "status quo" should point out what the benchmark of the current state-production is as well as what the problems of the current solution are. It is obvious that only a correct and comprehensive analysis of the status quo can serve as a basis for a benchmarking analysis of the possible future state.
This thesis will have a closer look at the current onroad suspension production area. What kinds of products are produced, how customers demand behaves and what the production area and the production strategy looks like are among the question to be answered. Therefore a deep investigation especially on the shop floor layout and the production system is made. The main focus lies on the assembly line of the onroad products. The other production areas such as pre-assembly, testing-stations and warehouse are - according to the information provided by the Head of Industrial Engineering, Mr. DI (FH) Harald Edlinger, no bottlenecks in the value chain.

For data evaluation a time period from August 2015 to August 2016 was selected. WP has its annual company holidays in August, so the considered time period covers one whole year between the annual company holidays. Due to the seasonality of motorbike parts within the repetitive cycle of one year, all interesting seasonal effects should be detected with the chosen time period.

Due to the forecasted drastic increase in production output, the target now was to find a solution for the shop floor layout and a production system which is able to increase the output while keeping the manufacturing costs at least at the current level or even reduce them.

2 Theoretical Aspects

Due to the transformation from craftsman-production to a highly specified and industrialized production with demand of a couple of thousand units per year, producing-companies have to think in detail about their manufacturing strategy. Losing seconds or minutes by assembling a product in craftsman-production with a couple of units per year is not really a big problem, the impact for production cost is tremendous when items are produced takt-time of 20s. Combined with high labor-costs, the waste of work time is a criterion to survive on the market, especially for European companies, which have to compete with low-wage countries ([Brun08], p. 52).

Even if the design of a production area, which is a particular problem of factory-planning, is a basic task of industrial engineering, it also links to other scientific disciplines like logistics, business administration and mathematics ([Mich14], p. 10). Industrial engineering itself is one of the most multidisciplinary fields in science. While spanning many technical, social and political domains, industrial engineering is often used as the primary method to improve the performance of organizations ([Mark13], p. xvii). Chapter 2 will give the reader a basic understanding of the different fields of research and summarize the different methods and tools for solving these specific types of problems as mentioned in chapter 1.2.

2.1 Production Strategies

2.1.1 History of Production Strategies

The very first question a production-company has to ask itself is which strategy for manufacturing it will choose to produce its products. The manufacturing strategy has to be determined at the strategic level and sets the framework for further tactical actions. A historical overview of the development of manufacturing strategies is shown in Figure 2.1. The origin of manufacturing strategies was the craftsman production at the beginning of the 20st century. At this point in time, special products were manufactured based on a specific order by an individual customer. The goods were produced manually without any kind of machines. The quantities where very low and every product was unique ([Bleh14], p. 13ff).

With the development of new technologies like the steam engine, electrical power and machine tools, the opportunity for higher production volumes opened. This, in combination with an increase in potential customers, led to the era of industrial production. One of the most famous examples for an industrial-mass-production is the Ford Model T. The production process for the Model T was developed by Henry Ford and was the first successful implementation of mass-production in the automotive sector ([DoMi15], p. 8ff). By implementing conveyor-belts for a continuous material-flow and a sophisticated work-load-balance for each worker, a significant increase of productivity and quality was achieved ([WoJR07], p. 26).

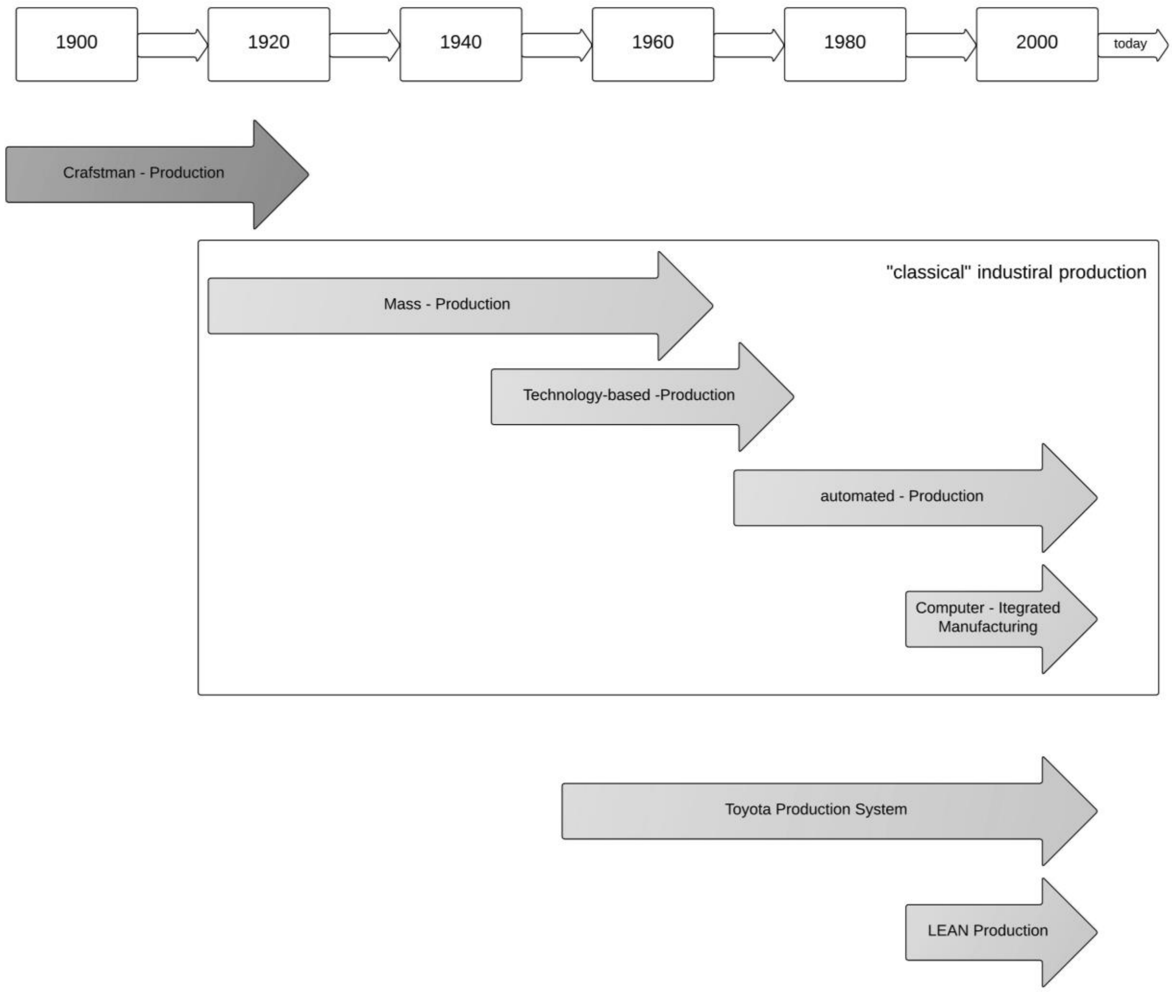


Figure 2.1: History of different Production Strategies (based on [DoMi15], p. 4)

With growing demand of consumer goods, fast development of the global economy and the rising demand of customized products, traditional mass-production was getting more and more inefficient ([LiMZ12], p. 730).

To face the challenges of mass-customization the Toyota Production System (TPS) was developed by Mr. Taiichi Ohno in Japan. Today there is hardly any company in the production industry which does not use at least some ideas of the TPS ([Dick07], p. 5). Therefore, it can be considered as the “state of the art” - production strategies for industrial production with a wide variety of different products.

2.1.2 Toyota Production System

There are many books, articles and websites about the TPS. Because of the large number of aspects and topics, which TPS covers, it would go far beyond the scope of this thesis to cover all elements. Therefore only some key elements shall be examined now. For a deeper insight into the TPS the book “The Machine that changed the World” [WoJR07] can be recommended.

2.1.2.1 Lean Production Management

One pillar of the TPS is Lean Production Management (LPM). The Implementation of LPM causes less inventory, less demand of workers, space for production as well as an improvement of quality ([Brun08],p.59). Table 2.1 gives an overview of the LPM concepts and the traditional buffered-production is compared to the LPM concept.

Table 2.1: comparison of traditional and lean production ([Brun08],p.62)

Manufacturing Strategy	
traditional	**lean**
division of labor	
• as extensive as possible • simple work with low cost labor • small work content • multiple interfaces	• as little as possible • highly qualified labor • large work content • few interfaces
work execution	
• per lot • sequenced • capacity oriented	• needs-based • overlapping • process oriented
execution time	
• minimal per work step	• minimal per job

• maximal output per minute	• maximal utilisation per time period
material- and information- flow	
• separate view	• integration

The positive effects on the production-level can also be seen in Table 2.2. The Table is an extract of an MIT-study from 1991 where the Japanese – lean production is compared to the traditional Western – buffered production ([Brun08], p.61).

Table 2.2: comparison of Japanese (lean) and Western (buffered) car-manufactures in the MIT-study (based on [Brun08], p. 61)

MIT –study (1991): Lean Production in Japan		
	Productivity (ø h / car)	Quality (ø assembly errors / 100)
Low Tech - Buffered	40,0	104,9
Low Tech – Lean	29,6	80,4
High Tech - Buffered	29,5	86,5
High Tech - Lean	21,1	59,8

As the MIT-study shows, by implementing LPM, both productivity and quality increases in the car-manufacturing industry. The positive effects can be seen in high-tech-production as well as in low-tech-production.

2.1.2.2 Muda

The foundation of the TPS is based on the simple goal of identifying and eliminating waste in all processes. The Japanese word for waste is *Muda* and describes all kind of actions and activities which are non-value-adding. The TPS describes seven major types of non-value-adding activities in manufacturing processes which are summarized in Table 2.3 ([LiMe06], p. 37).

Table 2.3: Seven Types of MUDA (based on [LiMe06], p. 37 ff)

Seven Types of MUDA	
MUDA Type:	**Description:**
Overproduction	Producing items earlier or in greater quantities than needed by customer.
Waiting (time on hand)	Worker merely serving as watch persons for an automated machine, or having to stand around waiting for the next processing step, tool, supply, part.

Transportation	Moving work in process (WIP) from place to place in a process, even if it is only a short distance.
Overprocessing	Taking unneeded steps to process the parts. Inefficient processing due to poor tool and product design.
Excess inventory	Excess raw material, WIP, or finished goods causing longer lead times, damaged goods, transportation and storage costs, and delay.
Unnecessary movement	Any motion employees have to perform during the course of their work other than adding value to the part.
Defects	Production of defective parts or correction. Repairing of rework, scrap and inspection means wasteful handling, time and effort.

2.1.2.3 One-Piece-Flow (OPF)

According to the philosophy of reducing *muda*, products that move continuously through the individual processing steps with minimal waiting time between the processing steps and the shortest distance traveled, will be produced with the highest efficiency ([LiMe06], p. 80 ff).

In the classical batch production, processing steps are organized in groups of work-places, where each work -place group is performing an individual task. These groups are working in parallel and deliver their goods in batches to the next group. Every time a batch is produced it is either transported to a buffer or directly transported to the following group. All parts of one batch are first processed in the first group and then allocated to the next one. One-piece-flow follows the simple principle of reducing the batch sizes to one piece and connecting all necessary processing steps in a line with no or at least very small buffers between each step ([Brun08], p. 109). The positive impact of OPF can easily be shown by a simple example. In Figure 2.2 a classical batch-production is illustrated. In Figure 2.3 an OPF Production is pictured. For both systems the work time per piece is assumed with 1 minute. The necessary work steps are A, B and C. As an example, an order of 10 pieces has to be manufactured.

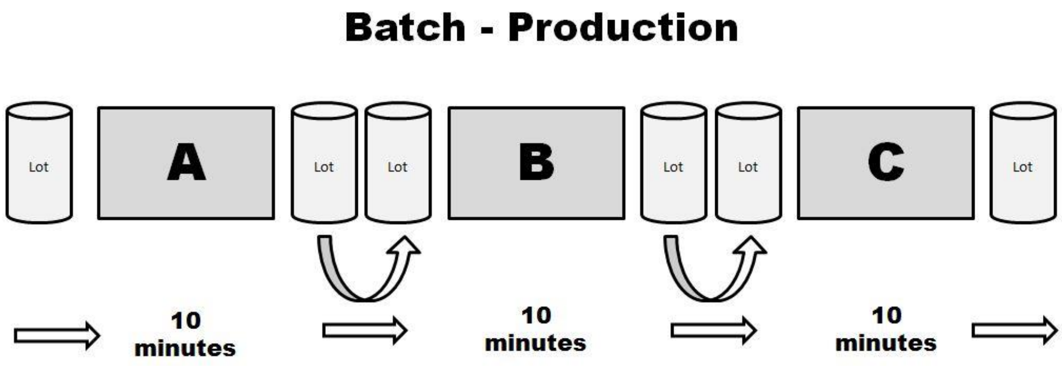


Figure 2.2: Batch – Production

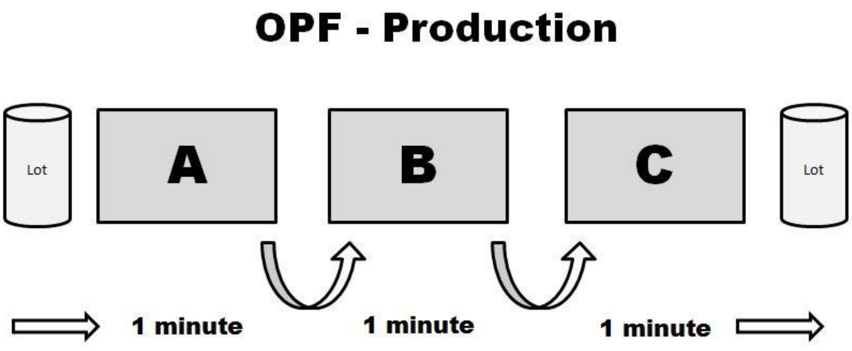


Figure 2.3: OPF - Production

For the comparison of both systems a job of 10 pieces should be produced. For analyzing the both concepts of manufacturing, typical key-performance-indicators (KPI) are listed in Table 2.4.

Table 2.4: KPI´s of Batch- and OPF - Production

Batch vs. OPF - Production		
	Batch	**OPF**
Job size	10 pieces	10 pieces
First Piece	21 minutes	3 minutes
Entire Job	30 minutes	12 minutes
maximum WIP	10 pieces	3 pieces

2.1.2.4 Pull - Principle

The terms “pull” or “pull-system” are often used interchangeably with the term “flow” or “flow-production”. It should be understood that, “pull” is a concept like “flow”. The two concepts are linked, but different. Flow describes the movement of products between the different process steps. Pull dictates when products or material is moved and who triggers this movement. The opposite of a pull-system is a push-system. A typical push-system is a system where the manufacturer produces on stock and delivers to the costumer out of this stock when an order is requested. The production-planning is realized with the help of forecasts ([LiMe06], p. 94).

In a pull-system the customer order releases a demand at the last process of the process chain. This last process step releases a demand to its predecessor and so on. A tool to handle the information-flow for these demands is the commonly used “Kanban system” ([LiMe06], p. 95) .

2.1.3 Demand Flow Technology (DFT)

DFT is a mathematics based technology whereby takt techniques and linear-models are used to design mixed-model lines and processes. It was developed by John R. Costanza, who worked in senior management, manufacturing, design engineering, manufacturing engineering and material management for such corporations as Hewlett-Packard and Johnson&Johnson ([MaZa01], p. 9.99). Even though DFT is not a method of the TPS, the idea of handling a mixed-model production with a continuous flow of products is related to the TPS. DFT is a more systematic and mathematical, TPS is more about changing the mindset and cultural behaviors of all employees in the company.

DTF is a pull process, pulled from the last production step or the last step in the process chain and continues forward through the flow, through the distinct process steps, to the point-of-usage inventories or semi-finished goods of a pre-production. The parts or products are pulled into the system and through the system by a requested demand that is established at the end. The daily rate is achieved at the end of the process as opposed to the scheduling and lead-times techniques of traditional manufacturing ([MaZa01], p. 9.100).

2.1.3.1 Sequence of Events (SOE)

The SOE is a natural flow of tasks required to produce a product. The SOE describes the sequential work and the quality criteria each work step to manufacture a product. Each SOE is classified in one of the following four categories of work ([MaZa01], p. 9.100 ff):

- *Required labor time* represents those employee-performed steps that are necessary to manufacture a product according to its specifications. Not all labor time is value-added.

- *Required machine time* represents the machine-performed steps that are necessary to manufacture a product according to its specifications. Required machine time, like required labor time, may or may not add value to the product.

- *Move time* is the time spent on moving the product through the process. Move time may be related to either labor or machine time. It is always non-value-added work. Appreciable move time is usually indicative of poor line layout.

- *Setup time* is work that is performed prior to required machine or labor time. It is too always non-value-added time.

The individual SOE are listed in a table. An example how such a table can look like is displayed in Figure 2.4. Every SOE is linked to one of the four categories of work and the needed time to perform this SOE is quantified in the column according to the type of work. In the column “V.A.” the SOE are categorized as “value add” or “non-value add”. This categorization helps to identify and eliminate non-value adding work in a later step ([MaZa01], p. 9.102) .

PRODUCT P/N MODEL 100 — **DEMAND FLOW® TECHNOLOGY** — PROCESS I.D. MOTOR

SEQ.	TASK DESCRIPTION	V.A.	SET-UP		MACHINE	LABOR	MOVE		TQC INFORMATION
			M	L			M	L	
7.0	Remove shim			0.10					
7.1	Remove second shim			0.10					
8.0	Remove armature cover (PN 752) from plastic bag			0.10					
9.0	Install armature cover over guide pins to armature base	*		0.15		0.10			Verify proper orientation
10.0	Remove guide pin			0.15					
10.1	Remove second guide pin	*				0.30			Torque to hand tight only
11.0	Attach armature cover to armature base with 8-	*							

Figure 2.4: DFT - Sequence of Events-Table ([MaZa01], p. 9.102)

2.1.3.2 DFT Line Design Calculations

After the total required work for producing a product is identified, the work content would ideally be grouped into equal pieces of work as we start designing a flow process. Since most processes are dominated by imperfect people and dissimilar machines, an absolute synchronization cannot be achieved. Therefore, a series of balancing techniques have been developed, to equalize the pieces of work ([MaZa01], p. 9.104).

Designed daily rate (capacity) must be established for each product to be manufactured. The designed daily rate is determined by marketing- and top-management agreements. According to Equation 1 the designed daily rate is calculated by dividing the targeted monthly volume by the number of workdays in a month ([MaZa01], p. 9.104):

Equation 1: designed daily rate ([MaZa01], p. 9.104)

$$Dcp = \frac{\mathrm{Pv}}{\mathrm{Wd}}$$

where Dcp	=	designed daily rate (capacity)
Pv	=	targeted monthly volume
Wd	=	work days per month

Flow rates are tools used in the design as well as in the daily management of a flow process. They are based on actual daily units completed at the back of the flow process. The daily flow rate is calculated according Equation 2, by the daily rate divided by the effective work hours a day ([MaZa01], p. 9.105):

Equation 2: daily flow rate ([MaZa01], p. 9.105)

$$Fr = \frac{\mathrm{Dr}}{\mathrm{H(S)}}$$

where Fr	=	daily flow rate
Dr	=	daily rate
H	=	effective work hours
S	=	work shifts per day

Operational cycle time is based on the designed daily rate. It is the targeted work-content time for a single product to be produced within the flow process. If the targeted work-content time exceeds the possible labor time of the persons who are working in the process, more people are needed to fulfill the designed daily rate. The operational cycle time is also called takt time and is calculated according to Equation 3 ([MaZa01],p. 9.105).

Equation 3: operational cycle time ([MaZa01], p. 9.105)

$$OP\ c/t = \frac{\mathrm{H}(S)}{\mathrm{Dcp}}$$

where H = effective work hours
S = work shifts per day
Dcp = designed daily rate (capacity)

If the designed daily rate cannot be produced by one person in one shift, it is obvious that ether the effective work hours or the headcount have to be increased. The required people in process can be calculated according Equation 4, by multiplying the specific daily rate quantity with the labor time from the sequence of events and then dividing by the effective work hours in a shift multiplied by the number of shifts ([MaZa01], p. 9.109).

Equation 4: people in-process ([MaZa01], p. 9.109)

$$People\ in - process = \frac{D \quad \times L}{\mathrm{H(S)}}$$

where D = specific daily rate quantity
L = labor time from sequence of events
H = effective work hours
S = number of shifts per day

These calculations are working as a basis for the process design. All calculations are directly influencing typical process factors like: inventory, buffers, amount of workplaces and production strategy.

2.2 Assembly-System Design

With the beginning of manufacturing products in an industrialized way, the field of Industrial Engineering was established. Since then the design of production systems has always been an important task in the field of industrial engineering. Due to the rapid progress of manufacturing technologies and the growing globalization, assembly line design becomes more important. Production systems today are characterized by short product-life-cycle times and therefore also short production-systems-life-cycle times. Especially in high labor-cost countries nowadays production systems are characterized by high level of automation, emergence of new manufacturing equipment and technologies and high investment to build modern production lines. These characteristics lead to new design problems as well as more frequent needs to design and redesign production systems. As a result, there is a need for new methods for designing and planning ([RDDB02], p. 163).

The design of a production system is always based on product data and limited by technological constraints ([RDDB02], p. 163). For gaining the necessary information a detailed analysis of the production portfolio as well of the production process is required. After the analysis of the existing production system, a redesign can use possible potentials. In the first step, different concepts for the redesign should be developed. Therefore, the dimensioning of the new system is an important task. The basis for dimensioning a new system is the product portfolio. It defines the necessary capacity of ([Grun09], p. 88):

- Equipment (technical equipment such as machines, tools etc.)
- Labor (required headcount)
- Space (required space at the shop floor)
- Media (working and supply media such as compressed air, oil etc.)

In Figure 2.5, a guideline for dimensioning an assembly system is illustrated. According to this guideline, the necessary methods are explained in this chapter.

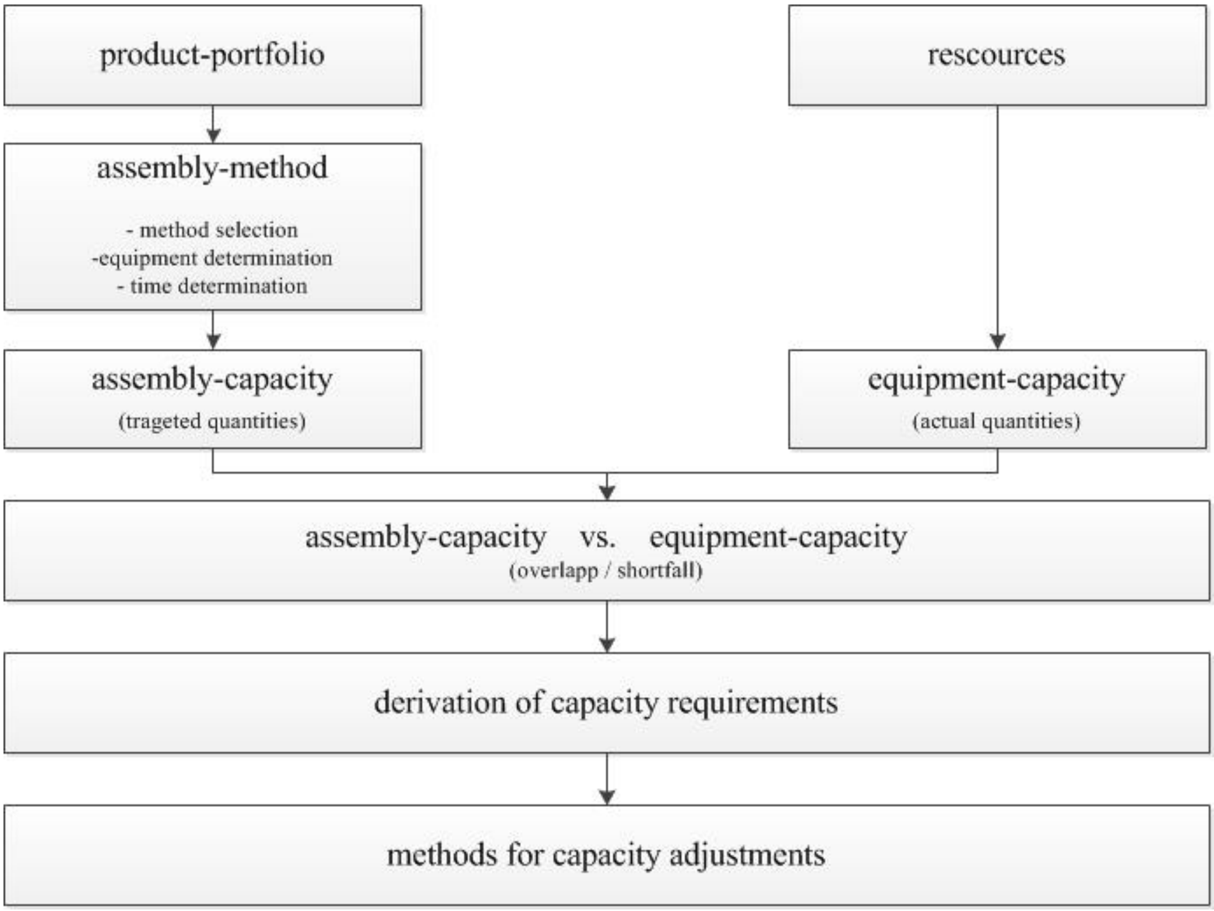


Figure 2.5: Guideline for dimensioning an assembly system (based on [Grun09], p. 90)

2.2.1 Product Analysis

2.2.1.1 ABC-Analysis

An ABC-Analysis is a method of a structure analysis. The ABC-Analysis is broadly used for analysing the relation between different entities and their features in many fields of activity. The ABC-Analysis may lead to suggestions for problem solving if the results are questioned critically ([Gude10], p. 131). One method of classification for the ABC-Analysis is the Pareto-classification. This classification is named after the inventor of the 80/20 rule, Vilfredo Pareto[4]. The 80/20 rule states that, for many events, roughly 80% of the effects are achieved by 20% of the causes [Wiki00].

[4] Vilfredo Pareto was an Italian engineer, sociologist and economist. He was born in 1848 and died in 1923. He is known for the 80/20 rule, named after him as Pareto-principle. https://en.wikipedia.org/wiki/Vilfredo_Pareto , 26.02.2017

This principle is applied to ABC-Analysis with Pareto-classification. Thereby, the amount of different objects is organized in descending order according to a quantifiable characteristic. The objects can be for instance articles, products, costumers or processes. The characteristics could be revenue, throughput time, customer lead time or annual production. The result of the Pareto-classification is the so called Lorenz-curve. On the x-axis of this Lorenz-diagram, for each object, the share in percent of the sum of all objects are plotted. On the y-axis the characteristic-share in percent of the overall characteristic is displayed. ([Gude10], p. 132) Figure 2.6 shows a Lorenz-curve of an ABC-Analysis with a Pareto-classification.

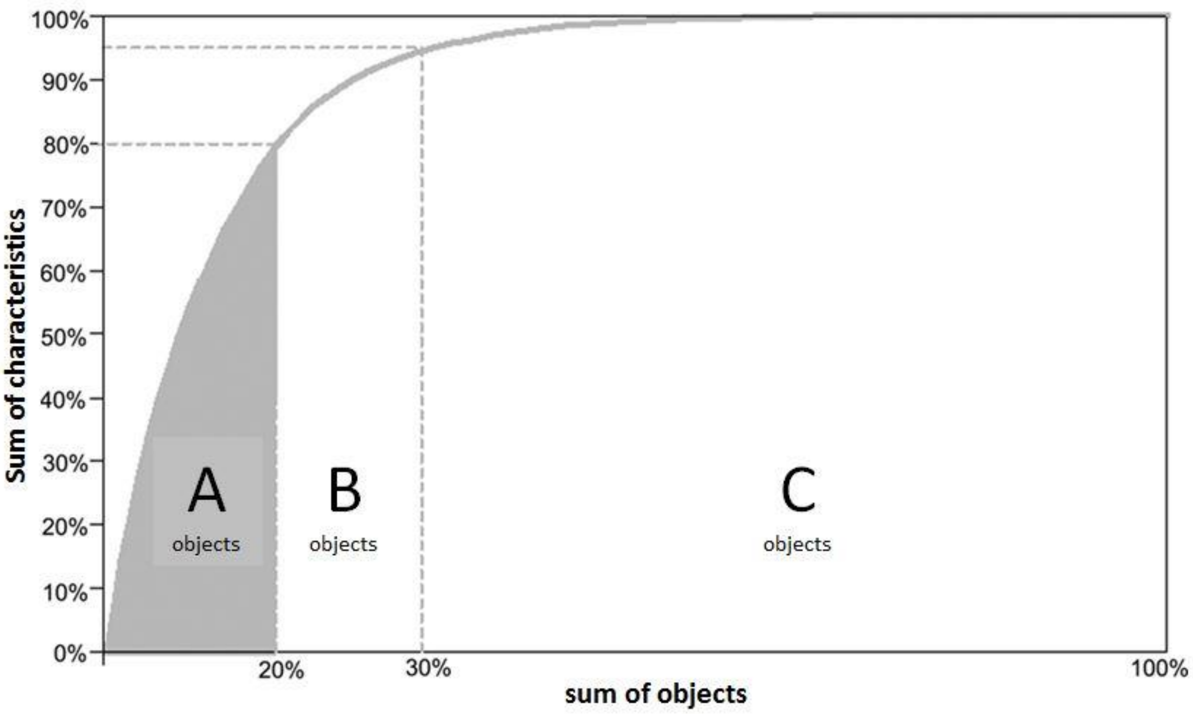


Figure 2.6: Lorenz-curve of an ABC-Analysis with a Pareto-classification (based on [HoHe11], p.2)

According to the 80/20 rule, objects can be classified into three distinct priority-classes. The boundaries for each class for a classical ABC-Analysis with Pareto-classification are shown in Table 2.5.

Table 2.5: Pareto-classification for a ABC-Analysis

Boundaries for a ABC-Analysis with Pareto-classification		
class	**%- border for the characteristic**	**cumulative %-border for the characteristic**
A	80%	80%
B	15%	95%
C	5%	5%

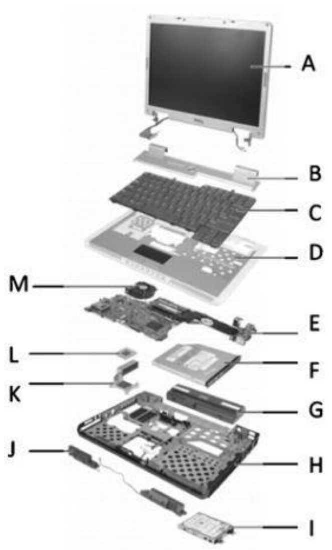
The Pareto-classification as shown in Table 2.5 means, that all A-objects are responsible for 80% of the characteristics. B- and C-objects combined are responsible for 20% of the characteristics. This classification allows quantifying the importance of different objects according to the chosen characteristic in a very easy way. This analysis works with a very wide range of objects and characteristics ([Gude10], p. 132).

2.2.1.2 BOM-Analysis

Next to the portfolio analysis, knowledge about single products and their components have to be gained to evaluate an assembly system. In particular the assembly representation and sequence are crucial during assembly system conceptual design.

There are different methods for representing the relationship between component parts in an assembly system. A commonly used assembly representation method is the Bill-of-Material (BOM). Generally a BOM lists all parts and materials a product consists of. Also some other information for producing, assembling or treatments can be included ([HKWE11], p. 716). A BOM usually has a tree-graph or tabular structure. In this structure a hierarchical level code is included to link the described part or material with the technical drawing. The technical drawing includes the same hierarchical level code linked to every part ([HKWE11], p. 716). Figure 2.7 shows an example of a BOM. The BOM has been a standard communication tool in industry for design, production and purchasing. Nowadays standard for generating a BOM is a CAD[5] application and integration in a ERP[6] system ([HKWE11], p. 716).

[5] CAD: shortcut for computer-aided-design
[6] ERP: shortcut for enterprise resource planning



Parts List	
A	display assembly
B	hinge cover
C	keyboard
D	palm rest (with touch pad)
E	system board
F	optical drive
G	main battery
H	computer base
I	hard drive
J	speakers
K	microprocessor thermal-cooling assembly
L	microprocessor
M	fan

Source: www.support.dell.com

Figure 2.7: Example of a BOM ([HKWE11], p. 716)

Due to the integration in the company IT-system it is rather simple to gain the required data through a BOM. Another advantage is that the BOM represents always the actual technical status because of the centralized administration of these data types.

2.2.1.3 Assembly Sequence

Next to the assembly representation the assembly sequence plays an important role in the assembly process. Determining all possible assembly sequences is an important stage in the total design process of an assembly system ([HKWE11], p. 717-718).

2.2.2 Process Analysis

2.2.2.1 Assembly System Configurations

Assembly systems can be designed in various configurations. One of the best known examples of a serial layout was the moving assembly line at the Ford Model T production introduced by Henry Ford, as mentioned in chapter 2.1. Such systems known as serial lines or flow lines are used for high volume production for single products. Since the establishment of assembly lines, these systems have become much more sophisticated and complex. Due to the increasing complexity of the products as well as increasing demand of flexibility, these assembly systems become much more sophisticated and complex ([HKWE11], p718).

Primarily system configurations can be classified into two different types ([HKWE11], p. 718):

- Synchronous configurations: where each part undergoes the same sequence of operations regardless of its path through the system

- Asynchronous configurations: where parts may undergo different operation sequences, depending on their path through the system

At synchronous systems, products or semi-finished goods move from one work place to the next at a constant pace. Therefore these systems are commonly used in mass production. In contrast to that asynchronous systems are more commonly used in assembly systems, especially when sub-assemblies are used ([HKWE11], p. 718).

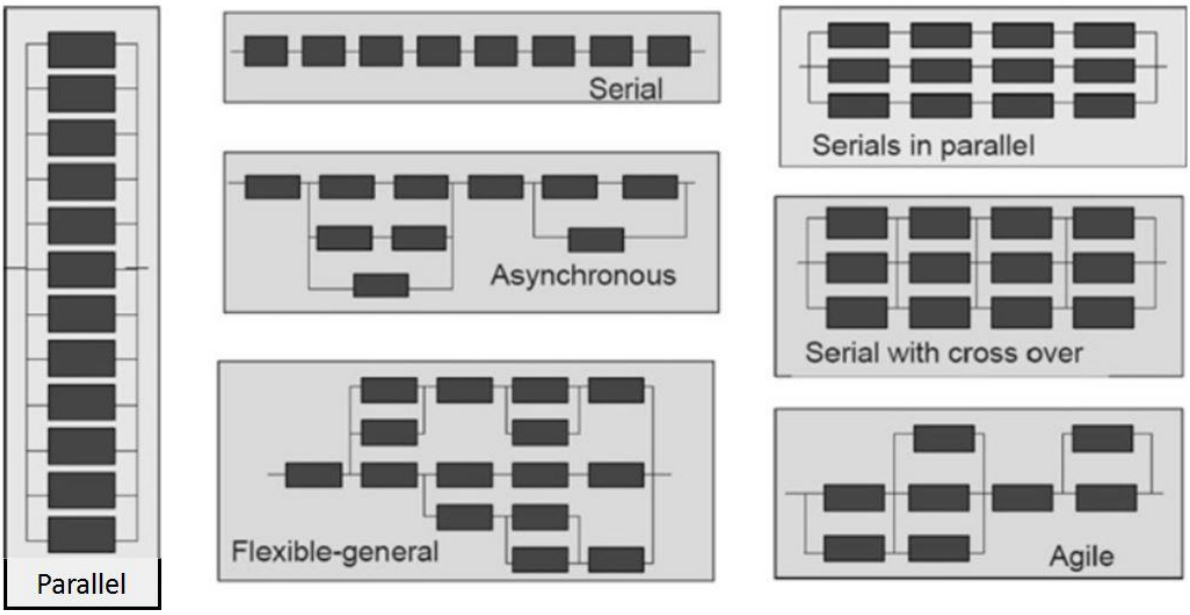


Figure 2.8: Different assembly system configurations ([HKWE11], p. 718)

Assembly system configurations are determined by the arrangement of machines and the connections between them. In Figure 2.8 different assembly system configurations are displayed.

2.2.2.2 Material-flow

Material-flow is the connection between all processes from sourcing to delivering products to the costumer. Basically there are two different types of industrial material-flow ([Grun09], p. 116):

- internal: Material-flow inside the production system or facility
- external: Material-flow outside the production system or facility

Internal material-flow covers all connections between process steps which are fulfilled inside the production system or factory. External material-flow covers all connections form the supplier to the factory and internal material-flow covers the connections form the factory to the customer ([Grun09], p. 116). Material-flow can also be classified through the basic function of the investigated process. The basic functions are ([Grun09], p. 116):

- production (manufacturing, assembling, testing)
- movement (transportation, manipulating)
- storage (planned or unplanned storage, commissioning)

Based on the available data the target of the material-flow analysis can either be the connection between the different processes or the intensity of the material-flow. The determination of the connections between the different processes is a qualitative analysis where the determination of the intensity between the processes is a quantitative one ([Grun09], p. 119).

Both, the quantitative and the qualitative analysis can be displayed in different ways. In the tabular display method, so called material-flow matrices are used. In this matrix all connected processes are listed in the first column as well as in the first row of the matrix. The first column represents the source of the material-flow. The first row represents the sink of the flow. The matrix is then filled with data according to the connection or intensity of the two considered processes. Figure 2.9 shows an example of a material-flow matrix ([Grun09], p. 121).

	WE	ZL	TF	M1	M2	M3	WA	Σ
WE		120000	180000					300000
ZL			90000	60000	60000	60000		270000
TF		90000					15000	105000
M1					15000	15000		30000
M2		15000				24000		39000
M3			30000				60000	90000
WA								
Σ		225000	300000	60000	75000	99000	75000	

Figure 2.9: Example of a material-flow-matrix ([Grun09], p.122)

The shortcuts WE, ZL, TF, M1, M2, M3, WA are representing the different processes. The values in the matrix are representing transported units between these processes. As an example process WE delivers 120.000 units to process ZL. In the special case which is displayed in Figure 2.9, the material-flow matrix provides qualitative as well as quantitative data about the material-flow. The quantitative information is that all listed values which greater than zero are show that there is a connection. The quantitative data is provided according to the amount of transported units.

A graphical method for displaying material-flow in a quantitative way is the material-flow-network-model. In this model every process is symbolized by a rectangle. The material-flow connection is symbolized with arrows pointing from sender to the receiver. Figure 2.10 shows an example of such a material-flow-network-model.

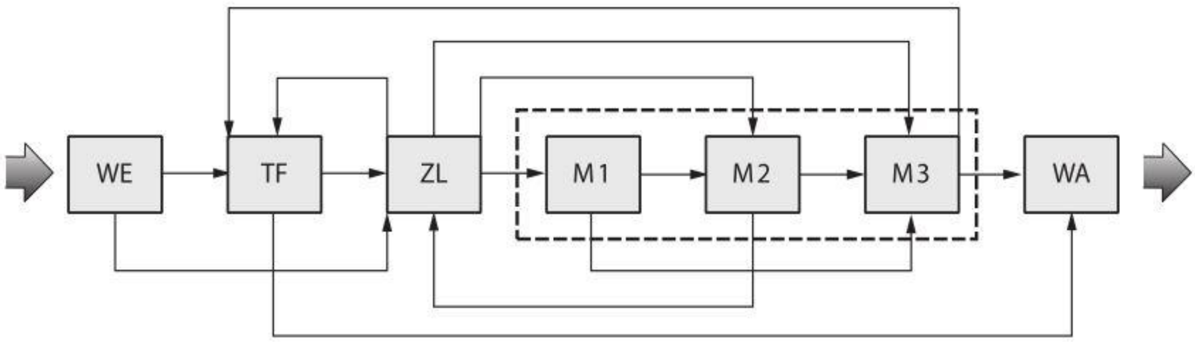


Figure 2.10: Example of a material-flow-network-model ([Grun09], p. 122)

2.2.2.3 Sankey Diagram

A Sankey–diagram is a graphical method for displaying material-flow quantitatively. The structure of a Sankey-diagram is basically identical with the material-flow-network-model but the thickness of the arrows is corresponding to the amount of transported units between the different processes. Therefor the Sankey-diagram can be described as an advanced material-flow-network-model. In contrast to the material-flow matrix the Sankey-diagram provides a simplified, graphical overview of the material-flow ([Grun09], p. 128). Figure 2.11 shows an example of a Sankey-diagram. Corresponding to the material-flow intensity the thicker the arrows are, the higher the material-flow intensity is. Therefore the Sankey-diagram provides a fast and rather simple overview of the material-flow system without any specific knowledge.

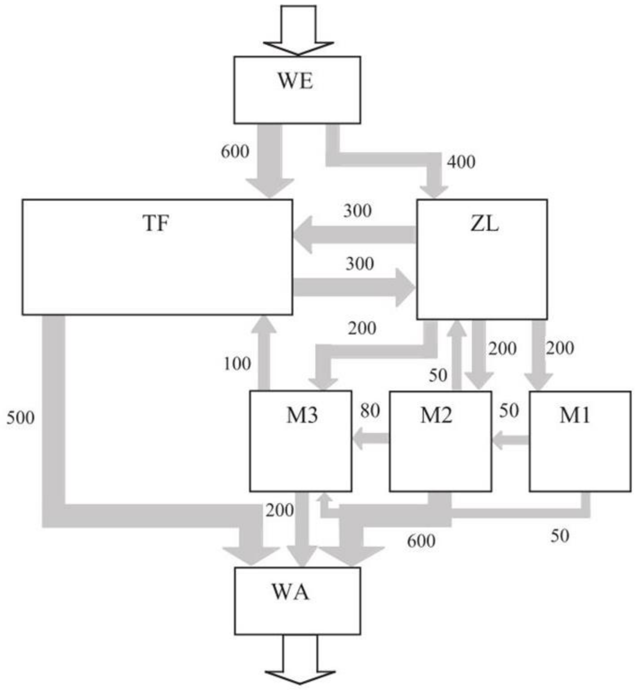


Figure 2.11: Example of an Sankey-Diagram ([Grun09], p. 128)

2.2.3 Work Time Analysis

After analyzing the relevant product- and process- parameters, the next step is to analyze the required labor time and process time for assembling the products in the desired way. In combination with the desired output-parameters, as it is explained in 2.1.3, the knowledge of labor time and process time is the basement for dimensioning the necessary labor and therefore the assembly system itself ([Grun09], p. 97). How the required labor headcount is calculated is explained in detail in chapter 2.1.3. According to Equation 4 detailed knowledge about the labor time for each sequence of event is necessary.

2.2.3.1 MTM - UAS

A method for determining the labor time for each sequence of event is the MTM method. Triggered by the need of highest productivity in the second world-war an elementary modular system for determining work time was established in the USA ([BoLa06], p. 508). MTM-UAS is a modular system on the hierarchical level of basic processes. With these basic processes all work steps which are performed in the production area, are modeled. MTM-UAS is specially designed for serial production. Every basic process is linked with a certain quantity of TMU[7]´s. One TMU is the equivalent of 0, 0006 minutes or 0, 036 seconds ([BoLa06], p. 508, p. 598). According to predefined MTM-UAS data tables, like the example in Figure 2.12, the real work steps are modeled and the total work time is defined. This work time is a target time and is representing the target process without any disturbances ([BoLa06], p. 599).

Due to the fact, that the MTM-Analysis is modeling the actual system rather than recording it, the quality of the model is important for further analysis. The relevant quality characteristic to guarantee that the determined time is reproducible even when the task is fulfilled several times is the statistical accuracy ([BoLa06], p. 525).

[7] TMU: shortcut for Time Measurement Unit

Motion Lenght in cm	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	1	2	3

Get and Place			CODE	1	2	3
				TMU		
	Case of Get	Case of Place				
$\leq$ 1kg	easy	approx.	AA	20	35	50
		loose	AB	30	45	60
		tight	AC	40	55	70
	difficult	approx.	AD	20	45	60
		loose	AE	30	55	70
		tight	AF	40	65	80
	handful	approx.	AG	40	65	80
> 1kg to $\leq$ 8kg		approx.	AH	25	45	55
		loose	AJ	40	65	75
		tight	AK	50	75	85
> 8kg to $\leq$ 22kg		approx.	AL	80	105	115
		loose	AM	95	120	130
		tight	AN	120	145	160

Figure 2.12: Example of a MTM-UAS table (based on [BoLa06], p. 600)

The statistical accuracy of a MTM determined cycle time can be measured with the confidence interval[8] and the standard deviation. The standard deviation is calculated according to Equation 5. The confidence interval is calculated according to Equation 6. At a MTM-analysis the determined target time sets the mean value for the statistical accuracy investigation. For calculating the standard deviation of an MTM analysis the following equations are used:

Equation 5: standard deviation for MTM analysis

$$sd = \frac{dev_{cycle}}{2}$$

where sd = standard deviation

dev_{cycle} = deviation per cycle

[8] The confidence interval contains 95% of all randomly chosen variables. The borders of this interval are two times the positive and the negative standard deviation. That means if the standard derivation is 5%, the confidence interval is ± 10%. Further 95% of all picked variables are in between the border of ± 10% referred to the mean value ([BoLa06], p.527).

Equation 6: deviation per cycle for a MTM analysis with a 95% confidence interval ([BoLa06], p. 527)

$$dev_{cycle} = \frac{0{,}98}{\sqrt{\text{n}}} \times 100\%$$

where dev_{cycle} = deviation per cycle

n = time for one work step [TMU]

The statistical accuracy of a MTM determined cycle time is best demonstrated using an example. Assuming that the determined target time is 1 min or 1667 TMU, the actual time of performing this work step, would range between ± 2,4 % with a probability of 95%. In Figure 2.13 the relation between deviation of the cycle time and determined cycle time is illustrated.

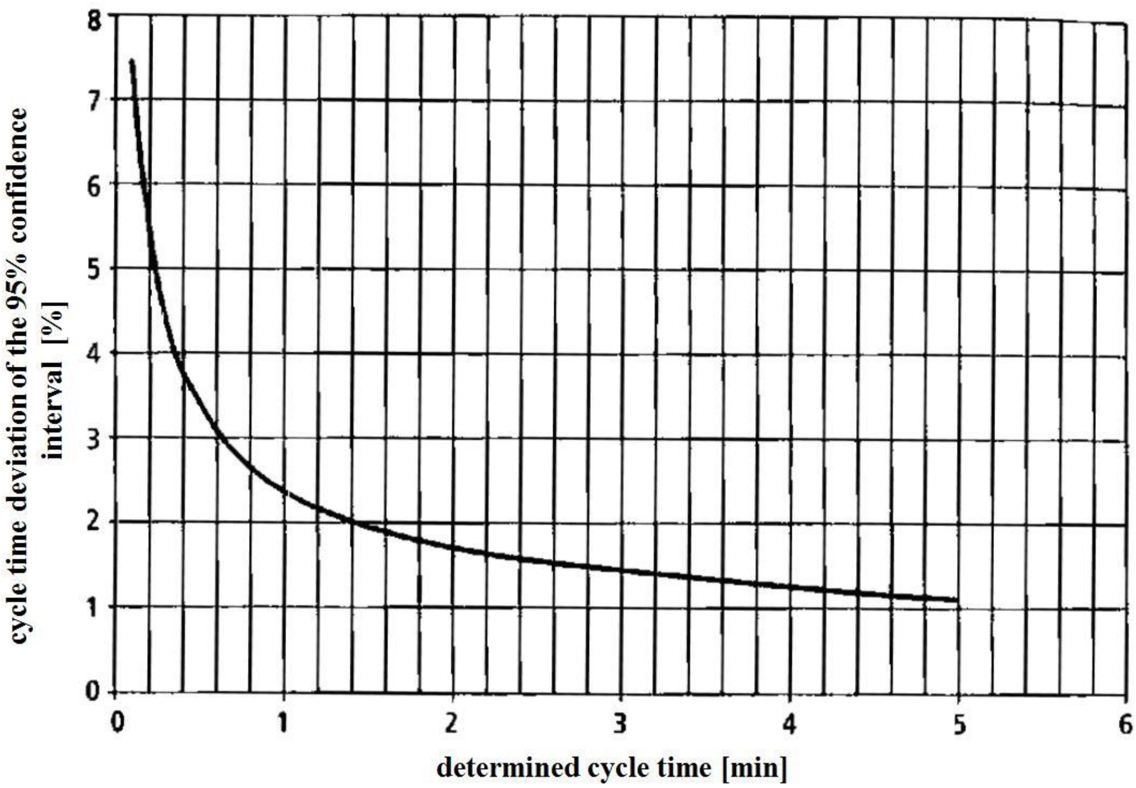


Figure 2.13: Relation between determined cycle time and cycle time deviation (based on [BoLa06], p. 528)

2.2.3.2 Takt Time and Line Balancing

In chapter 2.1.3, Equation 3 the takt time is explained as the pace of customer demand. It can be also seen as available time to produce products within a time interval divided by the number of products demanded. Therefore it is obvious, that the cycle time of each operation has to be less or equal to the takt time. If the cycle time of one single production steps exceeds the takt time, this operation will be a bottleneck and additional time will be necessary to meet the production schedule. If the cycle time is less than the takt time, there will be either overproduction or idle time at this single operation. Due to the direct correlation of cycle time of each single operation and takt time, the target is to reduce the gap between these two times as much as possible ([LiMe06], p. 137). The negative effects of a gap between cycle time and takt time can be rated as “muda” as it is discussed in 2.1.2. A technique that is used in manufacturing to reduce the gap between cycle time and takt time is line balancing. Line Balancing is a visual technique used to allocate and distribute work at the line ([Mark13], p. 316).

As Figure 2.14 shows, a line balancing diagram of an unbalanced line. The first step in line balancing is plotting all work steps of every work place in a diagram. The diagram contains every work station in the line, the work steps which cannot be splitted in smaller operations and the takt time.

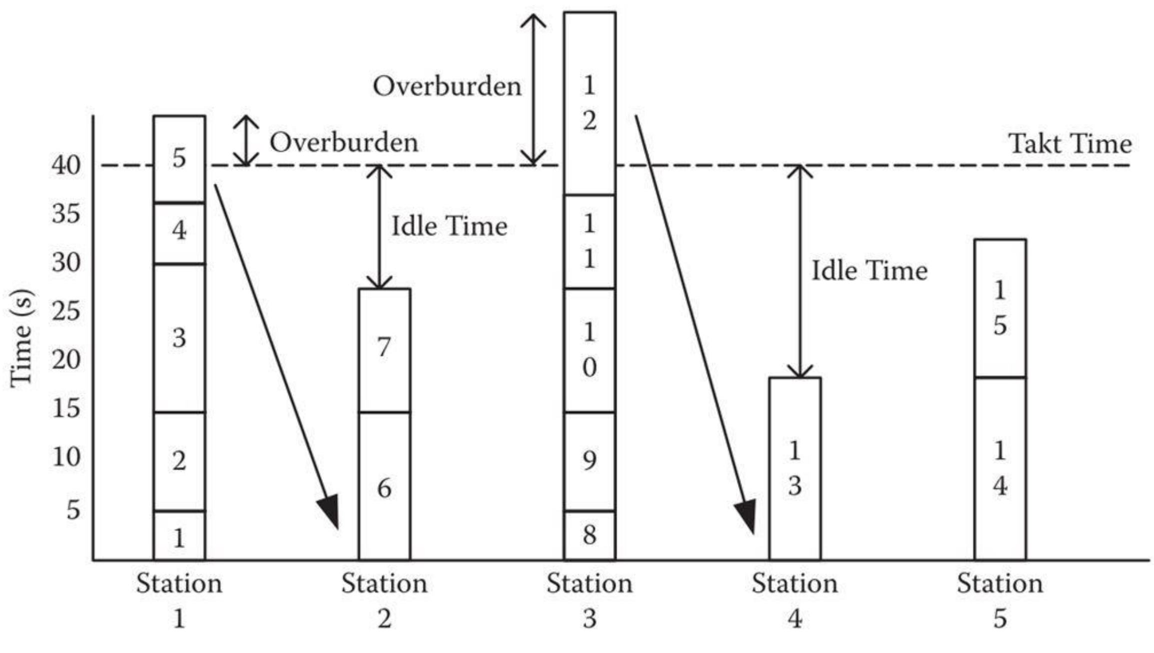


Figure 2.14: Line balancing diagram of an unbalanced line ([Mark13], p. 318)

For balancing the line, major work steps of the job are identified and distributed to different work stations. The target of balancing is to prevent overburdening and to reduce idle time. In the example of Figure 2.14 work step #5 needs to be moved to work station 2 because this station is overburdened. Also work step #12 needs to be moved to work station 4. These movements prevent the work stations 1 and 3 to be overburdened as well as reducing idle time on work stations 2 and 4 ([Mark13], p. 318). After moving the mentioned work steps a much smoother and more balanced line balancing diagram is the result. The result of shifting these work steps is displayed in a new line balancing diagram Figure 2.15.

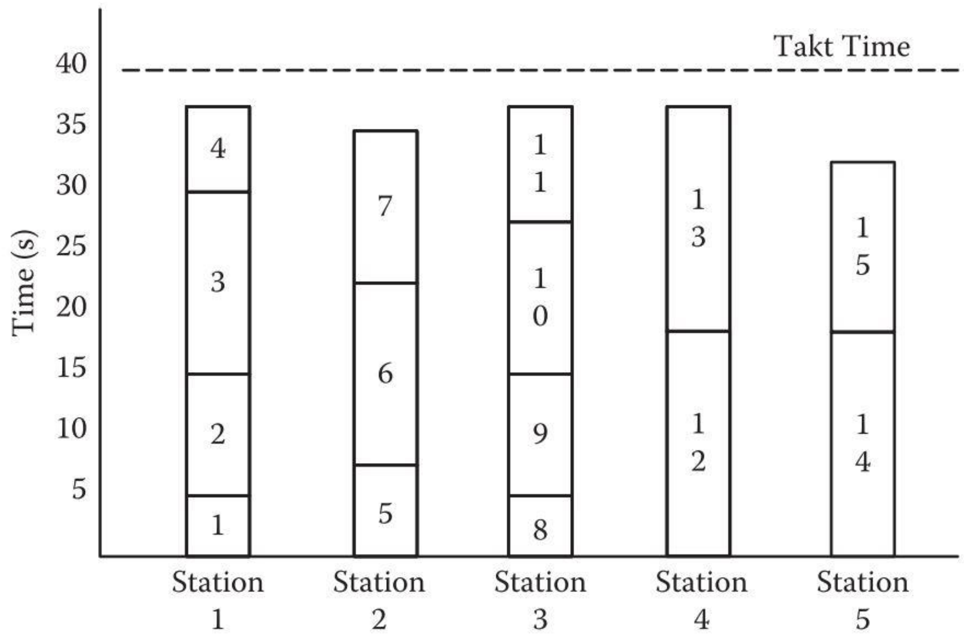


Figure 2.15: Line balancing diagram of a balanced line ([Mark13], p. 318)

To judge the performance of an assembly or manufacturing line not only graphically but also with metrics, the line balance rate according to Equation 7 as well as the line balance loss rate can be calculated ([CMCM16], p. 982) :

Equation 7: Line balance rate ([CMCM16], p. 982)

$$LBR = \frac{t_{total}}{t_{longest} \times n_{ws}} \times 100\%$$

where LBR = Line balance rate

t_{total} = total net time of all processes

$t_{longest}$ = longest process time

n_{ws} = number of workers

Equation 8: Line balance loss rate ([CMCM16], p. 982)

$$LBLR = 100\% - LBR$$

where LBLR = Line balance loss rate

LBR = Line balance rate

2.3 Simulation of Production Systems

Most real world systems are too complex to be evaluated analytically. To gain knowledge about the behavior of such systems, their models must be studied by the means of simulation. In a simulation a computer is used to evaluate a model numerically, and data is gained in order to estimate the desired true characteristics of the model ([LaKe91], p. 1).

As a technique, simulation is one of the most widely used ways of analyzing a system in the fields of operations research and management science. But simulation is not the only way. According to theory there are different ways to study a system. Figure 2.16 should give an overview of these ways.

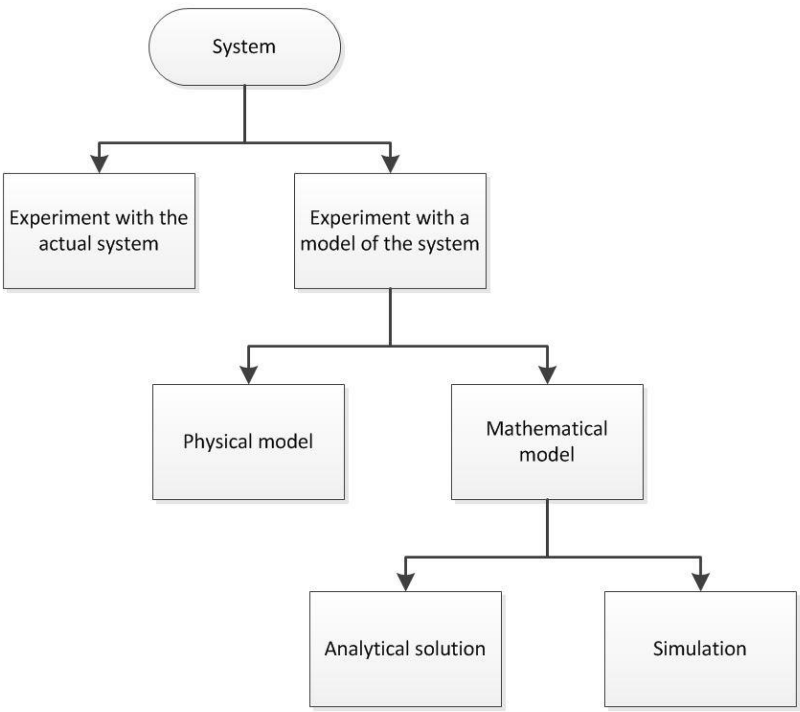


Figure 2.16: Ways to study a system (based on [LaKe91], p. 4)

In the following chapter the approach of study a system with a computer based simulation and the different types of computer based simulations are described.

2.3.1 Types of Computer-based-Simulation

As is displayed in Figure 2.16, there are different ways to study a system. For this thesis the simulation was chosen due to the high complexity brought by analyzing an assembly line.

Before starting a simulation, suitable tools have to be chosen. Therefore it is useful to classify the different simulation tools along three different dimensions ([LaKe91], p. 6) :

- Static vs. Dynamic Simulation Models
    - Static: the system is viewed only at one particular point in time or time plays no role e.g Monte Carlo models
    - Dynamic: represents a system as it evolves over time e.g. conveyor belt in a factory

- Deterministic vs. Stochastic Simulation Models
    - Deterministic: the system contains no random variables e.g. chemical reactions
    - Stochastic: the system contains random variables e.g. waiting queue

- Continuous vs. Discrete Simulation Models
    - Continuous: system state changes continuously e.g. differential equations
    - Discrete: system state changes at discrete points in time e.g. storage systems

In the field of production and logistics often systems and processes are simulated with computer based simulation models. Typical systems are factories, construction areas and storages. Typical processes are assembly and manufacturing. These models represent dynamic behavior of the physical system with the help of stochastic components and system state changes at discrete points in time. Therefore event based models are almost exclusively used. That means that the system state changes at the occurrence of events. These models are called Discrete Event Simulation (DES) ([MKRW11], p. 14).

Nearly all DES software applications are running the simulation according a rather simple algorithm. The concept of this algorithm is explained by a flowchart, shown in Figure 2.17 ([MKRW11], p. 16)

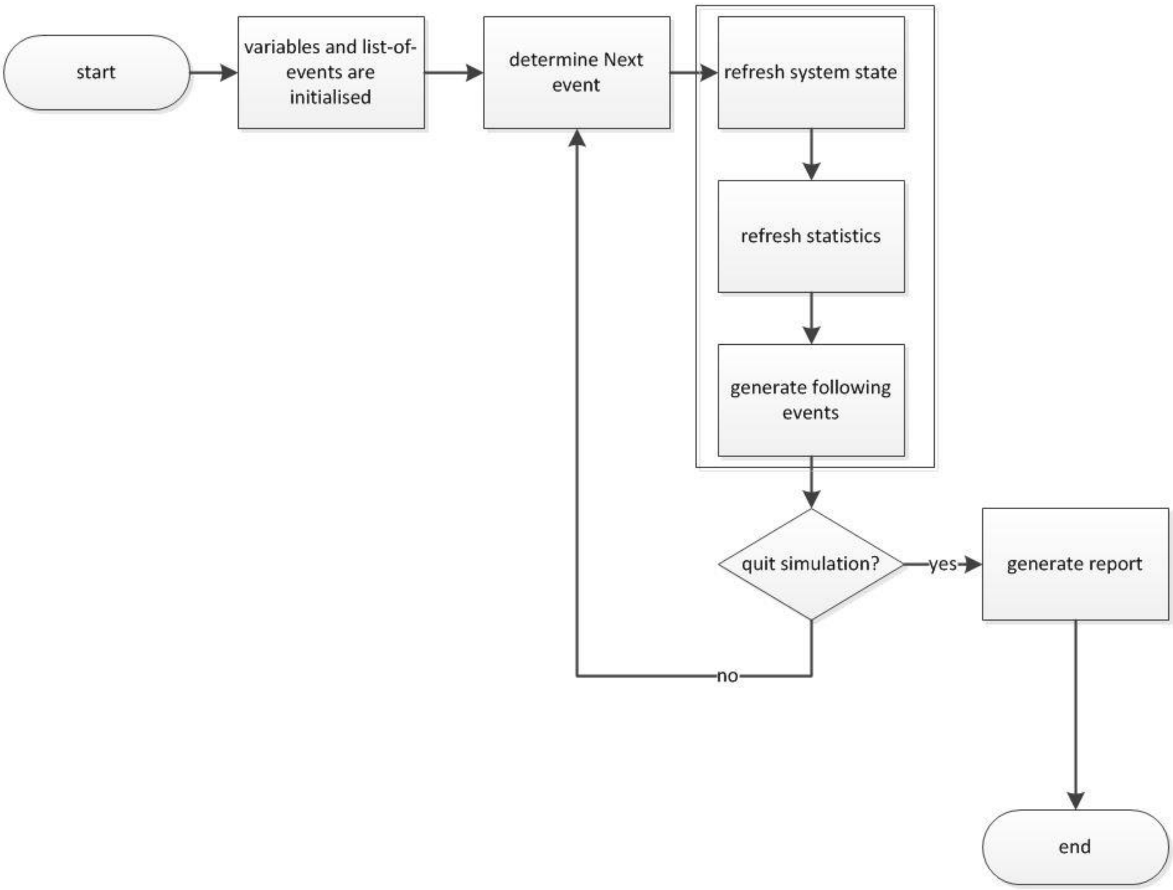


Figure 2.17: Flow chart of a Discrete-Event-Simulation (based on [MKRW11], p. 16)

2.3.2 Approach for a Computer-based-simulation

2.3.2.1 General Approach

The general approach of a computer-based-simulation is basically structured in three phases. These phases are preparation, implementation and evaluation. The phases are run through several times during the model generation and model usage. To understand the approach of a computer-based-simulation Figure 2.18 is showing a flow chart of this general approach ([Vdi93], p. 9).

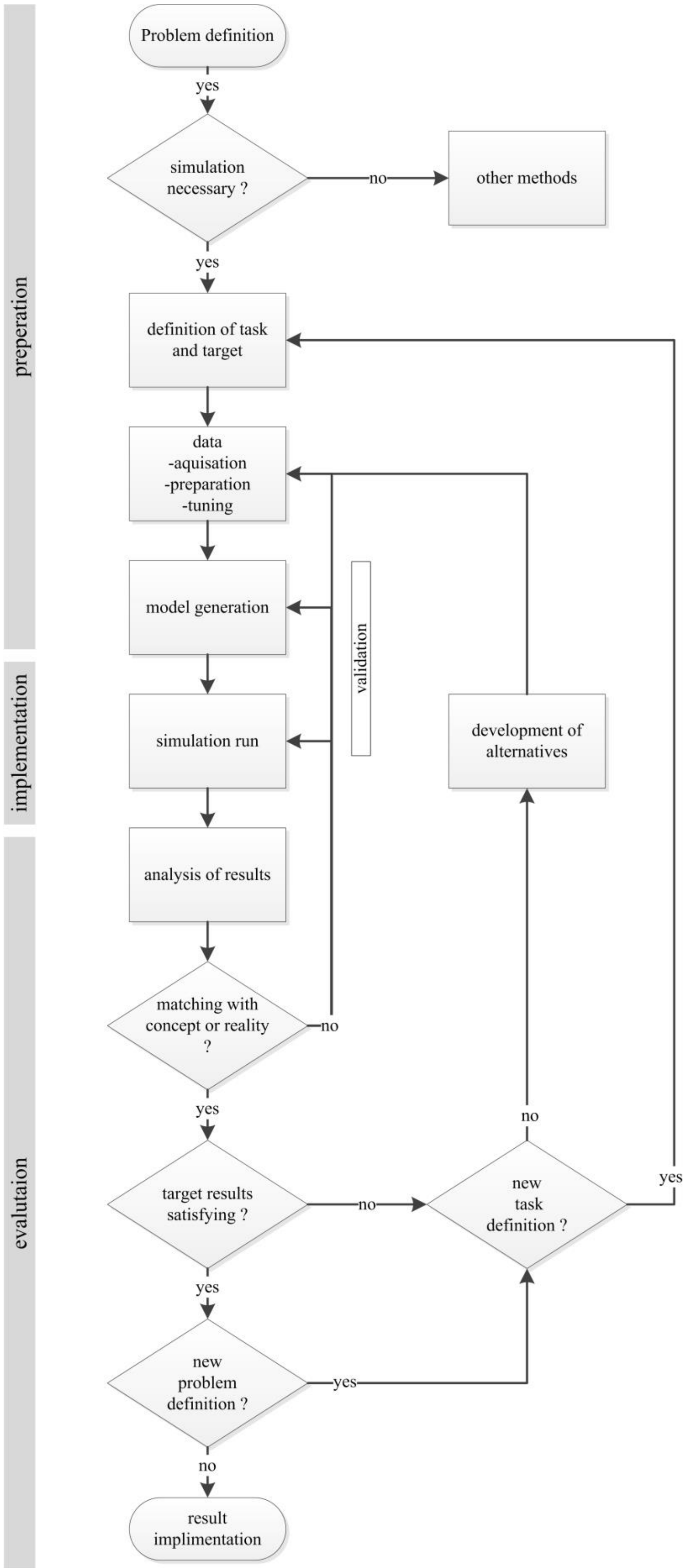


Figure 2.18: General approach of a computer-based-simulation (based on [Vdi93], p. 9)

2.3.2.2 Data Acquisition

Every model used in a simulation tool is described by data. This data is the basis of the simulation. Basically these data are part of every designing and planning process of a production system. Thus in a simulation the requirements concerning the quality of this data are much higher. The scope and time period of this data depends on the problem definition. The necessary data can be categorized in three different classes. This classes are *data of the system load, data of the organization* and *technical data* ([Vdi93], p. 10):

Because this data often does not exist in the desired completeness, an analytical estimation is necessary to validate every simulation run as it is described in chapter 2.3.2.5 ([Vdi93], p. 11).

2.3.2.3 Modeling

Modelling is the implementation of an existing or constructed system into an experiment able model ([Vdi93], p. 12). The simulation software creates events directly out of the different model elements. In simulation applications of production systems, order-oriented models are commonly used. The modeling process strongly depends on the used software tool. But a general problem of all modeling processes is the definition of the degree of model complexity. Choosing the right degree of complexity is a tradeoff between effort for modeling and necessary resolution for solving the problem ([MKRW11], p. 17).

2.3.2.4 Experiment Planning

Running experiments is directly influenced by the defined targets of the simulation. Feasibility studies or bottleneck analysis are requiring often only one simulation run with predetermined parameter setups. But for designing and dimensioning of production systems principally several simulation runs with varying input and process parameters are necessary. These different simulation runs can then be evaluated and compared to each other in order to find the right solution for the asked problem or to determine the impact of different parameters ([Vdi93], p. 18).

2.3.2.5 Validation

To validate, the simulation model is checked for the conformity to the real or constructed model. It has to be ensured that the simulation model behaves like the real model in an exact enough way. Validation is one of the most difficult yet most important tasks of a simulation ([Vdi93], p.

17). Due to abstraction and simplification of a simulation model, the total conformity of a simulation model and the real system is fundamentally not possible ([Vdi93], p. 17). When simulating a real system it is obvious to compare the results of the simulation with actual data. When simulating constructed systems the validation is not that easy and demands high qualification and expertise of the user of the simulation tool. One basic principle for validating a simulation model is the visual control of the animation. This technique allows identifying basic structural or parameter-related mistakes made in the modelling or data acquisition process ([Vdi93], p. 18).

3 Practical realization at WP

The introduced methods and approaches explained in chapter 2 will now be applied to analyze the current production system for assembling onroad-motorbike-forks and develop different concepts for a future system. The analysis starts at the product level, continuing with the process and production strategy analysis. All gained data and knowledge is further implemented in a computer based simulation model. The simulation of this model helps to rate the performance of the current production system. In the second step different concepts are developed in order to meet the requirements for the future system. These concepts are again tested in a computer simulation to evaluate the performance of these concepts.

3.1 Product Analysis

As mentioned in 2.2.1 the product analysis is split up into a qualitative and a quantitative part. The qualitative analysis gives an overview of the different types of goods which are produced at WP. Further the products are categorized according different criteria. Also differences of the technology of the products will be pointed out. The quantitative analysis shows how the product portfolio is split up, in terms of product types, customers and production load as well as how the demands of single products behave over the investigated period. A possible seasonal trend should be detected as well as the fluctuation of each product group over the season.

3.1.1 Data Acquisition

The acquisition of data for the product analysis is realized by a query from the Enterprise-Resource-Program (ERP). WP uses the common ERP system SAP®. For the further analysis the raw data of the ERP system are imported in a Microsoft EXCEL® sheet.

The query includes several data sets for the investigated time period form August 2015 to August 2016. This timeslot is chosen because of the company-holidays in August. It represents a whole production year. All data sets are listed in Table 3.1. The data generated out of this query is the base for further analysis. Due to the fact, that many departments form production through financial controlling to quality management at WP use the same data every day, the data can be rated as robust.

Table 3.1: data sets of the ERP-Query for the product analysis

Data Set	Translation:	Discretion:
BuchDatum	booking date	Date when order is booked in the system
ArbPlatz	work station	Requested work station for special product
Auftrag	order	order number
Material	material	unique number for each product or semi-finished product
Material-nummer	material number	Text for the description of the material
Ausschussmenge	scrap	amount of units which are booked as scrap
Menge NA	rework	Amount of units which are booked as rework
RMMG Gut	good part	Amount of units which are book as good part
Stdpreis	Standard price	Price which is stored for each part
Kurztext Vorgang	short text	short text for the booking process
FertSteuerer	production supervisor	special process specific number in SAP

Figure 3.1 shows how the EXCEL®-export of the ERP-Query looks like. The Export is necessary for further analysis of the data. All following analysis is based on this data. The evaluations are performed with Microsoft EXCEL®.

One important factor for data analysis is that every delivered onroad-motorbike fork consists of two single pillars. All figures of the query are related to pillars not complete forks.

[raw_data_DAY]	[raw_data_MONTH]	[raw_data_YEAR]	[raw_data_workplaceID]	[raw_data_orderID]		[raw_data_goodsID]	[raw_data_name]	
BuchDatum	Monat	Jahr	ArbPlatz	Auftrag	Material	Material bereinigt	Materialnummer	Ausschußme
17.11.2015	11	2015	3FBL2-EK	1062234	01281008-PT	01281008	FB.VT2 TRIUMPH EXPL1200 TSAS LOW	
13.11.2015	11	2015	3FBL2-EK	1062234	01281008-PT	01281008	FB.VT2 TRIUMPH EXPL1200 TSAS LOW	
28.09.2015	9	2015	3FBL2-EK	1062234	01281008-PT	01281008	FB.VT2 TRIUMPH EXPL1200 TSAS LOW	
18.08.2015	8	2015	3FBL2-EK	1064234	01287006-00	01287006	FB.TRIUMPH EXPLORER 1200 VG2	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
24.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	
25.08.2015	8	2015	3FBL2-EK	1066445	11067D04-G	11067D04	BMW K48 ESA 2 HINTEN 08	

Figure 3.1: Example of a ERP-Query

3.1.2 Product-Families of WP

Suspension Systems are the products with the longest tradition at WP and are the products what WP is famous for. Given the many years of developing and producing suspension systems the variety of this product group is huge. There are nearly 600 different suspension products which were registered in the ERP at WP´s production site only in the period from August 2015 to August 2016. In this period 282,000units were registered after the production in the suspension division. This means in average 470 units of each product per year. This figure seems very low when you think of an automotive supplier, but becomes more plausible when you take a closer look at the products itself.

Many products differentiate each other only by one single shim or by the labeling for the customer. Therefore it is necessary to cluster the range of products into groups with similar technical structure. The Product-Family-Tree as seen in Figure 3.2, shows the different product-groups and their relations.

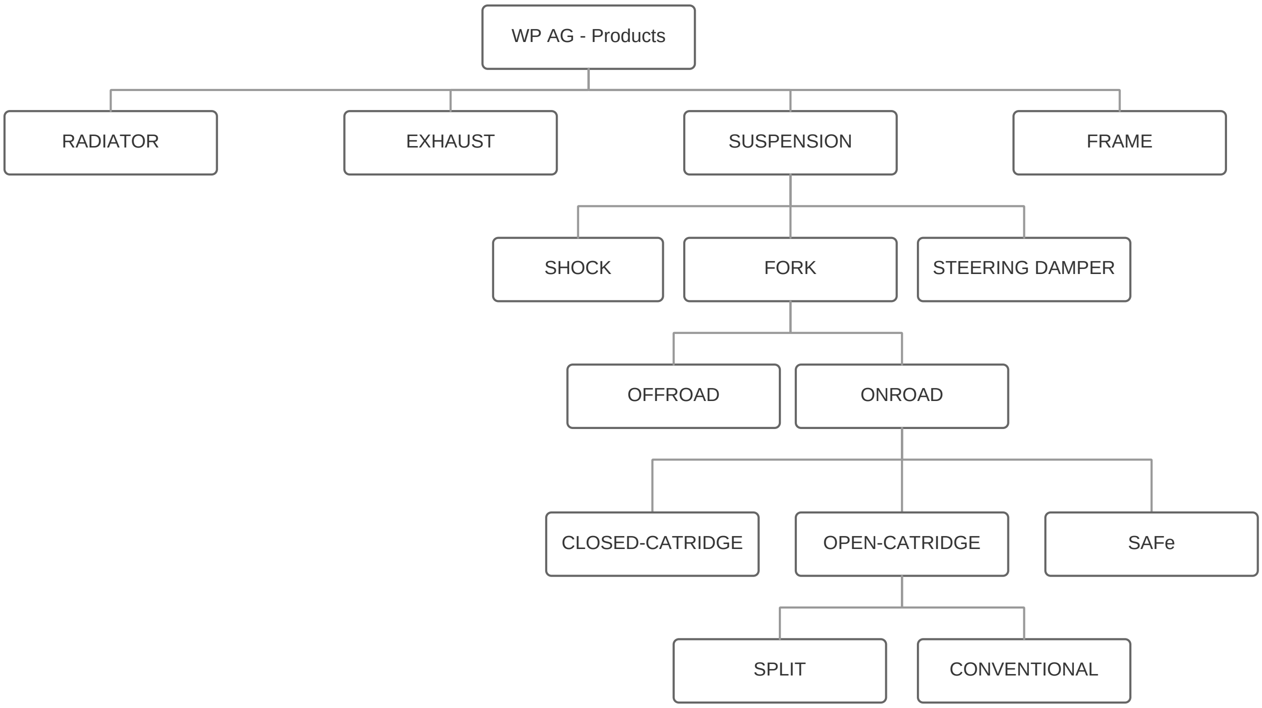


Figure 3.2: Product family tree of WP

On the first level the products can be divided into four groups, corresponding to the four divisions of WP, Radiator, Exhaust, Suspension and Frame. Going deeper in the product structure the three main products in the Division Suspension are: Shocks, Forks and Steering Dampers. The different kinds of forks can be categorized by the main purpose of the final vehicle where these products are used. These two categories are Offroad- and Onroad-Forks. The Onroad-Fork-Level is the subject of the investigation in this thesis. At this level there are another three construction types, the Open-Cartridge (OC), Closed-Cartridge (CC) and SAFe. OC and CC Forks differ from the type of construction of the damping system, but they are operating both purely mechanical. In contrast to OC and CC, the damping system of SAFe[9] Forks is working with a combination of electrical and mechanical parts.

[9] The German meaning of SAF is “Semi aktives Fahrwerk” which can be translated to “semi active suspension” and the e stands for the German word “elektrisch” which means “electrical”. With this Product-Family-Tree a first classification of one product can be done.

3.1.3 Numerical Product Code

For a further classification of each product, the numerical-product-code is used.

As seen in Table 3.1, each product has an explicit numerical code called “material” in the ERP. With this code each product can be identified exactly and also information about the type of construction, the customer and the model-year is included in this code. All codes follow the same template which was established by the R&D Department of WP. Figure 3.3 shows the systematic how the code is generated and can be read.

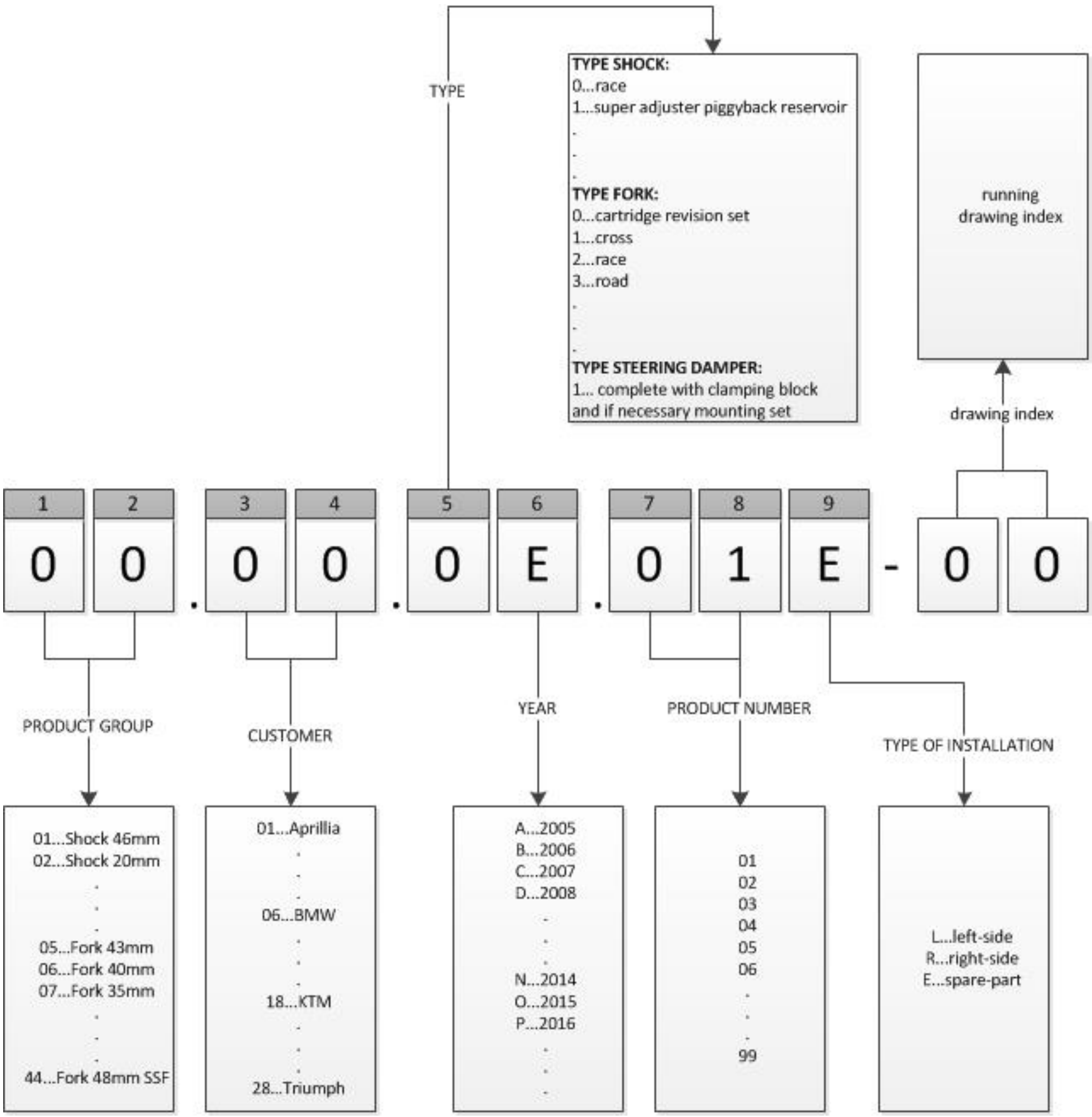


Figure 3.3: Numerical Product Code – Template

The information out of the numerical-product-code is used for a more detailed classification and is the subject of the next chapter 3.1.4.

3.1.4 Product Classification

In order to cluster all products and find similarities of the different products a product classification is made. This clustering is necessary to be able to define requirements for assembly in a higher level.

The first approach of a classification of the product portfolio is made by a classical ABC-analysis. This analysis should help gain a better understanding for the distribution of products in terms of production-volume.
With the information of the product-families and the numerical-product-code a classification by the type of construction can be done for each product of the onroad-fork family. The investigated time slot is the same as mentioned in chapter 3.1.1.

3.1.4.1 ABC- analysis

The first two methods for classifying products are more interesting to get an overall feeling how the portfolio is split up. The ABC- analysis focuses on the single product and compares the production volume of each product with the overall production volume, as it is described in 2.2.1.1. In the first step all indices in of the product codes were eliminated. The result of this elimination is that products with identical material number but different indices were grouped in one product number. Thus all products are addressed reliable in the analysis. For the overall onroad-fork ABC-analysis all products are considered which are in the product port-folio in the inspected time slot. The raw data for the analysis is gained from the ERP-query.
Not all products run through the same production steps and therefore not all products are registered in the ERP-System at every production step, as will be explained later in 3.2.2. According to 2.2.2.1 the system can be described as an asynchronous configuration.

One significant workplace for each product has to be chosen. It is recognized that nearly all products run through the work place 3GL2-50. The products run through 3GL2-60 instead of 3GL2-50. The detailed material flow is explained in detail in 3.2.2. After defining significant workplaces for each single product the annual produced amount can be summed up. This sum is the basis for weighting every product according to the sum of all products. The result is a list of all products with their annual production volume. Sorting the products, from the highest production volume to the lowest and then cumulating their individual share of the overall production volume, leads to a list with all products ranked according to their share of the overall production volume and the cumulative production volume of each product plus the production volume of all products figuring earlier in the list..

In the last step a classification is made to divide the portfolio into groups. Modeled along the example of the classical Parretto-Rule of 80/20, as it is described in 2.2.1.1, the range of each class is defined as shown in Table 3.2 .

Table 3.2: Product-Classification for the ABC-Analysis

class	Share of annual production [%]
A	80%
B	15%
C	5%

Following this classification, the cumulative production volume of all products rated with “A”, these are responsible for 80% of the overall production volume, class “B” are responsible for 15% and class “C” make 5% of the overall volume. “A” and “B” combined take a 95% share of the production volume and so on. The Analysis according to this ABC-scheme of the production data gained in 3.1.1 leads to the result described in Table 3.3. Overall 55 different products were produced on the onroad-assembly line and 136.951 units were produced between August 2015 and August 2016.

Table 3.3: ABC-Analysis Overview

ABC Analysis:				
class	**products**	**units**	**% units**	**% products**
A	17	109.062	79,64%	30,91%
B	12	20.748	15,15%	21,82%
C	26	7.141	5,21%	47,27%
SUM	55	136.951	100,00%	100,00%

But only 17 products, the class “A” products, take a share of nearly 80% of the overall production volume. On the other side almost half of the items in the product portfolio are rated as a “C” product, which are adding only 5% of the overall production. The rest of the products, the class “B” products, are responsible for 15% of the volume. The diagram in Figure 3.4 shows the drastic gap between share of production volume and share of product portfolio.

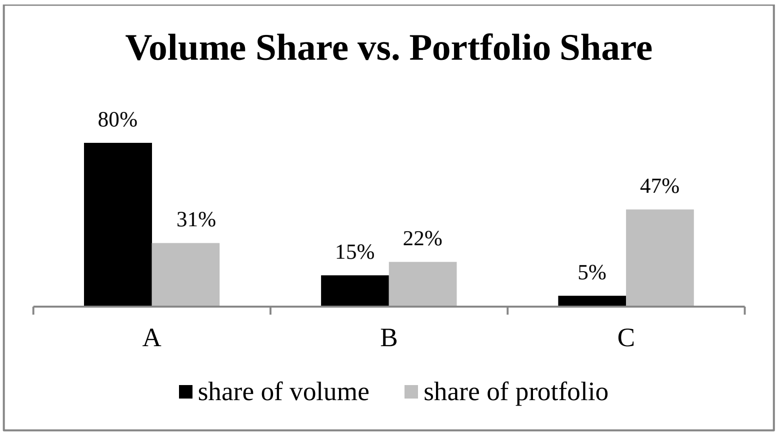


Figure 3.4: ABC-Analysis Volume Share vs. Portfolio Share

The unequal distribution of the production load over the portfolio is getting even more visible when drawing a Lorenz-Curve with production volume and share of the portfolio as two characteristics. This is displayed in Figure 3.5.

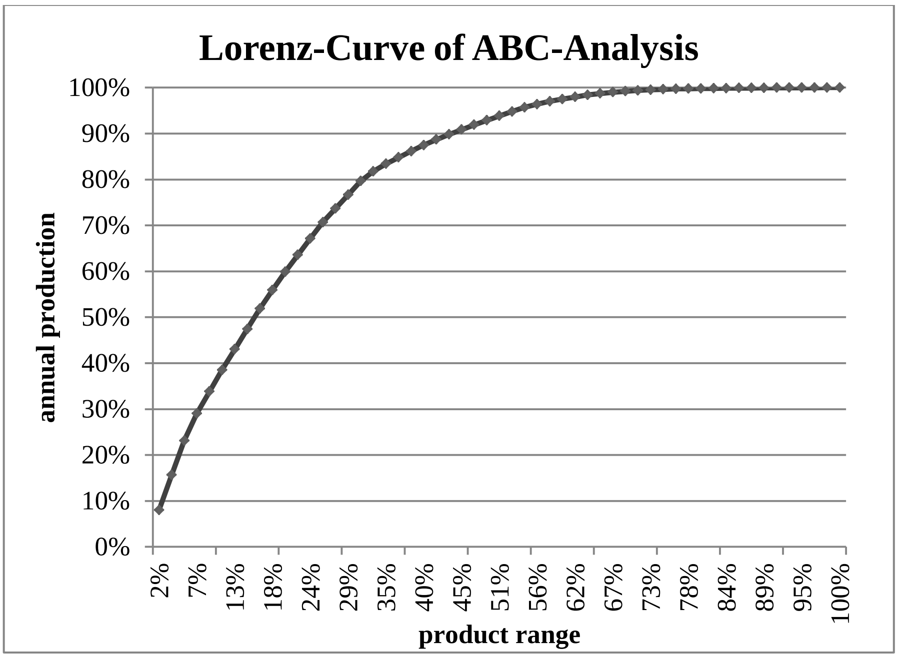


Figure 3.5: Lorenz-Curve of the ABC-Analysis

Would the production load be uniformly distributed over the portfolio, the curve would follow a linear function with a slope of 45°. In the case of the onroad-assembly, the distribution looks much more like an exponential one. That means that the class-“A”-products have a much higher impact on the production volume than the “B”- and “C”-class-products as stated above.

3.1.4.2 Construction Types - Analysis

By analyzing the data of the query and using the 5th digit of the numerical code, explained in chapter 3.1.3, which is representing the type of construction, an evaluation of the production-volume and the number of different models of each construction type is made.

Table 3.4: Construction Type Analysis of the Production

Construction Type Analysis:				
class	**products**	**units**	**% units**	**% products**
Split	21	51.405	37,54%	38,18%
Bleed Adjuster	22	47.510	34,69%	40,00%
EDS	3	17.104	12,49%	5,45%
Cross	6	16.406	11,98%	10,91%
Free	3	4.526	3,30%	5,45%

The first column of Table 3.4 shows that 5 different construction types were produced. The second column displays how many different products of each construction-type-class were produced. In the third column the produced units for each construction-type-class are shown. It is obvious that the types “Split” and “Bleed Adjuster” are the main products in terms of share of the portfolio as well as production volume. These two classes combined were responsible for over 70% of the overall production volume. The variety of the distribution of the single classes is also displayed graphically in Figure 3.6.

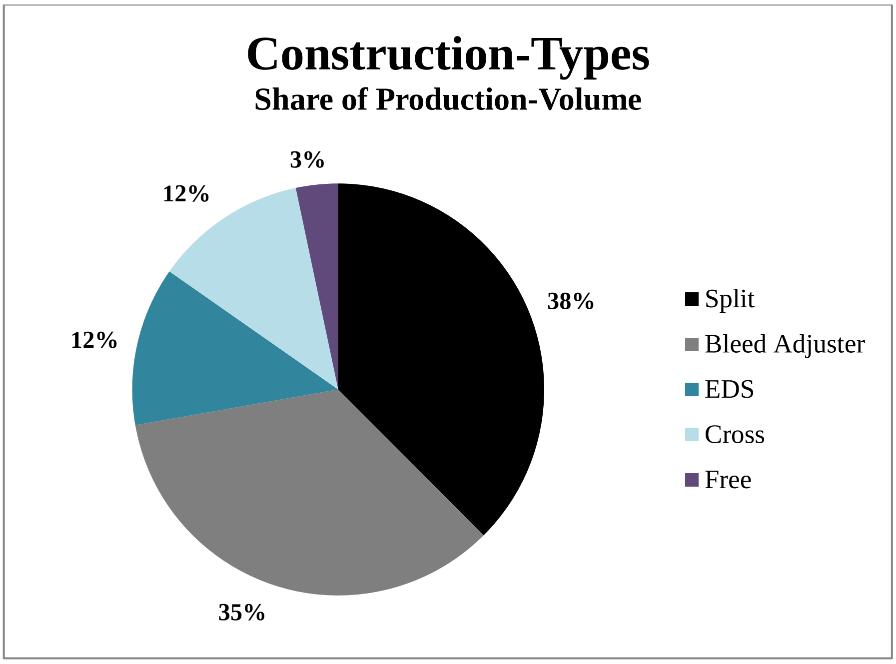


Figure 3.6: Share of Production-Volume for each Construction-Type

3.1.4.3 Customer – Analysis

Another classification of the overall production volume can be made according to the customer of each product. Therefore the data of the ERP-query is also linked to information based in the numerical-product-code (compare 3.1.3). By using the 3rd and 4th digit of the code each product can be matched with one customer. The result of this combination is displayed in Table 3.5: Customer Analysis of the Production

Table 3.5: Customer Analysis of the Production

Customer Analysis:				
class	**products**	**units**	**% units**	**% products**
KTM	31	86.586	63,22%	56,36%
Triumph	6	21.718	15,86%	10,91%
BMW	2	12.772	9,33%	3,64%
CFMOTO	2	5.880	4,29%	3,64%
Husqvarna	7	5.187	3,79%	12,73%
Sherco	4	4.405	3,22%	7,27%
Alta Motors	1	224	0,16%	1,82%
Armstrong/CCM	2	179	0,13%	3,64%

The first column of Table 3.5 shows the different customers, the second column shows the number of different products of each customer and the third column shows the number of produced units per customer. The customer with the biggest yearly demand is clearly KTM, it has a share of over 63% of the overall production volume. The second biggest customers are Triumph with nearly 16% and BMW with nearly 10% of the production volume. Combining these three customers they are responsible for almost 90% of the overall yearly production volume. The other 5 customers combined take only a share of 10%. Figure 3.7 graphically displays the importance of KTM as a costumer well as the small share of the volume for the smallest 5 customers.

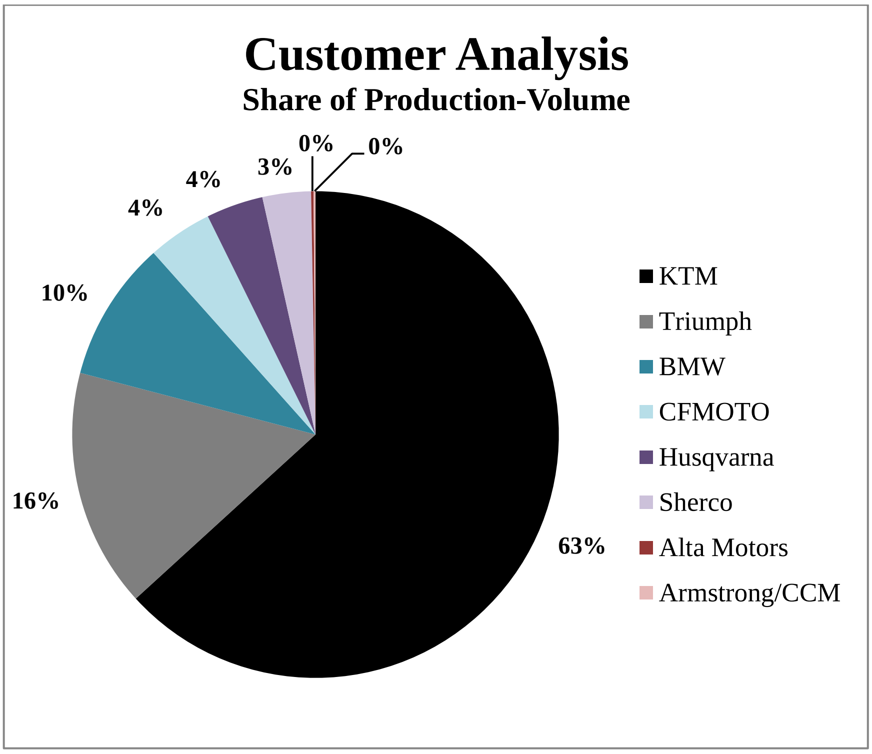


Figure 3.7: Share of Production-Volume of each Customer

3.1.4.4 Assembly-Type - Analysis

Based on the information provided by Mr. Edlinger (Head of Industrial Engineering) and Mr. Höllwarth (Head of Industrial Engineering / Division Suspension), the construction-type, as it is described above, is no sufficient indicator for the type of assembly. Further investigation is therefore needed. The information for the classification after necessary assembly-steps was gained with the help of a workshop with Mr. Edlinger and Mr. Höllwarth at 19th of December 2016.

In the first step all construction elements are defined, which determine the different assembly-types. It was determined that there are six different criteria for the assembly of the onroad-motorbike forks. These criteria are listed in Table 3.6 .

Table 3.6: Assembly Criteria

Assembly Criteria			
Criterion	**Description**	**Variants**	**Code**
Tube-Material	material of the fork-tube	• steel • aluminum	• 1xxxxx • 2xxxxx
Tube-Type	construction type of the tube	• one-piece • three-piece	• x1xxxx • x2xxxx
Bleed-Adjuster	describes if there are bleed-adjusters and where they are located	• no • top • top/bottom • step-motor	• xx1xxx • xx2xxx • xx3xxx • xx4xxx
Spring-Support	location where the spring is supported	• screw cap • hydrostop	• xxx1xx • xxx2xx
Hydrostop-Nut	construction type of the hydrostop-nut	• added • integrated	• xxxx1x • xxxx2x
Piston-Ring	Construction type of the piston-ring	• band • z-ring	• xxxxx1 • xxxxx2

All produced forks are analyzed with regard to these criteria. To figure out how many different variants are produced, a numerical code is implemented. Each digit of this code describes which variant of each criterion is used in the fork. By implementing this code in an Excel-Sheet it is possible to delete all duplicates and so obtain the different assembly- types for all onroad forks.

			Construction							Variants						
goodID	Customer	Type	Tube-Material	Tube-Type	Bleed Adjuster	Spring-Support	Hydrostop-Nut	Pistion Ring	Assembly-Line	TM	TT	BA	SS	HN	PR	Code
05067L01	BMW	Bleed Adjuster	steel	one-piece	no	screwcap	added	band	Onroad	1	1	1	1	1	1	111111
14289O06	Triumph	EDS	steel	one-piece	step motor	hydrostop	added	band	Onroad	1	1	4	2	1	1	114211
14188N22	KTM	Split	steel	one-piece	top	hydrostop	added	band	Onroad	1	1	2	2	1	1	112211

Figure 3.8: Example of the Excel-Sheet for assembly-type-analysis

After eliminating all duplicates of codes, only three different assembly-types remain. These three types combined with two new types which will have Start-of-Production (SOP) in 2017 result in five different assembly-types of onroad-forks for the future.

By combining this information with the query of the ERP-System Table 3.7 is generated. The column “code” contains all unique codes which are generated after the elimination of duplicates. In the second column the different assembly-types are listed. The content of the column “products” is the number of different forks for each assembly-type. In “units” the production amount in the investigated time period for each assembly-type is displayed. The last two columns are the percentage of the overall production volume and the share of the product portfolio for each assembly-type.

Table 3.7: Assembly Type Analysis of the Production

Assembly - Types:					
code	**Type**	**products**	**units**	**% units**	**% products**
112211	steel2-top_bleed	7	29.225	21,34%	12,73%
223121	alu-t/b_bleed	10	27.845	20,33%	18,18%
112121	steel1-top_bleed	4	21.928	16,01%	7,27%
114211	steel2-EDS_bleed	4	17.734	12,95%	7,27%
111111	steel1-no_bleed	3	14.052	10,26%	5,45%
000000	other	27	26.167	19,11%	49,09%

Figure 3.9 shows graphically the share for each assembly-type of the overall production volume. In total there are six different types of forks in terms of assembly. The type “other” can be ignored. Forks of the type “other” are only forks which were planned and assembled on this line because of capacity problems or break-downs on other lines in the past. So this types should normally be assembled on other lines and will no longer be considered in further investigations. The remaining 5 types can further be summarized by 3 main-assembly-types.

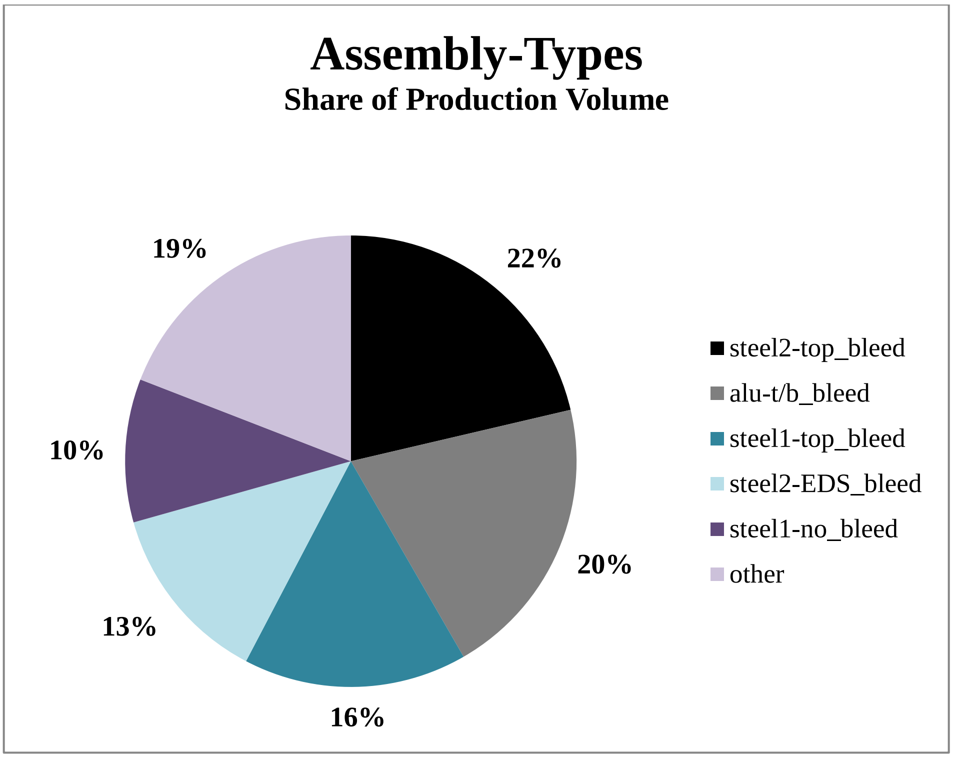


Figure 3.9: Share of Production-Volume for each Assembly-Type

The types “steel2-top_bleed” and “steel2-EDS_bleed” are distinguished only by a single and very short production step. Therefore these two types are grouped in the main-assembly-type “steel2”. That also applies to the types “steel1-top_bleed” and “steel1-no_bleed” so these two types are summarized in the main-assembly-type “steel1” With regard to the information of R&D in 2017 a new fork with two completely different pillars will be implemented. So these two types will also be considered as the two main-assembly-types “air_l” and “air_r”.

After these further summarizations five different main-assembly-types remain. These five types which are listed in Table 3.8 and illustrated in Figure 3.10 will be the focus for all further investigations. The content of Table 3.8 is the name of the remaining main-assembly-types, the number of different products of each single type, their production-volume, their share of the overall production as well as their share of the product- portfolio.

Table 3.8: Main-Assembly-Types

Main-Assembly-Types:				
Type	**products**	**units**	**% units**	**% products**
steel_1	7	35.980	30,96%	23,33%
steel_2	11	46.959	40,41%	36,67%
alu	10	27.845	23,96%	33,33%
air_r	1	2.710	2,33%	3,33%
air_l	1	2.710	2,33%	3,33%

As Figure 3.10 shows, the new assembly-line concept has to be able to handle 5 different types of forks, whereby three of them are responsible for 96% of the overall production volume.

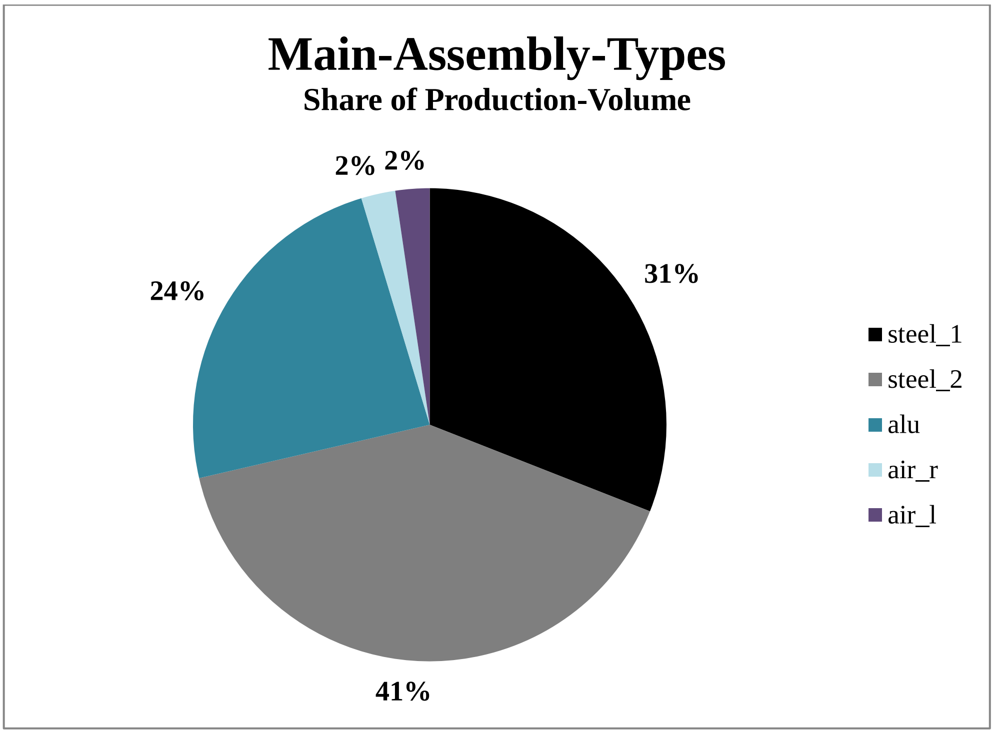


Figure 3.10: Share of Production-Volume for each Main-Assembly-Type

3.2 Process Analysis

After evaluating the different products and their classification, the production process of these products will be investigated. The data for this analysis is gained through the ERP-query in combination with interviews of the supervisor of the Onroad-Fork-Assembly-Line.
The focus of this analysis is again the onroad-assembly-line as it is implemented at the time of research. The system boundaries for the analysis are the first workplace of the assembly line as well as the last workplace of the assembly line. At the beginning, the boundary is the first workplace of the production line and on the end it is the last workplace, the test-bench. Some processes outside of these boundaries will be discussed but they are not the focus of this analysis and of this thesis.

3.2.1 Production Layout

The onroad-fork-assembly-line is located in the production-floor of the suspension-division of WP. Next to onroad-fork, off- and onroad-shocks as well as offroad forks are produced.

Figure 3.11 shows a layout of the suspension shop-floor. Each rectangle represents one production area. All light-grey-areas have no connection to the onroad-fork production. The dark-grey-areas are supplying areas for the onroad-fork-production which is colored blue. The blue-lines are representing the transportation relation between the different areas. The red-arrows are according to the material-flow direction of the onroad-fork-production.

For suspension products, WP does not manufacture any parts itself. All necessary parts a delivered by external vendors. The value-adding-process is the assembly of these parts. Therefore the process flow of an onroad fork starts with receiving delivered parts at the goods-income. Some modules like the setting or the base-tap are pre-assembled and then transferred to the onroad-fork-assembly-line. All other parts are directly delivered to the assembly-line by a warehouse-employee. The assembly-line itself consists of seven single workplaces which are all full manual assembly work places, though some workplaces are equipped with electric screw drivers and one semi-automated workplace where the oil-filling is operated.

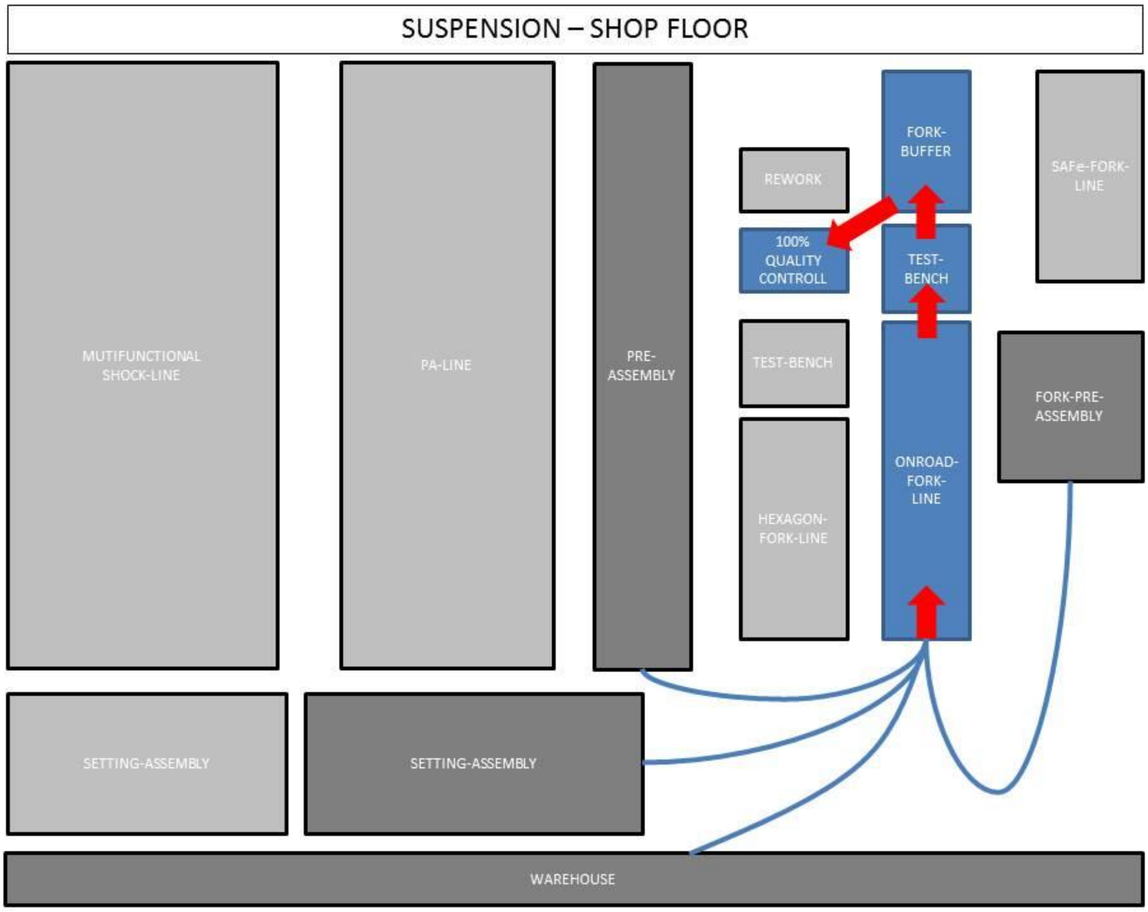


Figure 3.11: Layout of the SUSPENSION-Shop-Floor

Not all products pass through all of these stations, except for the oil filling. The detailed material flow is described in the chapter 3.2.2. After oil-filling the pillars of the fork are transferred to the test-bench where a dynamic and a static load test are done. If the products pass this test they are stored at least for 24h. The storage was implemented to detected possible leakage at the 100% quality check where an employee visually controls the pillars and then packs them into boxes for delivery. The whole production process is illustrated in Figure 3.12.

Figure 3.12: Process-Flow of the onroad-fork-production

3.2.2 Material Flow

As mentioned in chapter 3.2.1, not all products take the exact same path through the assembly line. According to the different necessary work steps, the products pass the line in various ways. In Table 3.9 all workplaces of the assembly-line are listed. The “Code” identifies the workplace of the assembly line. The same “Code” is used in the ERP-system as well as in all further descriptions of the workplaces. The column “Type” describes what kind of work is done at this workplace. “Equipment” describes the type of equipment which is located on the workplace, either assembly with hand-tools or a semi-automated workplace which is set-up and started by an operator but processes autonomously. The column “production area” defines where the workplace is located in the layout.

Table 3.9: Workplaces in the onroad-fork-assembly-line

Workplaces of the Assembly-Line:				
Code	**Type**	**Equipment**	**all products passing**	**Production area**
3GL2-10	Assembly-Workplace	hand-tools	no	Onroad-Assembly-Line
3GL2-20	Assembly-Workplace	hand-tools	no	Onroad-Assembly-Line
3GL2-30	Assembly-Workplace	hand-tools	no	Onroad-Assembly-Line
3GL2-40	Assembly-Workplace	hand-tools	no	Onroad-Assembly-Line
3GL2-50	Assembly-Workplace	hand-tools	no	Onroad-Assembly-Line
3GL2-60	EDS-Check	hand-tools	no	Onroad-Assembly-Line
3GL2-70	Marriage	hand-tools	no	Onroad-Assembly-Line
3GL2-OELB	Oil-Filling	Semi-automated-Workplace	yes	Onroad-Assembly-Line
3GL2-P	Test-Bench	Semi-automated-Workplace	yes	Test-Bench

With data from the ERP-query it is possible to identify which path the different products take through the assembly line. All needed workplaces for every single product are stored in the ERP-system. In combination with the annual production of all products a material-flow-matrix is generated, as it is described in 2.2.2.2. This matrix contains the annual amount of every product seen by every workplace. If the annual amount is zero, this workplace is not used for this specific product. In this special way of a line production without any bidirectional material flow the products are passing the work places in one direction. An example of this material-flow-matrix is shown in Figure 3.13.

	produced units at:								ABC Analysis:					
	3GL2-							3GL-P	annual production	%	cumulative %	share of product range	cumulative SOPR	class
goodID	10	20	30	40	50	60	70							
05067L01	-	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922	7,98%	7,98%	1,82%	1,82%	A
14289O06	10.550	10.550	10.550	10.550	10.550	10.550	10.550	10.550	10.550	7,70%	15,68%	1,82%	3,64%	A
14188N22	10.232	10.232	10.232	10.232	10.232	10.232	10.232	10.232	10.232	7,47%	23,15%	1,82%	5,45%	A
14181P26	4.024	-	-	-	-	8.049	8.049	7.999	8.049	5,88%	29,03%	1,82%	7,27%	A
14188N10	6.570	6.570	6.570	6.570	6.570	6.570	6.570	6.570	6.570	4,80%	33,82%	1,82%	9,09%	A
14188N12	6.450	6.450	6.450	6.450	6.450	6.450	6.450	6.450	6.450	4,71%	38,53%	1,82%	10,91%	A
14187P63	6.136	6.136	6.136	6.136	6.136	6.136	6.136	6.136	6.136	4,48%	43,01%	1,82%	12,73%	A
14187P67	6.052	6.052	6.052	6.052	6.052	6.052	6.052	6.052	6.052	4,42%	47,43%	1,82%	14,55%	A
05288O05	6.040	6.040	6.040	6.040	6.040	6.040	6.040	6.040	6.040	4,41%	51,84%	1,82%	16,36%	A
14181P23	2.793	-	-	-	-	5.586	5.586	5.474	5.586	4,08%	55,92%	1,82%	18,18%	A
05187M05	5.420	5.420	5.420	5.420	5.420	5.420	5.420	5.420	5.420	3,96%	59,88%	1,82%	20,00%	A
14189M24	5.034	5.034	5.034	5.034	5.034	5.034	5.034	5.034	5.034	3,68%	63,56%	1,82%	21,82%	A
05538O02	4.920	4.920	4.920	-	4.920	-	-	4.920	4.920	3,59%	67,15%	1,82%	23,64%	A
14158P12	4.840	4.840	4.840	4.840	4.840	4.840	4.840	4.840	4.840	3,53%	70,68%	1,82%	25,45%	A
07187L04	4.098	4.098	-	4.098	-	4.098	4.098	4.098	4.098	2,99%	73,68%	1,82%	27,27%	A
05188M11	2.730	2.730	2.730	4.095	1.365	2.730	2.730	2.730	4.095	2,99%	76,67%	1,82%	29,09%	A
14188N25	4.068	4.068	4.068	4.068	4.068	4.068	4.068	4.068	4.068	2,97%	79,64%	1,82%	30,91%	A
14527L01	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2,12%	81,75%	1,82%	32,73%	B
14187P69	2.271	2.271	2.271	2.271	2.271	2.271	2.271	2.271	2.271	1,66%	83,41%	1,82%	34,55%	B
05187N42	1.880	1.880	1.880	1.880	1.880	1.880	1.880	1.880	1.880	1,37%	84,78%	1,82%	36,36%	B
07186Q03	90	90	-	90	-	90	1.855	1.730	1.855	1,35%	86,14%	1,82%	38,18%	B
05067L02	-	1.850	1.850	1.850	1.850	1.850	1.850	1.850	1.850	1,35%	87,49%	1,82%	40,00%	B
05288O07	1.638	1.638	1.638	1.638	1.638	1.638	1.638	1.638	1.638	1,20%	88,69%	1,82%	41,82%	B
14289O08	1.520	1.520	1.520	1.520	1.520	1.520	1.520	1.520	1.520	1,11%	89,80%	1,82%	43,64%	B
07181L03	-	1.473	-	1.473	-	1.473	1.473	1.473	1.473	1,08%	90,87%	1,82%	45,45%	B
07186Q02	46	46	-	46	-	46	1.391	1.391	1.391	1,02%	91,89%	1,82%	47,27%	B
05187N40	1.350	1.350	1.350	1.350	1.350	1.350	1.350	1.350	1.350	0,99%	92,87%	1,82%	49,09%	B
14288O06	1.340	1.340	1.340	1.340	1.340	1.340	1.340	1.340	1.340	0,98%	93,85%	1,82%	50,91%	B
05186O08	-	1.280	1.280	1.280	1.280	1.280	-	1.280	1.280	0,93%	94,79%	1,82%	52,73%	B
14187P61	1.243	1.243	1.243	1.243	1.243	1.243	1.243	1.243	1.243	0,91%	95,69%	1,82%	54,55%	C
05538N01	960	960	960	-	960	-	-	960	960	0,70%	96,39%	1,82%	56,36%	C
14527P63	-	-	-	-	-	866	866	866	866	0,63%	97,03%	1,82%	58,18%	C
07181Q01	-	640	-	640	-	640	640	640	640	0,47%	97,49%	1,82%	60,00%	C
05287L04	630	630	630	630	630	630	630	630	630	0,46%	97,95%	1,82%	61,82%	C
07181L01	-	622	-	622	-	622	622	622	622	0,45%	98,41%	1,82%	63,64%	C
14527L04	438	438	438	438	438	438	438	438	438	0,32%	98,73%	1,82%	65,45%	C
14187O03	-	-	-	-	-	378	378	378	378	0,28%	99,00%	1,82%	67,27%	C
14157P08	-	-	-	-	-	297	297	297	297	0,22%	99,22%	1,82%	69,09%	C
14547P08	-	-	-	-	-	224	224	224	224	0,16%	99,38%	1,82%	70,91%	C
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 3.13: Example of the material flow matrix

To visualize the content of the material-flow-matrix graphically the data is used to draw a Sankey-diagram, as it is described in 2.2.2.3. In this diagram the transportation from one workplace to another is symbolized by an arrow. The width of the arrow correlates with the annual amount of units in each class, transported through this path. The transportation paths are divided into the three classes A, B and C. This classification is according to the ABC-analysis in 3.1.4.1. Therefore it is possible to see differences in the material flow of each product class.

Figure 3.14 shows the Sankey-diagram of the onroad-fork-assembly-line. In the middle of each arrow the annual material flow is displayed. The main material flow runs straight through the workstations without bypassing or skipping any workstations. An exception is workstation 3GL2-60 where 15k units of class “A” products and 1k of class “B” products run through. This station is a necessary station for all forks of the construction type “EDS”. This can also be seen in Table 3.4 where the annual production volume of “EDS” forks is listed. The difference of 1k units is caused by rounding-errors of the material-flow-analysis. As Figure 3.14 shows, some products skip some workstations due to less effort being required for their assembly, but these are only small shares of the overall material flow.

A more striking deviation of the main flow can be recognized at workstation 3GL2-70. At this workstation the marriage of two sub-assemblies is performed. The deviation is caused by the fact that some sub-assemblies are not produced at the 3GL2-line, but then are infiltrated to 3GL2-70 for marriage and then continuing the production flow of the ordinary 3GL2-line. These exceptions of the main-material-flow are caused by individual decisions of the foreman of the production-area but are not planned to be performed in that way. Therefore only the main-material-flow will be reconsidered in further investigations.

As is described in 3.2.1, the existing production-architecture is a line-layout with an asynchronous configuration. The Sankey-diagram and the material-flow-analysis point out that this planned layout-strategy fits for producing this special product-portfolio. All necessary work steps are arranged after each other without any back-loop. Only some products are skipping certain work places. This is necessary because of the different effort required for assembly.

In terms of material-flow this skipping is not ideal because of a longer transportation distance for some products but pays off by the multifunctional use of the line. By using only one line for all onroad products the utilization of the line is much higher.

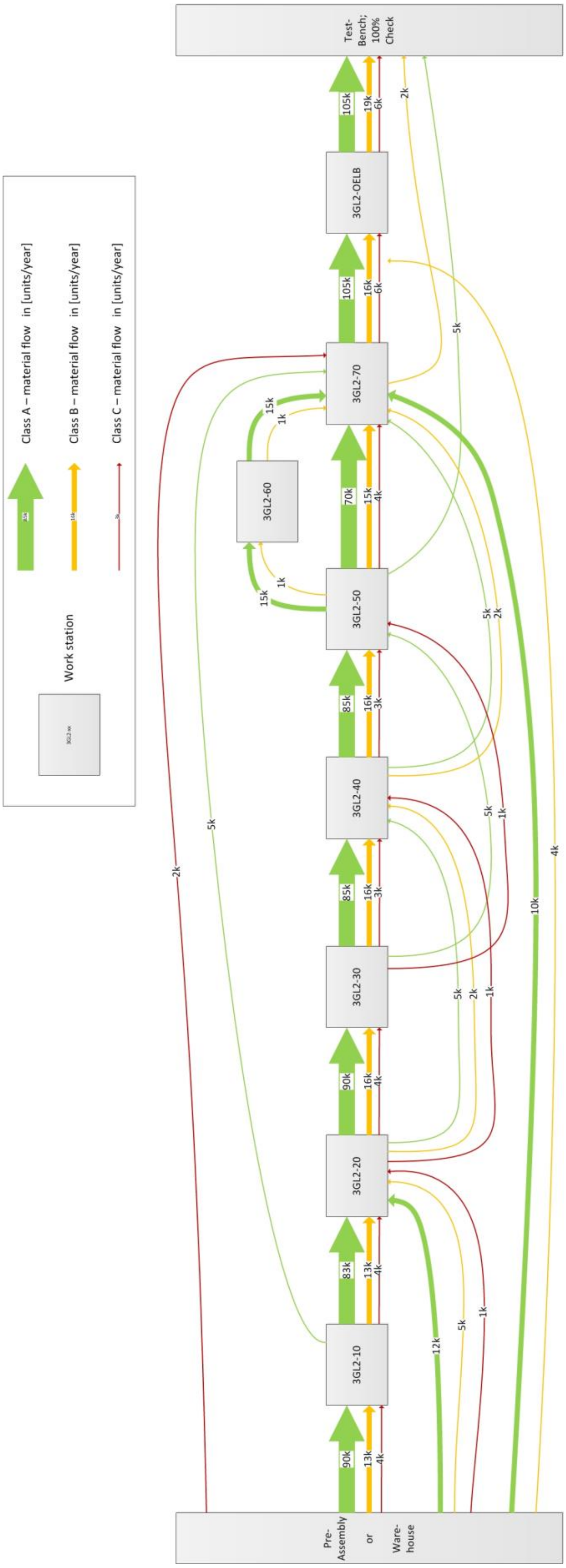


Figure 3.14: Sankey-Diagram of the onroad-fork-assembly-line

3.2.3 Work -Time Analysis

For a proper analysis and benchmarking of the status-quo, in addition to the product and process analysis, knowledge of the actual time for performing each work step is necessary. This data was gained by an external consulting company, which analyzed different products according to the assembly-type analysis in 3.1.4 . The external consulting company chose the MTM-UAS method, as is described in 2.2.3.1, for determining standard times for all work steps.

According to 2.1.3.2 and 2.2.3.2, based on this data it is possible to calculate the cycle- and takt-times and also investigate the system in terms of bottleneck and maximum output. These calculations will further be compared to the simulation of the status-quo-production.

3.2.3.1 Data Acquisition

The actual work times for all workplaces where captured by an MTM-Analysis performed by the consulting company Con-Sens GmbH in November 2016. The MTM-analysis captures three different product types, according to the definition in 3.1.4 -Assembly Types. The data for this analysis was handed in as a printed table including every workplace and the times for performing every single work step. An example of such a table is shown in Figure 3.15 .

3GL2-40

	Anz	Häuf	Sek	Code	Name
1	1	1,00	2,34	AF2	verschraubte Kolbenstange in Schraubvorrichtung platzieren
2	1	1,00	3,06	M-FMA	Bauteil in Vorrichtung verriegeln
3	1	1,00	6,00	REFA	Kolben mit Druckluft heraus + Schraubdeckel kontern
4	1	1,00	1,44	BA3	Verriegelung lösen
5	1	1,00	1,08	PC1	Bauteil aus Schraubvorrichtung herausnehmen
6	1	1,00	1,62	AB2	Bauteil ablegen
Men			15,54		

Figure 3.15: Example of the raw data table of the MTM-Analysis

3.2.3.2 Data Analysis

In the first step, the provided raw data is transformed into an EXCEL®-Sheet. Modeled unto the example of Sequence-of-Events and Demand Flow Technique described in 2.1.3.1, the time data is divided into manual work and time for operating a machine or tool for each work place. Also the cycle times are calculated for labor as well for the machine or tool.

This differentiation is necessary, to show the difference of the machine cycle time and the overall cycle time of the work step. A gap between the overall cycle time of the work step and the machine cycle time would mean, that the utilization of the machine is not optimal due to the idle time of the machine. The scheme how the data is filled in the EXEL®-Sheet is shown in Figure 3.16.

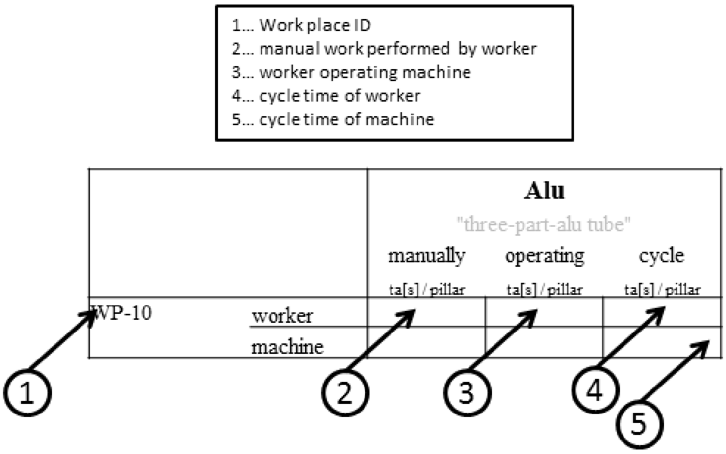


Figure 3.16: Scheme of EXEL®-Sheet for Work-Time-Analysis

The EXEL®-Table like it is shown in Figure 3.17 contains all times for performing manual work steps, operating machines and the cycle times of the machines.

At the work places 3GL2-OELB and 3GL2-PR the cycle time of the machine differs from the time needed to operate the machine. This difference occurs because the worker sets up and starts the machine and then the machine is performing the task autonomously. Thus some work steps are overlapping. In the box at the bottom of Figure 3.17 the work times are summed up in groups of manual work and operating machines. The total workload is the sum of all manual work steps and the cycle times of the machines for each product-class. The overall workload ranges from 182s for the product-class “Alu” to about 152s for the “Steel 2” and “Steel 1”. The difference between the workloads is about 30%. The distributions of the total workload for all assembly-types are displayed in Figure 3.18, Figure 3.19 and Figure 3.20. The share of manual work for the type “Alu” is about 61%. For the types “Steel 1” and “Steel 2” the share of manual work is about 70%.

		MTM-Analysis								
		Alu "three-part-alu tube"			Steel 1 "steel- tube with SS on srewcap"			Steel 2 "steel- tube with SS on hydrostop"		
		manually ta[s] / pillar	operating ta[s] / pillar	cycle ta[s] / pillar	manually ta[s] / pillar	operating ta[s] / pillar	cycle ta[s] / pillar	manually ta[s] / pillar	operating ta[s] / pillar	cycle ta[s] / pillar
3GL2-10	worker	11,70	3,60	15,30	7,02		7,02	13,14	3,60	16,74
	machine			3,60						3,60
3GL2-20	worker	10,80	4,80	15,60	17,64	2,40	20,04	16,74		16,74
	machine			4,80			2,40			
3GL2-30	worker	12,06	4,60	16,66	13,68	4,60	18,28	16,92	5,00	21,92
	machine			4,60			4,60			5,00
3GL2-40	worker	9,54	6,00	15,54	9,54	6,00	15,54	6,48	5,00	11,48
	machine			6,00			6,00			5,00
3GL2-50	worker	24,44	11,40	35,84	12,30		12,30	12,30		12,30
	machine			11,40						
3GL2-60	worker									
	machine									
3GL2-70	worker	20,52	13,51	34,03	17,10	4,80	21,90	10,26	12,00	22,26
	machine			13,51			4,80			12,00
3GL2-OELB	worker	15,48	9,00	24,48	11,52	9,86	21,38	14,46	2,40	16,86
	machine			17,46			14,36			9,30
3GL2-PR	worker	15,66	11,95	27,61	15,78	14,90	30,68	15,66	7,35	23,01
	machine			15,73			14,90			11,13
total workload manually [s]		120,20			104,58			105,96		
total workload operating [s]			64,86	77,10		42,56	47,06		35,35	46,03
total workload [s]				197,30			151,64			151,99

Figure 3.17: EXCEL®-Sheet extract of the Work-Time-Analysis

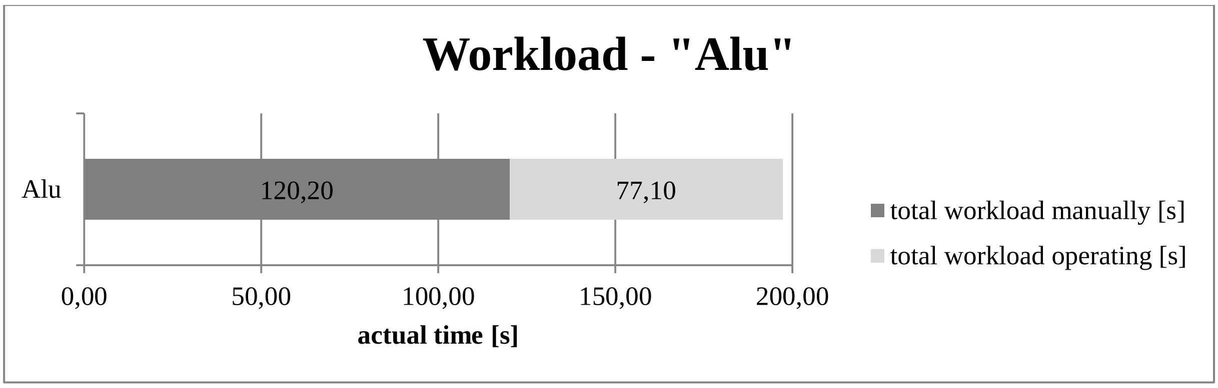


Figure 3.18: Distribution of the total workload of type "Alu"

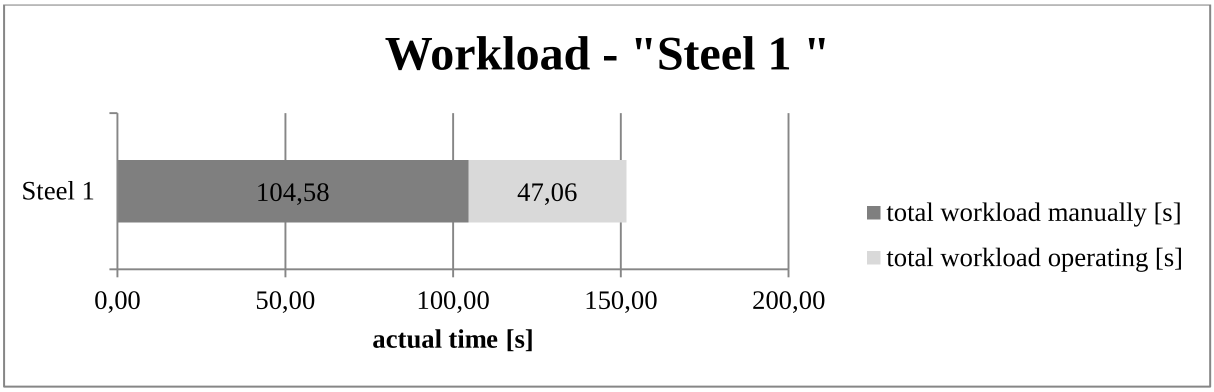


Figure 3.19: Distribution of the total workload of type "Steel 1"

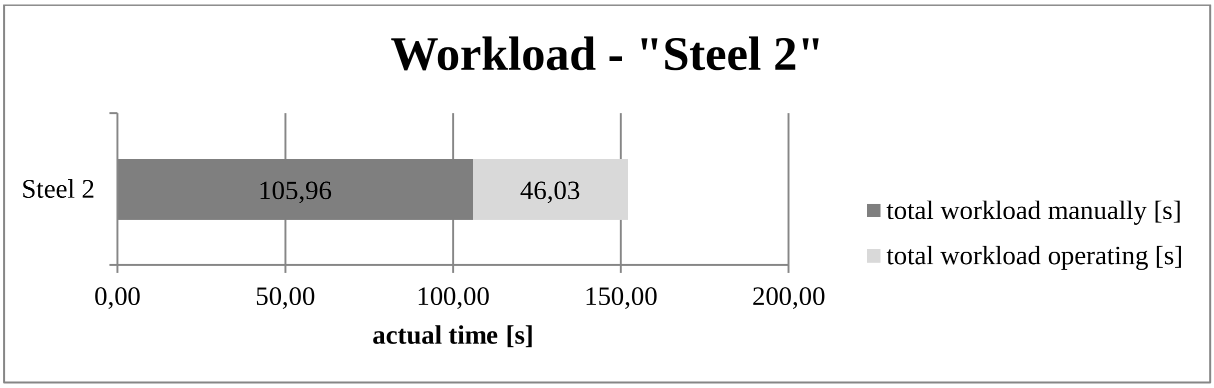


Figure 3.20: Distribution of the total workload of type "Steel 2"

3.2.3.3 Bottleneck Analysis

The maximum throughput is directly linked to the bottleneck cycle time as it is explained in the theory chapter 2.2.3. For the type “Alu” the bottleneck process is work place 3GL2-50 and for “Steel 1” and “Steel 2” the test-bench process at 3GL2-PR is the bottleneck. Next to the actual bottleneck the test-bench cycle-time is crucial because this process is limited by the standards required by the R&D department.

As displayed in the extract of the Excel-Sheet Figure 3.21, the bottleneck cycle time spread between 36s for “Alu”, 31s for “Steel 1” and 23s for “Steel 2”. This means a difference in bottleneck cycle time and therefore maximum theoretical throughput of about 50%. The difference of the bottleneck-cycle-time and the test bench cycle time for the products of type “Alu” is 8,23s or 23%. For the types “Steel 1” and “Steel 2” the bottleneck-cycle-times are the test bench cycle-times.

	MTM-Analysis		
	Alu "three-part-alu tube" cycle ta[s] / pillar	**Steel 1** "steel- tube with SS on srewcap" cycle ta[s] / pillar	**Steel 2** "steel- tube with SS on hydrostop" cycle ta[s] / pillar
Bottleneck cycle time [s]	35,84	30,68	23,01
Test-Bench cycle time [s]	27,61	30,68	23,01

Figure 3.21: EXEL®-Sheet extract of the Bottleneck- and Test-Bench-Cycle-Times

3.2.3.4 Line Balancing

An important factor regarding the utilization of labor as well as machines is the balancing of the assembly line. As explained in 2.2.3 the balance of the different work places of an assembly line is determined by the sum of time-differences of each cycle-time to the bottle-neck-cycle-time. An optimal balanced line would have exact equal cycle-times at every work step. For the line-balancing-analysis all cycle-times are plotted. Figure 3.22, Figure 3.23 and Figure 3.24 show these plots. Every diagram contains all cycle times divided into manual work and operating machines. The test-bench-cycle time is also displayed. The test-bench-cycle-time is important because it is the only cycle-time which cannot be splitted and is limited by the standards asked by the R&D department as mentioned earlier.

The line-balance of all three assembly-types is showing drastic deviations to an optimal balanced line. Especially the work places “3GL2-50” and “3GL2-70” of the type “Alu” stand out. The cycle-time of these two work places is longer than the test-bench-cycle-time. Also the difference to the cycle-times of the first four work places is over 50%. This results in long idle-times for all other work places which can be categorized as waste according to the TPS mentioned in 2.1.2 and should be improved. To classify the balancing of the line the “balance efficiency” (compare Equation 7) and the “balance loss” (compare Equation 8) are calculated in the Excel-Sheet and displayed in Figure 3.25. These calculations are described in the theory chapter 2.2.3.2.

The “balance efficiency” is normally calculated by the total workload divided by the bottle-neck-cycle-time multiplied by the headcount at the line. In this specific case this calculation would not provide a sufficient solution because there are more active workplaces then workers at the line.

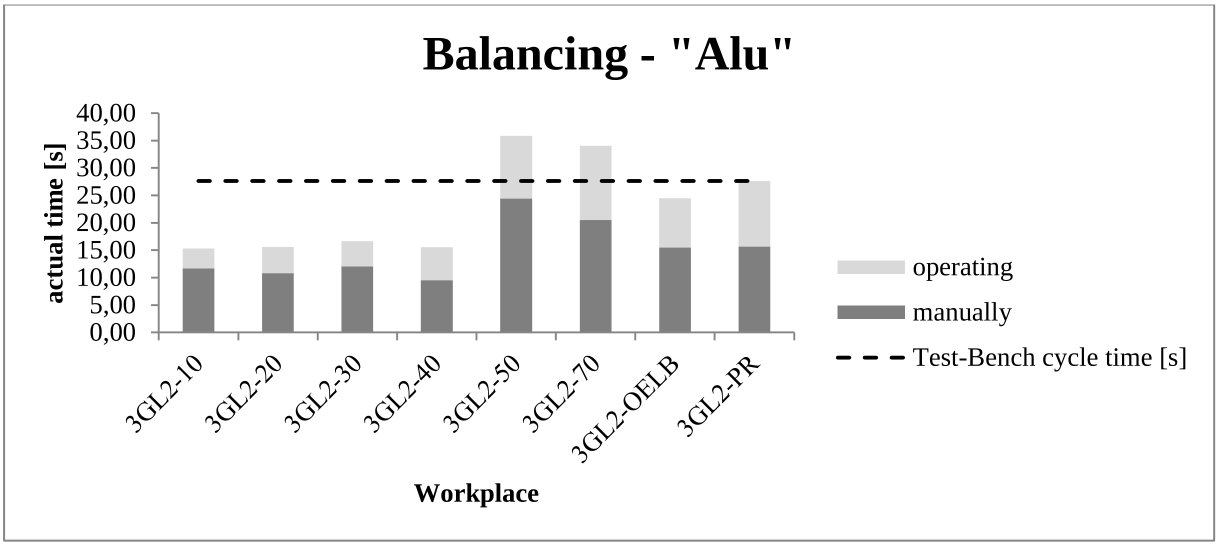


Figure 3.22: Line-Balance of type "Alu"

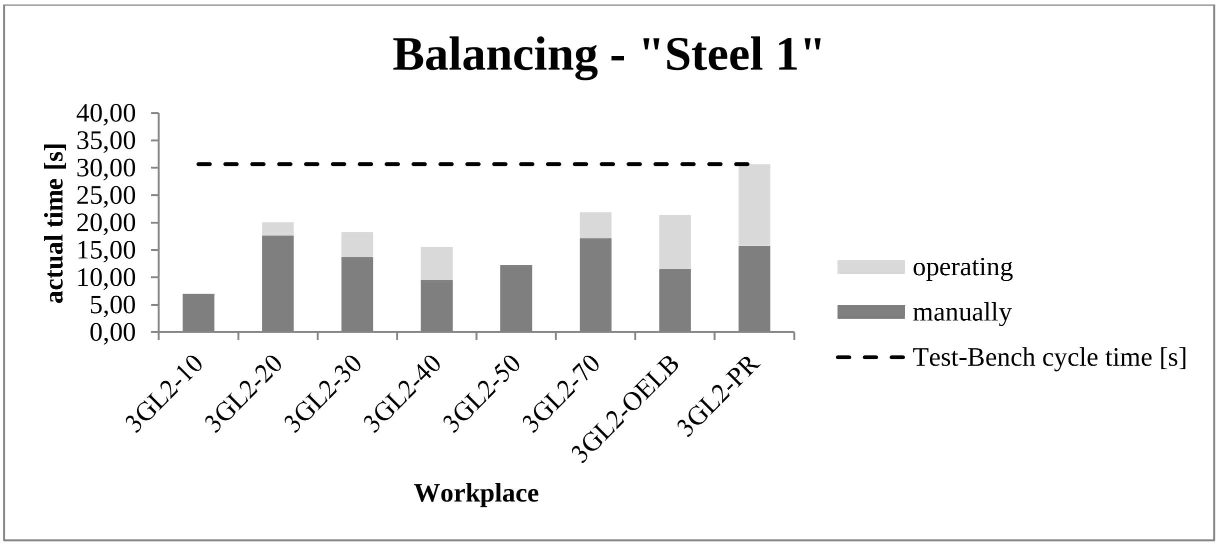


Figure 3.23: Line-Balance of type "Steel 1"

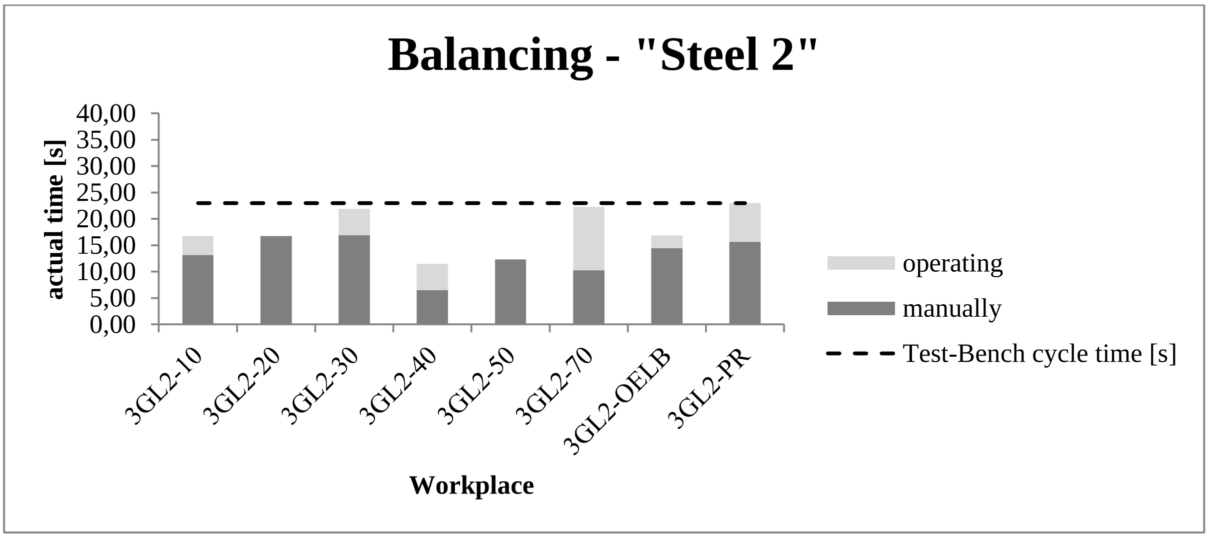


Figure 3.24: Line-Balance of type "Steel 2"

Thus workers are not only working at one work place, they are all allowed to switch between the workplaces to level out the gap between work places and workers at the line. This special labor-strategy is discussed more precisely in 3.3.1. For a correct calculation of the “balance efficiency” and the “balance loss”, not workers but active work places are used in this calculation. The extract of the EXEL®-Sheet shown in Figure 3.25 contains the “balance efficiency” and the “balance loss” of the assembly-line for all three products.

	MTM-Analysis		
	Alu "three-part-alu tube"	**Steel 1** "steel- tube with SS on srewcap"	**Steel 2** "steel- tube with SS on hydrostop"
Headcount	7	7	7
Workplaces active	8	8	8
Banlance efficiency [%]	68,81%	61,78%	82,57%
Balance loss [%]	31,19%	38,22%	17,43%

Figure 3.25: EXEL®-Sheet extract of the Balance efficiency

The most efficient balance of the line occurs by producing the type “Steel 2”. The types “Alu” and “Steel 1” show significant higher “balance loss”. The high value for the “balance loss” means that there is a theoretical potential of optimizing the line in terms of work time and so directly labor-costs up to 38% for “Steel 1” and still over 17% for “Steel 2” products.
The theoretical optimization potential for “Alu” products is about 31%.

It has to be mentioned, that an optimal balancing of the line cannot be realized in practice, because the individual work steps cannot be spitted as needed. A screwing process for instance, has to be finished in one step when it has been started. Nevertheless the potential of balancing will be considered in the evaluation of future concepts.

3.2.3.5 Sequencing

The important gap between theoretical balance efficiency and feasibility of the optimization potential is directly linked to the sequencing of the assembly as mentioned in 2.2.1.3. Every work step has to be analyzed individually if splitting is possible or not. In the first step the sequence of manual operation and processing a machine has to be displayed. Processing times are so important, because they can usually not be split into steps. The different assembly sequences for each product type are displayed in Figure 3.26.

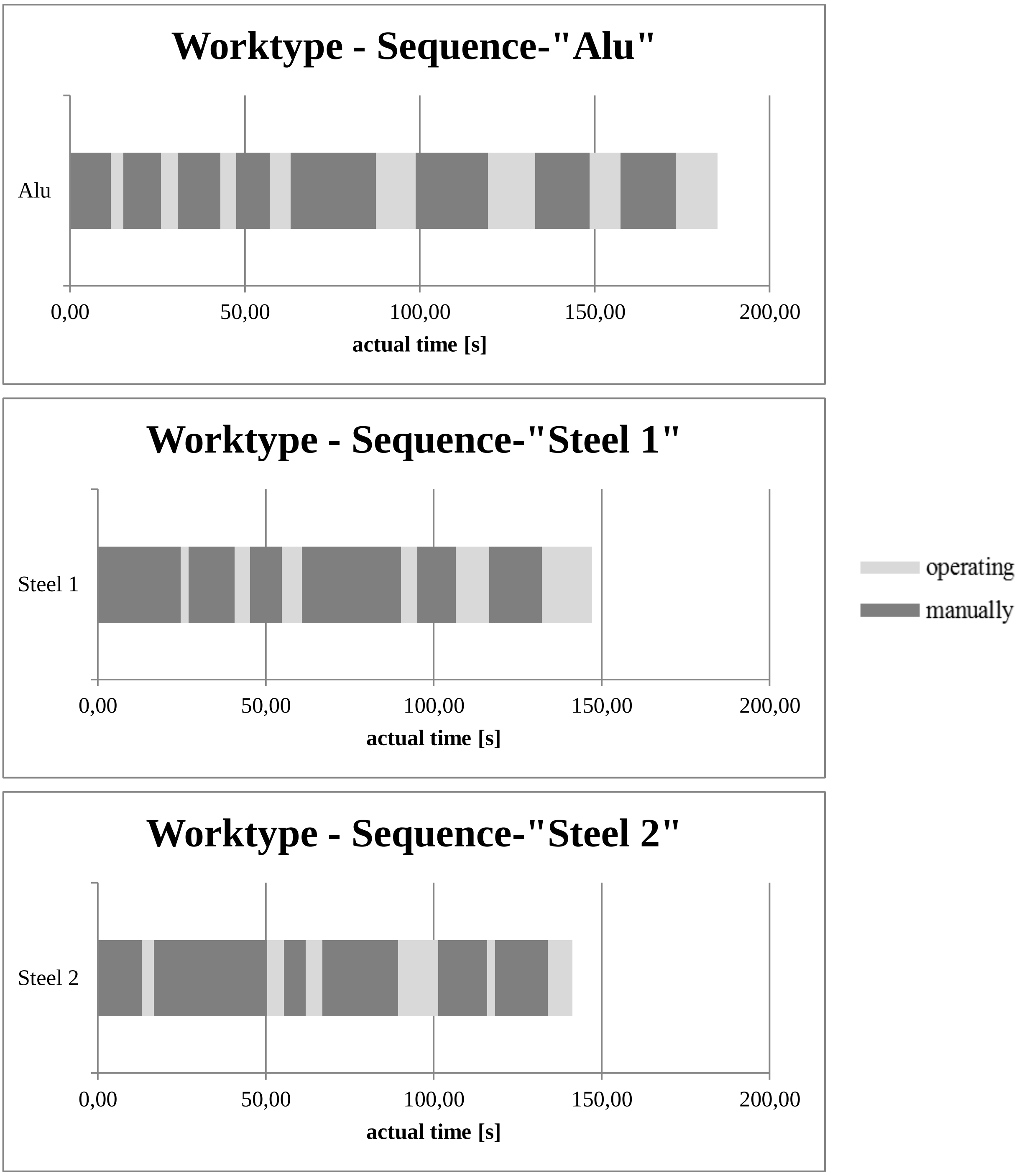


Figure 3.26: Worktype-sequence for all assembly types

As can be seen in the sequence-charts there is a frequent change between operating and manual work steps. This factor makes the balancing of the line more difficult. The impact which a balanced line will have on the performance of the assembly line is explained in 3.6.

3.3 Production Strategy Analysis

In the first step, the production strategy analysis investigates the labor as well as the shift strategy at the onroad assembly line at WP. Combining the data from the labor and shift strategy with the time data gained in 2.2.3, the theoretical possible output is calculated in a second step. This chapter sums up with a comparison of the theoretical possible output with the production reports.

3.3.1 Labor and Shift Strategy

3.3.1.1 Labor

All production areas at WP are managed in the same way as shown in Figure 3.27. In every division the Head of Production is directly reporting to the Board. In the suspension, the Head of Production is supported by the Vice Head of Production who acts as a staff position. There are several supervisors, responsible for single areas in the shop floor such as “pre-assembly” or “multifunctional-shock-line”. These supervisors are reporting the Head of Production and manage a team of workers. All supervisors are responsible for fulfilling the production orders which are planned by the production planning department at time. The supervisors are allowed to shift the staff according to the demand of products. This is necessary because some supervisors are responsible for more than one line or production area which they have to handle with one team.

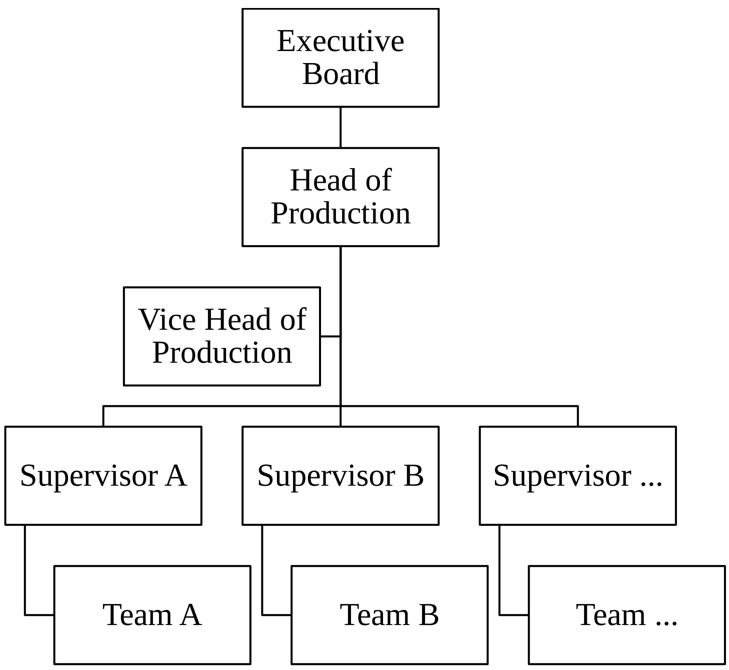


Figure 3.27: Hierarchy of the Production-Management

In the special case of the onroad-fork-line 3GL2, the team shifts between the onroad-fork-line and the hexagon-fork-line. Therefore these two lines are never operated at the same time.

As mentioned in 3.2.3 the line 3GL2 is operated by seven workers even though there are eight active work places. In some cases there are even less workers present at the line. This happens when the full headcount is not available. In this case the workers are jumping through the work places at their own discretions to level out the different workload.
The same team and supervisor operating the hexagon-line where normally five workplaces are active and five workers are at the line. This special operation-strategy is very flexible but does not always utilize the labor efficient. This can also be categorized as waste according to the TPS in 2.1.2. It also leaves a margin of errors in terms of not using the production-system as it was planned and thus does not allow reaching the planned capacity and takt-times of the system. Which impact an insufficient labor strategy on output has, will be discussed in 3.5.5.

3.3.1.2 Shift

The existing production system is planned to produce the required quantities of different products in one single shift. Due to the increasing demand some areas work with a second shift or expand the first shift by some hours. The different time slots for the shifts at the onroad-fork-assembly-line from Monday to Thursday are displayed in Table 3.10 and for Friday in Table 3.11.

Table 3.10: Shift model for Monday-Thursday

Shift model 3GL2-Line for Monday - Thursday:				
Shift	**Time of day**	**Work time [min]**	**Break [min]**	**Effective Work time [min]**
Shift 1	05:45-07:00	75	0	75
	07:00-08:00	60	0	60
	08:00-09:00	60	7	53
	09:00-10:00	60	5	55
	10:00-11:00	60	0	60
	11:00-12:00	60	33	27
	12:00-13:00	60	0	60
	13:00-14:00	60	7	53
	14:00-14:30	30	0	30
SUM Shift 1				473
Shift 1 extension	14:30-15:30	60	7	53
	15:30-16:30	60	7	53
SUM Shift 1 + extension				579

Table 3.11: Shift model for Friday

Shift model 3GL2-Line for Friday:				
Shift	**Time of day**	**Work time [min]**	**Break [min]**	**Effective Work time [min]**
Shift 1	05:45-07:00	75	0	75
	07:00-08:00	60	0	60
	08:00-09:00	60	7	53
	09:00-10:00	60	5	55
	10:00-11:00	60	0	60
	11:00-12:00	60	33	27
SUM Shift 1				330
Shift 1 extension	12:00-13:00	60	7	53
	13:00-14:00	60	7	53
SUM Shift 1 + extension				436

In Table 3.12 the effective work-time-potentials are summarized. As the table shows the first shifts on the days from Monday to Thursday are the same. The shift on Friday is shorter.

Table 3.12: Effective work-time-potential

Effective work-time-potential			
Shift	**per day (Mo-Thu)**	**per day (Fri)**	**per week**
Shift 1	473 min	330 min	2.222 min
Shift 1 + extension	579 min	436 min	2.752 min

The shift model with the extension provides additional 530min for a production week. The supervisor and the Head of Production decide whether the extension is needed or not depending how many orders the production has to fulfill.

3.3.2 Theoretical Performance

In this chapter the theoretical performance of the assembly system is evaluated.
All necessary data is gained as presented in earlier chapters.

Dividing effective work-time-potential by the bottleneck cycle time, leads to the theoretically possible output. Dividing the theoretically possible output per shift by the amount of workers, leads to the output per worker. Table 3.13 shows these output parameters for all possible shift models. The output at a regular shift (Mo-Thu) ranges between 792 and 1233 pillars per shift, depending on the produced product. That means a spread of nearly 56%. It has to mentioned, that the output is measured by produced pillars and not forks as it was the case in the chapters above. For producing one fork, two pillars are necessary. The performance data displayed in Table 3.13 is the benchmark for the comparison with the production report and the simulation of the current state.

Table 3.13: Theoretical Performance of the current assembly line

	Theoretical Performance		
	Alu	**Steel 1**	**Steel 2**
headcount	7	7	7
bottle neck cycle time [s]	35.84	30.68	23.01
output per regular shift on Mo-Thu [#]	792	925	1233
output per regular shift on Fri [#]	552	645	860
output per exten. shift on Mo-Thu [#]	969	1132	1510
output per exten. shift on Fri [#]	730	853	1137
output per worker with regular shift Mo-Thu [#]	113	132	176

output per worker with regular shift Fri [#]	79	92	123
output per worker with exten. shift Mo-Thu [#]	138	162	216
output per worker with exten. shift Fri [#]	104	122	162

3.3.3 Production Report

Caused by the special strategy, mentioned in chapter 3.3.1.1, there is no exact record at which point in time, who many workers were working at the onroad assembly-line. Even when products are booked as finish-product in the ERP-system, there is no guarantee that the line was operated with the full headcount. These circumstances make a reliable statement of the line utilization impossible. This knowledge should be gained in the simulation chapter 3.5.

However there exist some manual records of the onroad-assembly line supervisor. These reports are added into an Excel-sheet and compared to the theoretical performance, explained in chapter 3.3.2. For this comparison only the shifts are chosen where the line was operated with the full headcount. In Table 3.14 the production report data and the theoretical performance are compared.

Table 3.14: Production report vs. theoretical performance

Production Report													
		Alu				Steel 1				Steel 2			
Date	shift	units / shift [#]	theoretical performance [#]	diff. theoretical performance [#]	diff. theoretical performance [%]	units / shift [#]	theoretical performance [#]	diff. theoretical performance [#]	diff. theoretical performance [%]	units / shift [#]	theoretical performance [#]	diff. theoretical performance [#]	diff. theoretical performance [%]
15.09.2015	regular (Mo-Thu)					792	925	-133	-14,4%				
28.10.2015	regular (Mo-Thu)									818	1233	-415	-33,7%
23.11.2015	regular (Mo-Thu)									866	1233	-367	-29,8%
01.12.2015	regular (Mo-Thu)									762	1233	-471	-38,2%
18.02.2016	regular (Mo-Thu)					860	925	-65	-7,0%				
03.02.2016	regular (Mo-Thu)	784	792	-8	-1,0%								

The backlog of the real production compared to the theoretical values is ranging between -1,0% and -38,2% . This difference is caused due to non-value-adding processes which have to be performed but are not represented in the determined work times. Other influence factors are model changes and set-up tasks. These tasks are also not represented in the theoretical performance. WP has the internal agreement of 20% allowance time, which is added to the determined work time.

3.4 Production Planning Analysis

The chapter production-planning-analysis the seasonality of the demand as well as the sizes of the individual production lots will be analyzed. Same as in the chapters above, the needed data is gained by a query of the ERP-system. An important factor for the utilization of the assembly system is the customer takt. Therefore a further analysis should give an overview of the demanded products per month. The inspected time period for all analysis in this chapter is, as it was in the chapters above, August 2015 till July 2016.

3.4.1 Customer Demand

For a Tier-1 supplier it is obvious that the demand of the customer is the most important factor in terms of a production system evaluation. For analyzing the utilization of the production system, the demanded products, categorized in class A-, class B- and class C-products according to chapter 3.1.4.1 are listed over the months. Also the *Dcp* is calculated. This calculation is made according to Equation 1. As it can be seen in Table 3.15, the demand of products ranges between 7.035 units (August 2015) and 18.615 units (March 2016). The *Dcp* (compare Equation 1) ranges between 397 units (January 2016) and 846 units (March 2016).

Table 3.15: Demanded products per month

class	produced units per month:											
	2015					2016						
	8	9	10	11	12	1	2	3	4	5	6	7
A	5.668	8.295	10.504	6.365	8.341	6.648	12.277	17.959	14.074	8.112	6.868	7.506
B	47	3.314	2.435	2.128	1.866	602	1.275	361	905	1.430	1.700	1.575
C	1.320	270	517	311	1.348	297	742	295	624	1.005	669	703
SUM	7.035	11.879	13.456	8.804	11.555	7.547	14.294	18.615	15.603	10.547	9.237	9.784

work-days	11	22	21	21	19	19	21	22	21	18	22	21
Dcp [#]	640	540	641	419	608	397	681	846	743	586	420	466

3.4.2 Seasonal Demand

With the generated data in 3.4.1 it is possibly to plot the demand per month for each product category. This enables detecting possible peaks in the seasonal demand. In this analysis the product portfolio was also categorized into class A-, class B- and class C-products.

Figure 3.28 shows the different demands for each month in the investigated time period. The black bars are representing the demanded class A-products, the dark-grey bars are representing the class B-products and the light-grey bars are representing the demand of class C-products. The overall demand is the sum of all three classes and displayed as line with little asterisks.

A peak of overall demand in March can be detected. This peak is triggered by the higher production rate of the KTM onroad bikes in the spring and caused by a peak of class A-products. It can be also seen, that the demand peaks of class A- and class B-products are not correlating. Class B-products are more demanded in winter as well as in summer. This non-correlation of class A- and class B-products have a smoothing effect on the overall demand.

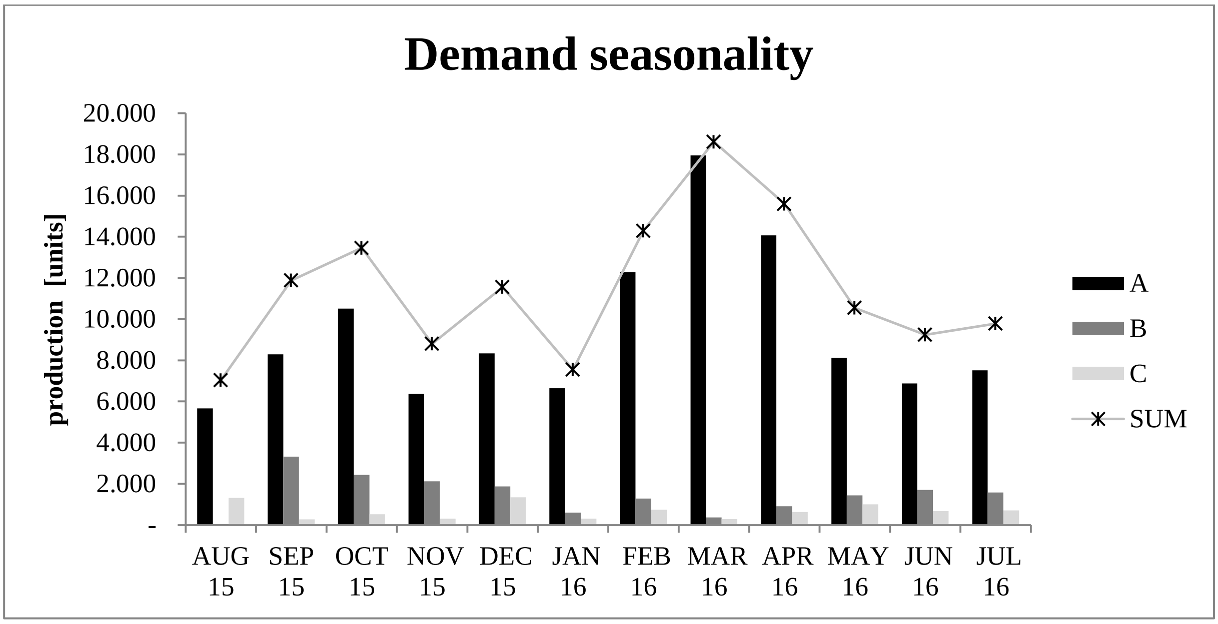


Figure 3.28: Demand seasonality

3.4.3 Lot Size

According to chapter 2.1.2.3 One-piece-flow, the size of the individual lots for fulfilling the production orders have a direct influence on the performance of a production system. Therefore an analysis of the lot-sizes is necessary to rate the efficiency of a production system.

The data for this analysis is gained as in the previous chapters, by a query of the ERP-system. All executed orders and the size of these orders are displayed in Figure 3.29. The mean lot size is the average of all lot sizes in the period. For a better detection of possible trends a moving average with an interval of 10 orders is displayed as well. The mean lot-size of all orders was 296 units per lot. The highest lot-size of an order was 1048 and the smallest lot had a size of 1. Having a look on the moving average strong fluctuations can be seen. By categorizing the different orders according to the ABC-product classification and calculating a mean lot-size per month enables an analysis of the difference of the lot-size related to the product class. The result of this analysis is shown in Figure 3.30.

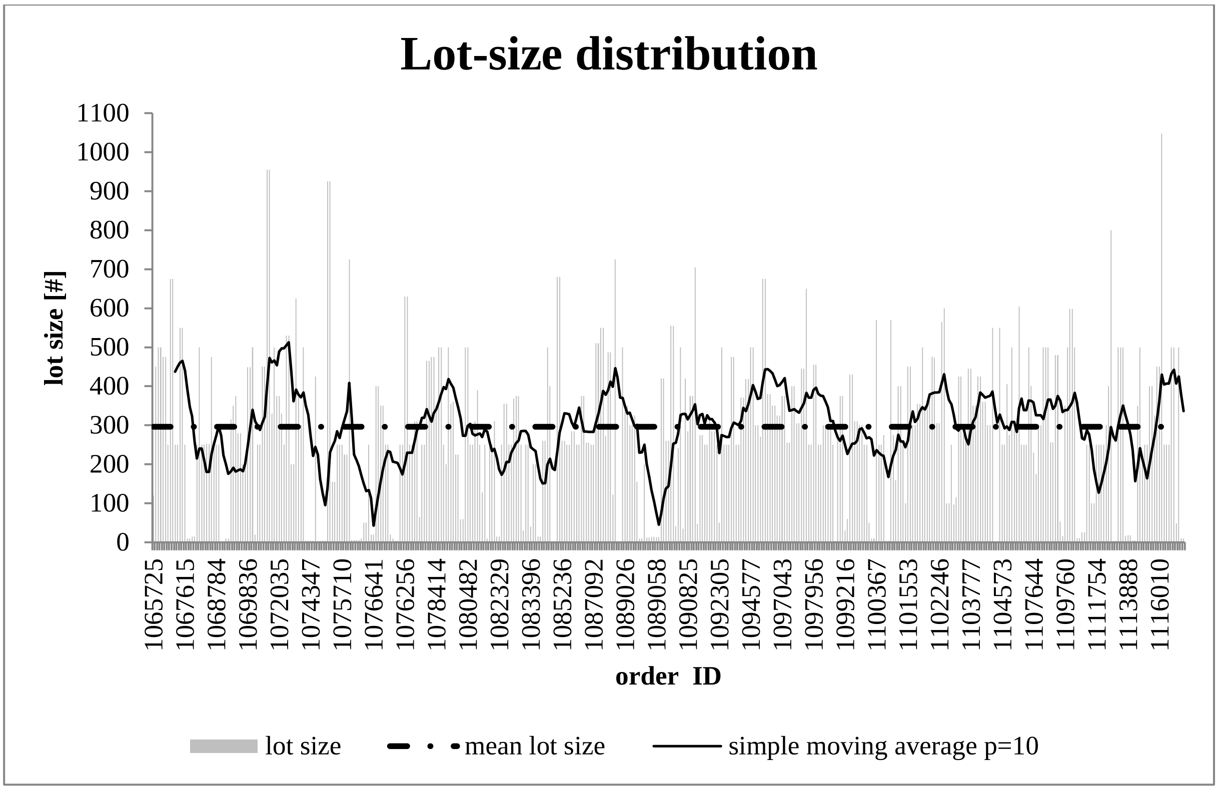


Figure 3.29: Lot size distribution

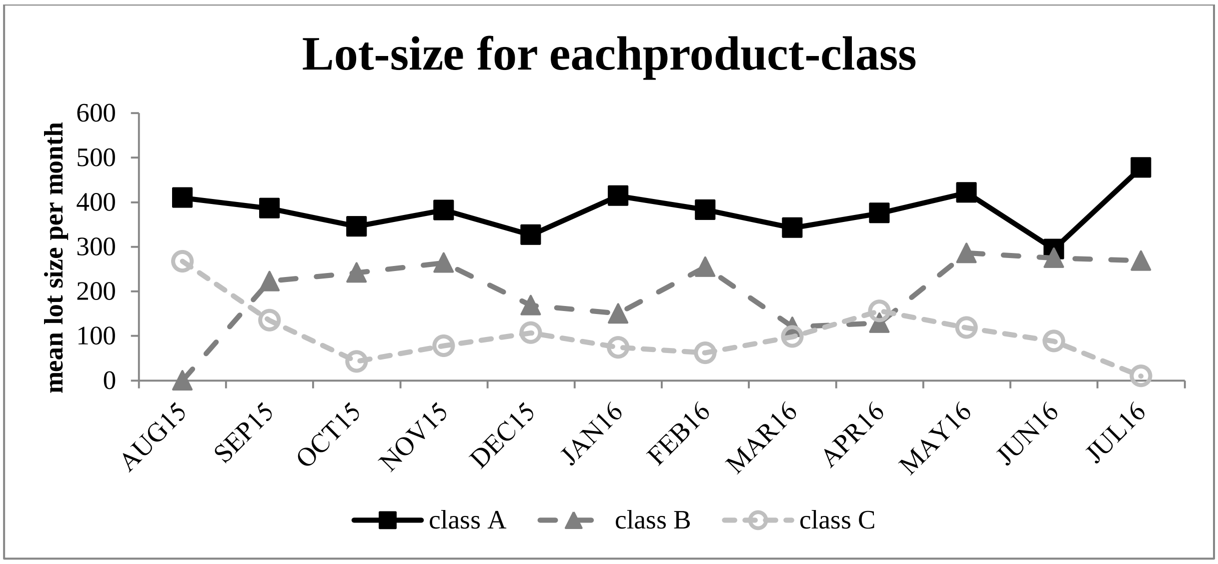


Figure 3.30: Lot-size for each product-class

It can be seen, that the class A-products are produced with a higher lot-size than class B- and class C-products. The mean lot size for class A-products is 372 units, for class B-products 220 units and for class C-products 87 units. All lot-sizes are fluctuating slightly around their mean values. This means, that there is no recognizable strategy in lot-sizing which have further a strong impact on the production system.

3.5 Simulation of the current Production System

Due to the fact, that there is no record when the onroad-assembly-line was operating and when the offroad-assembly line was, no reliable statement of the capacity of the onroad-assembly line can be made. The theoretical performance of the onroad-assembly line is already calculated in chapter 3.3.2. To validate this results and get a reliable statement of the performance of the current production system a computer based simulation is used. According to chapter 2.3.1 for this specific problem a Discrete-Event-Simulation is a standard tool.

The simulation was performed with the software *Teconomatix PlantSimulation®* distributed by *Siemens PLM Inc.* ™. PlantSimulation® is a simulation tool which uses *SIMTALK 2,* an object-oriented programming language. Therefore all models can be implemented object-oriented.

3.5.1 Model

The simulation model is basically oriented on the existing production layout. The general structure of the implemented model is displayed in Figure 3.31. The model exists of six different types of elements, (1) material-flow elements, (2) material-flow objects, (3) workers, (4) databases, (5) methods and (6) event trigger.

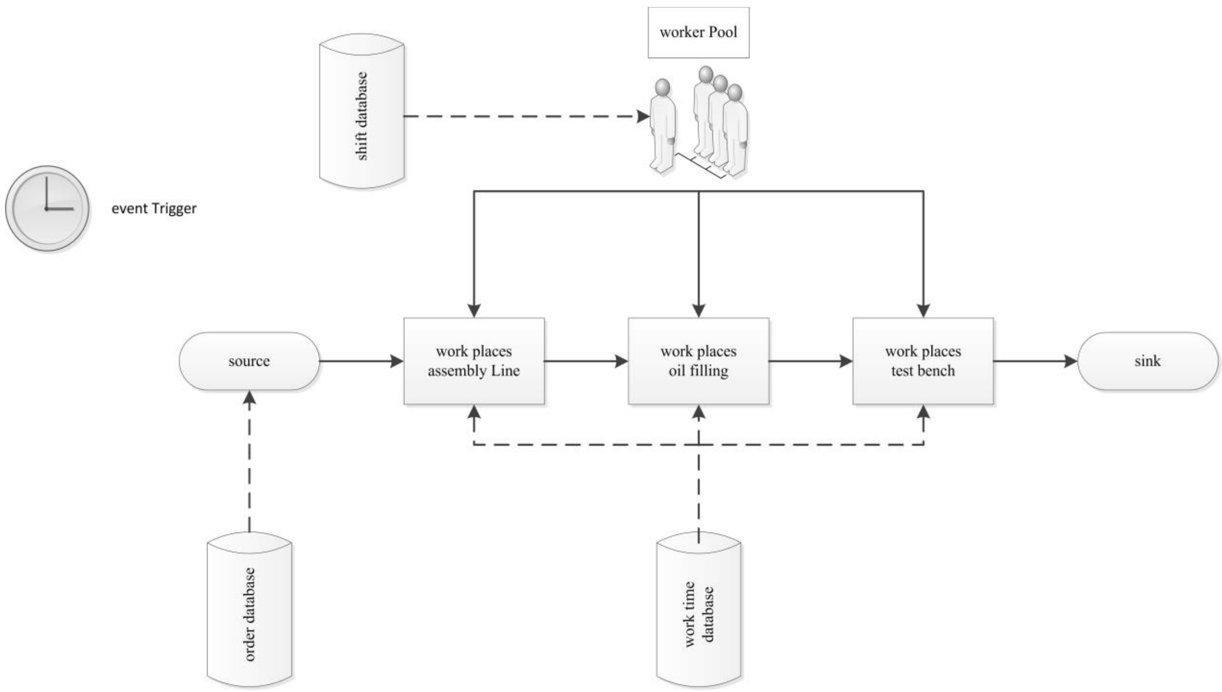


Figure 3.31: Scheme of the simulation-model

Material-flow elements (1) are changing the property of the material-flow objects or providing resources for other material-flow elements. The following material-flow elements are used in the simulation model:

- *Source:* is the element where material-flow objects are generated and enter the system. The source generates material-flow objects according to the information of the order database.

- *Work stations:* are changing the property of material-flow objects in terms of processing them. The time for processing is provided by the work time database. Work stations can require workers. The workers are provided by the worker pool.

- *Buffers:* can store a defined amount of material-flow objects.

- *Worker pool:* is providing workers to the different work stations according to the requested service. The shift database provides the information when workers are on and off-duty.

- *Sink:* is the element where material-flow objects are destroyed and exit the system.

Material-flow objects (2) are representing the products. The different properties of these objects have to be defined before running the simulation. There a three different types of products in the simulation. The types are corresponding to the assembly types, described in chapter 3.1.4.4.

Workers (3) are providing different services. The services of every worker class have to be defined before running the simulation. The worker pool is hosting the individual workers and distributes them according to requests of the work station as well as their availability according to the shift database.

Databases (4) are arrays into different kind of elements can read and write information.

Methods (5) are routines were code is implemented by using the programming language SIMTALK 2. All common conditional statements such as *if-then-else* or *loop-while* can be used.

Methods can be called by any material-flow element and intervene in all elements of the simulation.

The event trigger (6) controls the simulation run. It starts and stops the simulation, collecting statistical data and is hosting the list-of-events.

Based on these elements and the existing work places in the real system, described in chapter 3.2.2, the modelling of the current production system is performed. Due to distinctly different behavior of the system components, all elements have to be programmed and arranged individually to replicate the real system reliable. A screenshot of the front-end of the simulation model is shown in Figure 3.32.

The availability of the equipment is modeled with 98% of the simulation time with a MTTR (mean time to recover) of 05:00 minutes. This availability is defined according to assumptions of the Industrial Engineering department of WP.

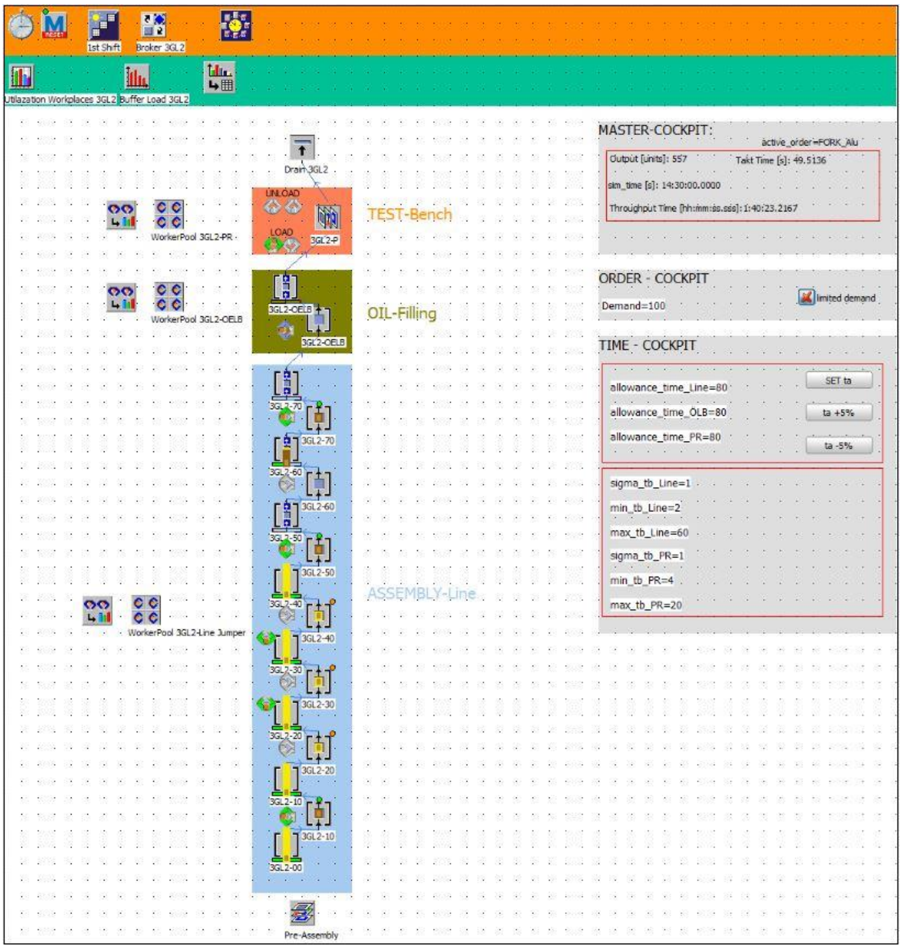


Figure 3.32: Screenshot of the simulation model of the current production system

3.5.2 Data

Basically there are three types of data which are necessary for the simulation in PlantSimulation®:

- *Work time data*: determined by the MTM-UAS analysis, mentioned in chapter 3.2.3. The work times for manual work steps are modelled normal distributed. This assumption is taken in reference to the statistical significance of a determined time with the MTM-UAS method, explained in detail in chapter 2.2.3.1. All work steps performed by a machine are modeled without a distribution.

- *Product data*: determined by the product analysis, mentioned in 3.1.4.4. The simulated products are according to the assembly types: alu, steel_1 and steel_2.

- *Shift data:* determined by the production strategy analysis, mentioned in 3.3.1

3.5.3 Validation

The validation process is performed according to the VDI guideline, described in chapter 2.3.2.5. For validation of the simulation model the graphical visualization is observed. The path of each material-flow is controlled as well if the required workers are provided to the right work stations. The plausibility of the simulation experiments are controlled by comparing the results with the theoretical performance of the current system, mentioned in 3.3.2.

3.5.4 Experiments

For evaluating the performance of the modeled system, simulation-runs have to be performed and analyzed. All values which cannot be evaluated due to a lack of information a varied in different simulation runs. By adjusting these variables the impact of them on the performance can be detected. For this specific benchmark-test seven different variables are varied:

- *capa buffer-line:* represents the maximum capacity of material-flow objects for all buffers between work place 3GL2-10 and 3GL2-70

- *capa buffer-special:* represents the maximum capacity of material-flow objects for all buffers between work place 3GL2-70 and 3GL2-PR

- *worker efficiency-line:* represents the efficiency of all workers, who are demanded by work place 3GL2-10 to 3GL2-70.

- *worker efficiency-oil:* represents the efficiency of the worker, who is demanded by work place 3GL2-OELB.

- *worker efficiency-test:* represents the efficiency of the worker, who is demanded by work place 3GL2-P.

- *sigma tw-line:* represents the standard deviation of all performed manual work steps on work place 3GL2-10 to 3GL2-70.

- *sigma tw-test:* represents the standard deviation of the performed manual work step on work place 3GL2-P.

These variables are varied in four experiments. Table 3.16 shows the different values of each variable in each distinct experiment. Due to stochastic elements in the model as the work time of manual workplaces and the equipment availability each experiment has to be run for 10 times do guarantee a statistical signification of all experiments of $\geq 95\%$.

Table 3.16: Variables for the simulation-run of the current production system

Variables for the simulation							
experiment	**variables**						
	capa buffer-line [#]	**capa buffer-special** [#]	**worker efficiency line** [%]	**worker efficiency oil** [%]	**worker efficiency test** [%]	**sigma tw line** [s]	**sigma tw test** [s]
1	10	10	100	100	100	1	1
2	20	20	100	100	100	1	1
3	10	10	80	80	80	1	1
4	20	20	80	80	80	1	1

All experiments are performed with each type of product. That means four experiments for assembly type alu, four experiments for assembly type steel_1 and four experiments for assembly type _steel_1. For all experiments a regular work shift from Monday – Thursday with an effective work-time-potential of 473 min is chosen. The individual shift models are explained in detail in chapter 3.3.1.2.

3.5.5 Result

For evaluating the performance of the current production system, different result parameters are defined. These parameters are:

- *output per shift:* represents the mean value of the produced units, calculated on all simulation-runs for each experiments

- *takt-time:* represents the mean time-period between two units exit the system, calculated on all simulation-runs for each experiments

- *throughput-time:* represents the mean time-period between entering and exit the system for one distinct unit, calculated on all simulation-runs for each experiments

The values for each of this parameter are listed in three tables: Table 6.1, Table 6.2 and Table 6.3. In Figure 3.33, Figure 3.34 and Figure 3.35 diagrams for all result parameters and experiments are displayed. In this figures the mean value as well as the variations for all experiments can be seen.

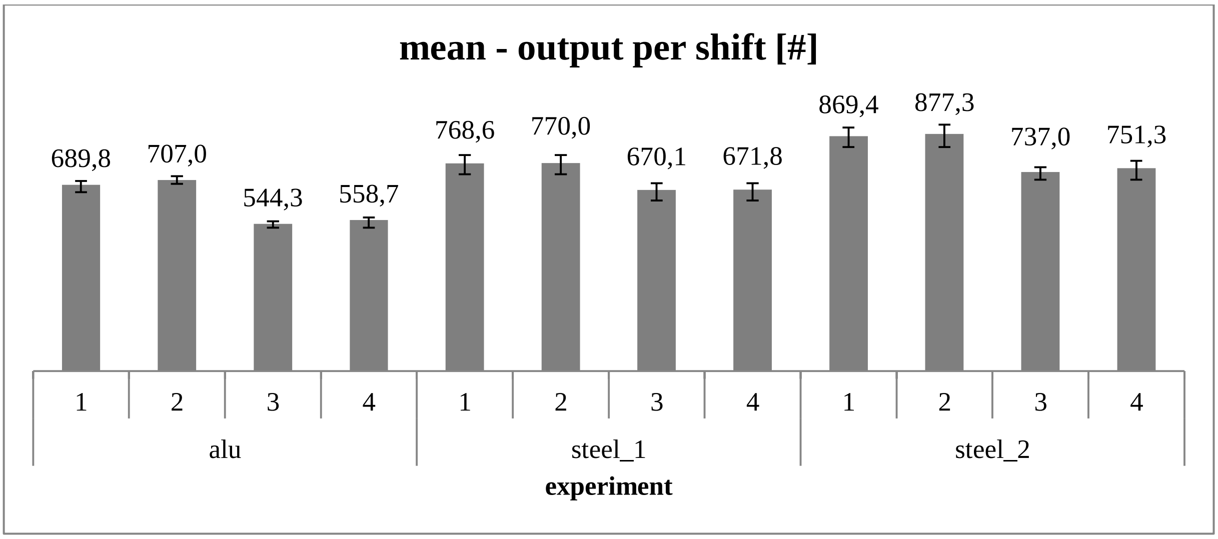


Figure 3.33: Result-diagram of the simulation: output per shift

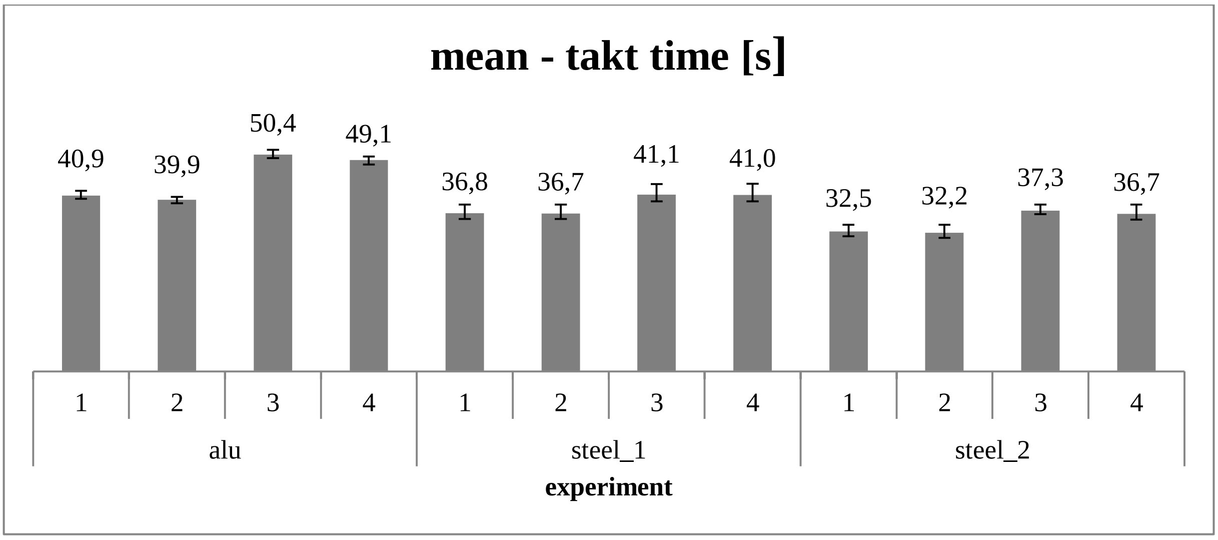


Figure 3.34: Result-diagram of the simulation: takt time

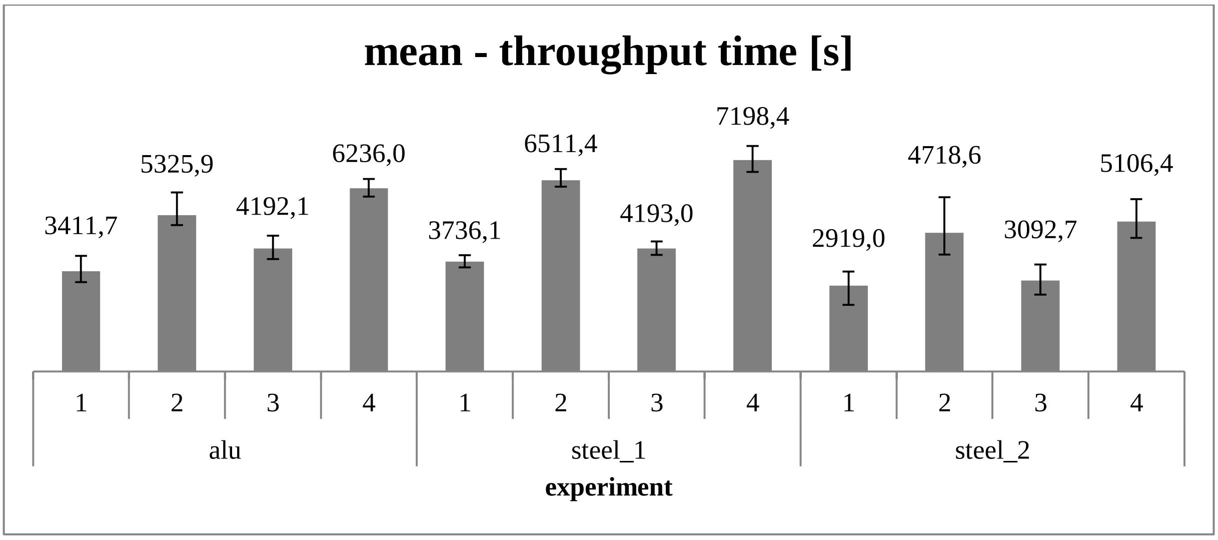


Figure 3.35: Result-diagram of the simulation: throughput time

The results are showing a slight increase of the output per shift when the buffer size is increased. The takt-time slightly decreases due to the causal connection of takt time and output. Important to mention is the much bigger increase of the throughput-time when increasing the buffer capacity. Also the variety increases when increasing the buffers. The correlation of worker efficiency and the output performance is obvious. Less efficient workers yield to less output. Therefore the direct impact of the worker performance is visible.

To compare the simulation results with the actual production, the result parameter “output per shift” is taken. In Table 3.17 the different values gained by the theoretical calculation, the production report and the simulation are displayed. Table 3.18 shows the proportional difference between the reported output and the simulation result.

Table 3.17: Benchmark of the output per shift

Benchmark				
output per shift				
	regular shift (Mo-Thu)			
Assembly Type	Theoretical [#]	Report mean [#]	Simulation Experiment 1-2 mean [#]	Simulation Experiment 3-4 mean [#]
Alu	792	784	698	551,5
Steel 1	925	826	770	671
Steel 2	1233	815	873	744,15

Table 3.18: Benchmark comparison

Benchmark comparison			
SIM Exp. 1-2 vs. Report			
	Alu	Steel 1	Steel 2
Alu	89%		
Steel 1		93%	
Steel 2			107%

Benchmark comparison			
SIM Exp. 4-3 vs. Report			
	Alu	Steel 1	Steel 2
Alu	70%		
Steel 1		81%	
Steel 2			91%

The difference between the report and the simulation ranges between -11% and +7% for experiment 1 and 2, for the experiment 3 and 4 the deviation ranges between -30% and -9%. Therefore it can be assumed, that the true efficiency of the workers is accounting close to 100%.

3.6 Summary of the Status-Quo Analysis

At first glance, it looks like that the capacity of the production system is high enough even if there is an increase in demand. As mentioned in 3.3.1 the available labor for the onroad assembly line also has to work on the offroad assembly line. One of both lines was operated at any time, in the investigated time slot. An increase in production at the onroad assembly line would yield to a backlog at the offroad assembly line. Therefore a concept to increase production output at the onroad assembly line has to be found.

High lot-sizes are reducing the setup-time and therefore setup-costs but leading to high inventory and throughput-times. Long throughput-times have also an impact at transportation-effort and waiting-time. According to the Toyota Production System Theory, explained in chapter 2.1.2, high inventory, throughput-time and waiting-time are muda and should be eliminated.

The unclear buffer size strategy has an impact at the overall performance of the production system. As mentioned in results of the simulation 3.5.5, an increasing buffer capacity results in a much higher throughput-time and effecting only slight improvements on the output. According to the Lean production philosophy, mentioned in 2.1.2.1, the buffer size should be as small as possible or even one.

The strong correlation of worker efficiency and performance parameters detects, that the production system is strongly depending on the worker performance. This seems obvious, because all tasks are performed manually or requiring an operator. There are no fully automated tasks implemented yet. The true efficiency of the workers seems to account close to 100%, as it is shown in 3.5.5. This means, that the existing production system, in combination with the actual production management strategy is operated close to maximal utilization.

In terms of material-flow, the current arrangement as assembly line seems to fit well for the specific tasks. The Sankey diagram, displayed in chapter 3.2.2 shows a direct material-flow from one station to another with only some exceptions.

According to the “pull”- principle in the Lean production philosophy, chapter 0, the arrangement as a line enables a continuous flow of the products. This kind of arrangement should be kept also in future concepts.

3.7 Requirements for the future system

The requirements for the future system are mainly influenced by the forecasted increase in demand. As mentioned in chapter 1.2 the increase in demand is forecasted to the most part in the segment of onroad motorbikes. In rough figures this means, the onroad-assembly line has to be capable to produce additional 50.000 forks or 100.000 pillars a year. In consultation with Mr. Dipl.Ing (FH) Harald Edlinger (Head of Industrial Engineering) the target for the future production system is, to operate both, the onroad- as well as the offroad-assembly line simultaneously with a *Dcp* (compare Equation 1) of ~900 units /day at the onroad-fork-assembly line. The buffer sizes between each work place are limited to 15 units. This limitation is set according to the TPS-philosophy of holding the inventory as low as possible as it is described in 2.1.2. Furthermore, the future system should be evaluated in terms of investment cost and variable costs for operating the system. The actual headcount is five workers for the offroad assembly line and seven for the onroad assembly line.

3.8 Concepts for Future System

To meet the requirements of the future system mainly two approaches are investigated. The first approach is, to use the existing system and handle the increasing demand with extension of the headcount and improving the line balance. The second approach is to handle the increasing demand with a semi-automated assembly system. How the technical implementation of such a semi-automated assembly system could look like, was defined in several workshops with the Industrial Engineering-Automation department and is further explained in 3.8.3 and 0.

3.8.1 Concept 1: Extension of Headcount

The first concept for fulfilling the requirements of the future system is a headcount increase of the team responsible for the onroad assembly line and the offroad-assembly line. This increase would enable to operate both lines in parallel. The demand of labor for this concept results in total 12 workers on the lines. This means an increase in headcount of five workers. For production workers a mean hourly wage of 38,5 € is calculated and 221 workdays per year are assumed.

The Dcp for this concept is identical with the benchmark analysis in 3.5.5. The investment costs for this concept would be zero but according to the average wage four additional workers would mean an annual increase in labor costs of about 327 578 €.

3.8.2 Concept 2: Line Balancing

The second approach for fulfilling the requirements of the future state is to balance the work content on the existing line in order to increase productivity. The approach of line balancing is described in detail in 2.2.3.2.

For balance the assembly line the existing time data of the MTM-UAS of each manual work station are summarized and then divided by the amount of workstations. The work places 3GL2_OELB and 3GL2_P are not balanced, because at these work places machines with fixed cycle times are operated. This means an optimal line balance for the manual work steps, regardless if the leveling in this manner would be technically feasible.

To proof the potential of such an approach a further simulation is used. The model of this simulation is exactly the same as it is described in 3.5.1. All parameters are set equal to the model of the existing system, except of the work times. The work times for the simulation run are displayed in the chapter additional information, Table 6.4.

The investment cost for this concept are also zero, the increase of labor is depending on the labor strategy. Therefore two different labor strategies are simulated. The first strategy is the same as described in 3.3.1.1, all workers on the line are allowed to switch work places as they assume to be optimal. The second strategy does not allow such work place switching. That means every worker works on a distinct work place. Therefore either five or six additional workers are required for this concept. The additional annual labor costs for five workers are 327 578 € and for six workers the additional annual labor costs are 393 093 €.

3.8.3 Concept 3: Semi-Automated Production Line Stage 1

At concept 3 a completely different approach to meet the requirements of the future stage is taken. The production system is changed from a fully manual assembly line to an assembly line with semi-automated workplaces. The Industrial Engineering department has developed in 2012 a machine called *Hexagon* in order to automate some work steps of the offroad assembly line. The idea now is, to adopt the functionality of these machines in a way that they can be used for automating work steps at the onroad assembly line as well.

In several workshops the technical feasibility of adopting these machines for tasks at the onroad assembly line was proofed and the new sequence of assembly at the onroad line was determined.

The new developed production system is realized with 3 main workplaces, one additional intermediate workplace and the test bench. In total required labor for operating these line is four employees. The basic set up of this concept is displayed in Figure 3.36.

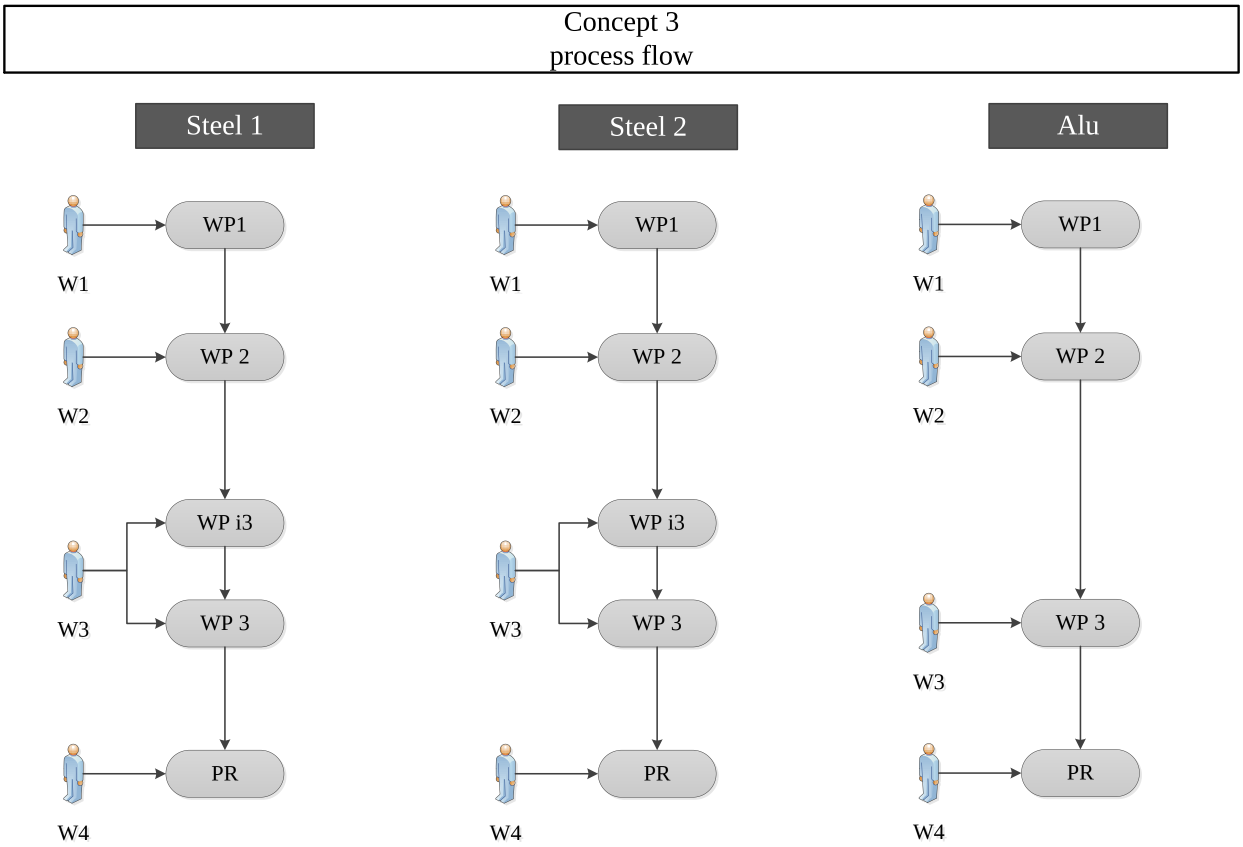


Figure 3.36: Process flow of concept 3

The work places WP1, WP2, WPi3 and WP3 are replacing the workplaces 3GL2-10 to 3GL2-OELB of the existing system. The test bench TB is the same as 3GL2-PR in the existing system. All performed tasks as well as the sequence of these tasks are described in detail in Figure 3.37, Figure 3.38, Figure 3.39, Figure 3.40, Figure 3.41 and Figure 3.42.

The work times for these tasks are gained by summation of the sub work steps. The raw data for the sub work steps are gained by the MTM-UAS analysis, described in chapter 3.2.3, as well as by assumptions made in the workshops with the Industrial Engineering team.

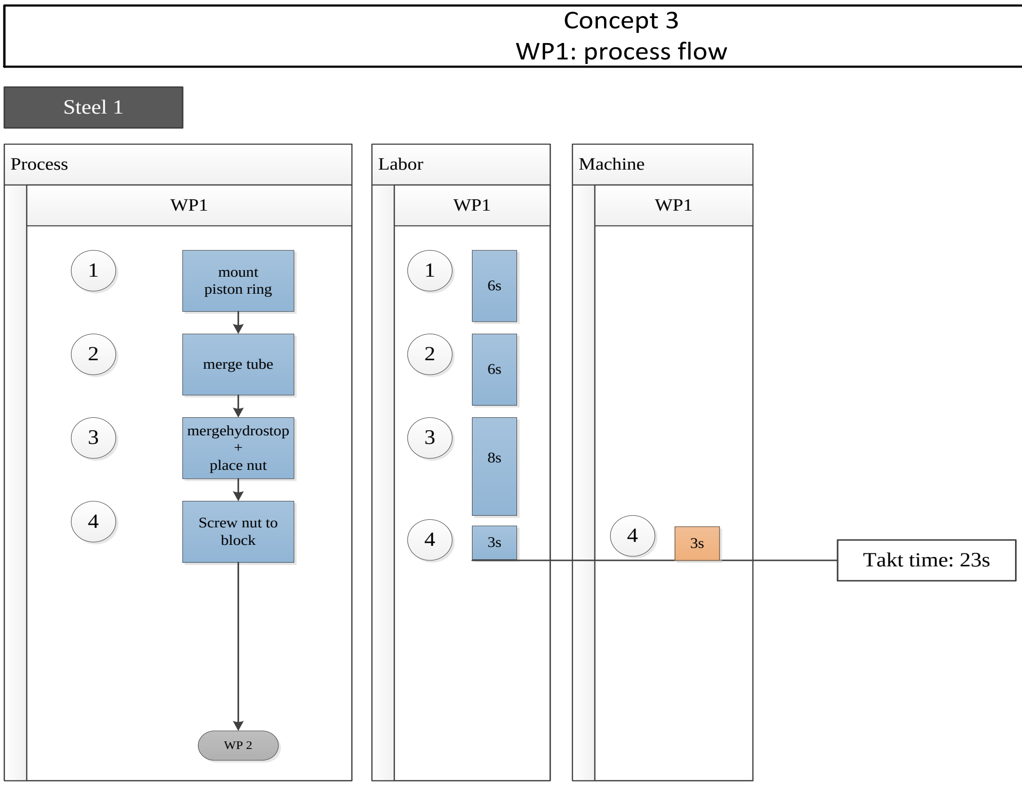


Figure 3.37: C3-process flow of WP1 / Steel 1

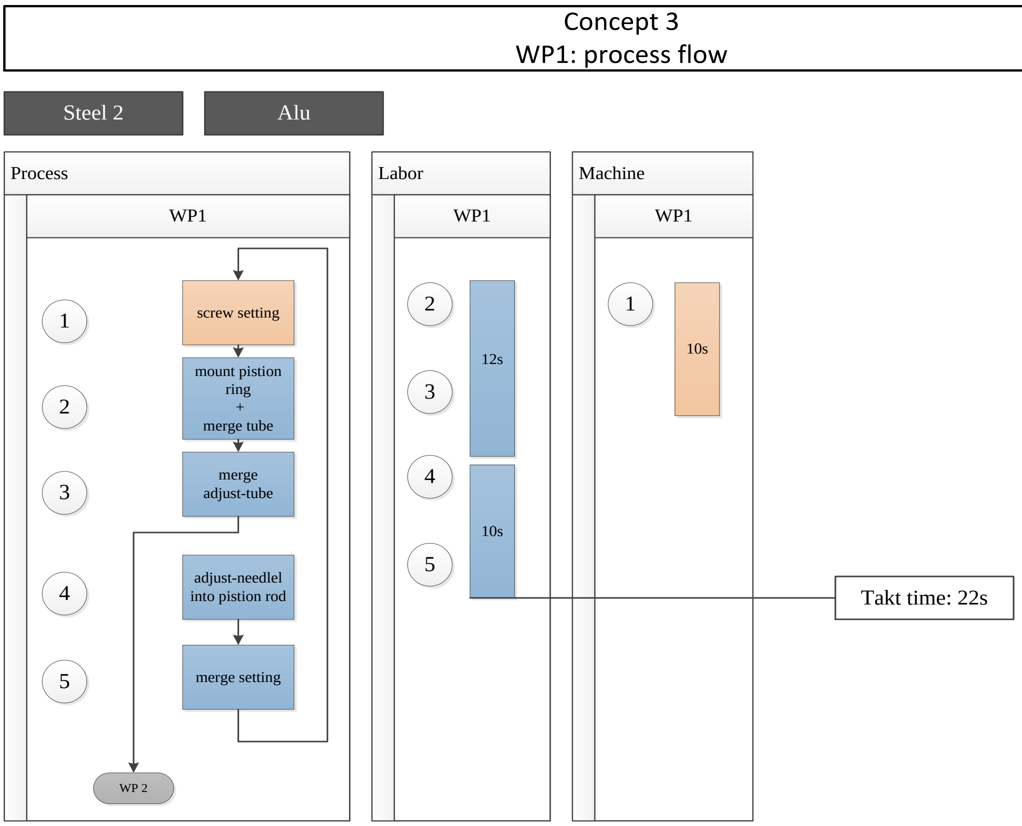


Figure 3.38: C3-process flow of WP1/ Steel2 and Alu

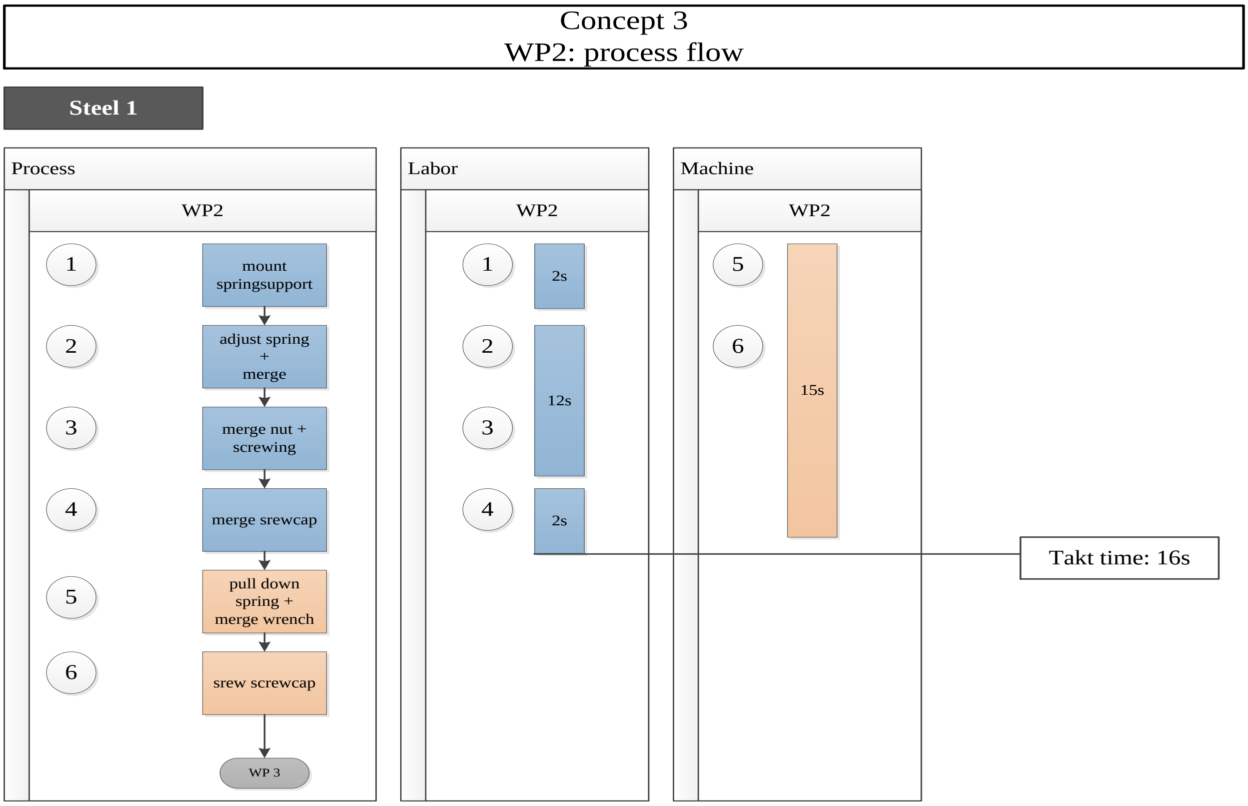


Figure 3.39: C3-process flow of WP2/ Steel 1

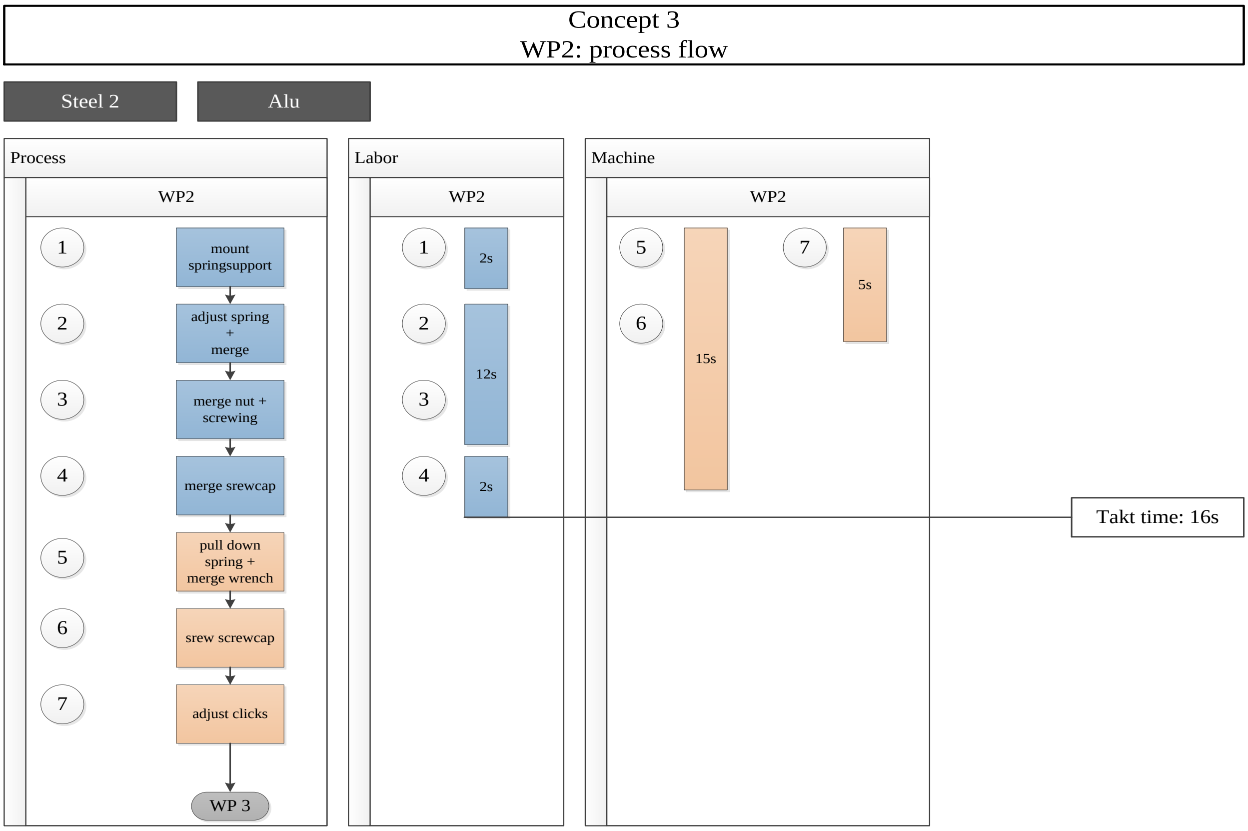


Figure 3.40: C3-process flow of WP2/ Steel 2 and Alu

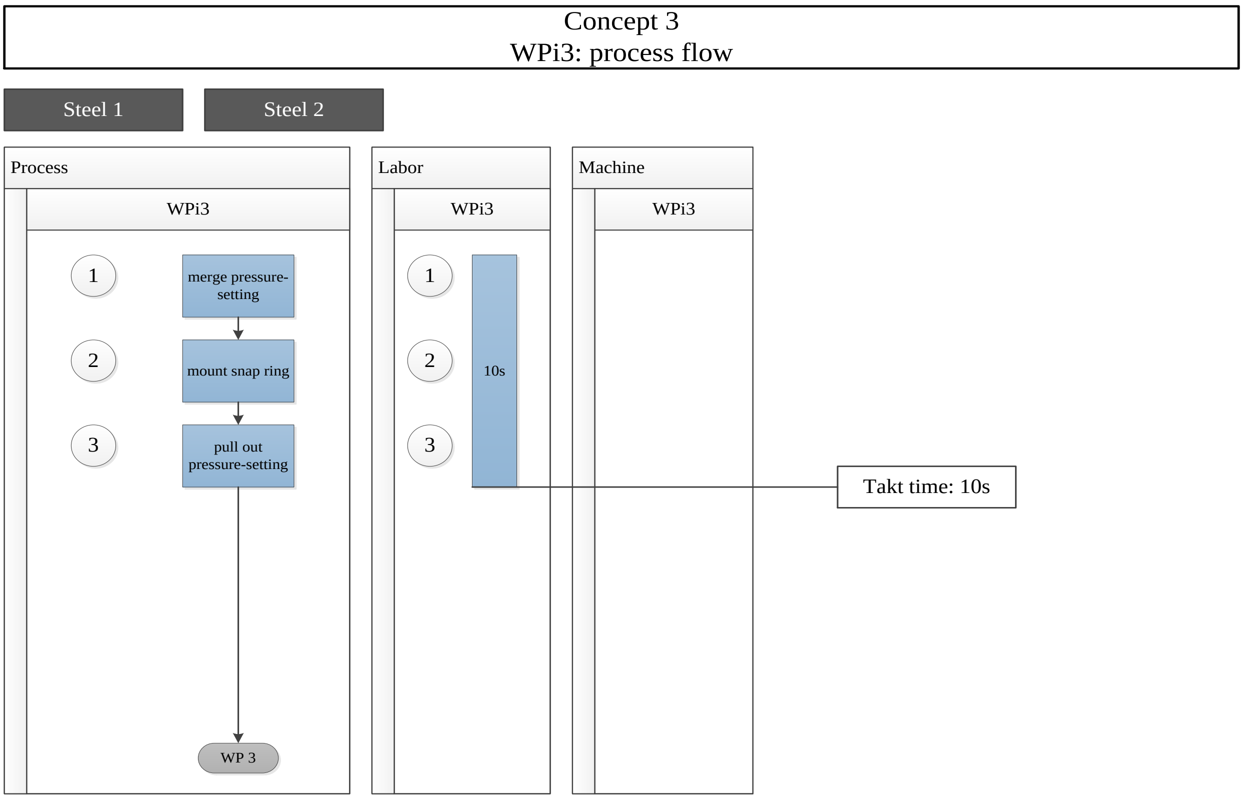


Figure 3.41: C3-process flow of WPi3/ Steel 1 and Steel 2

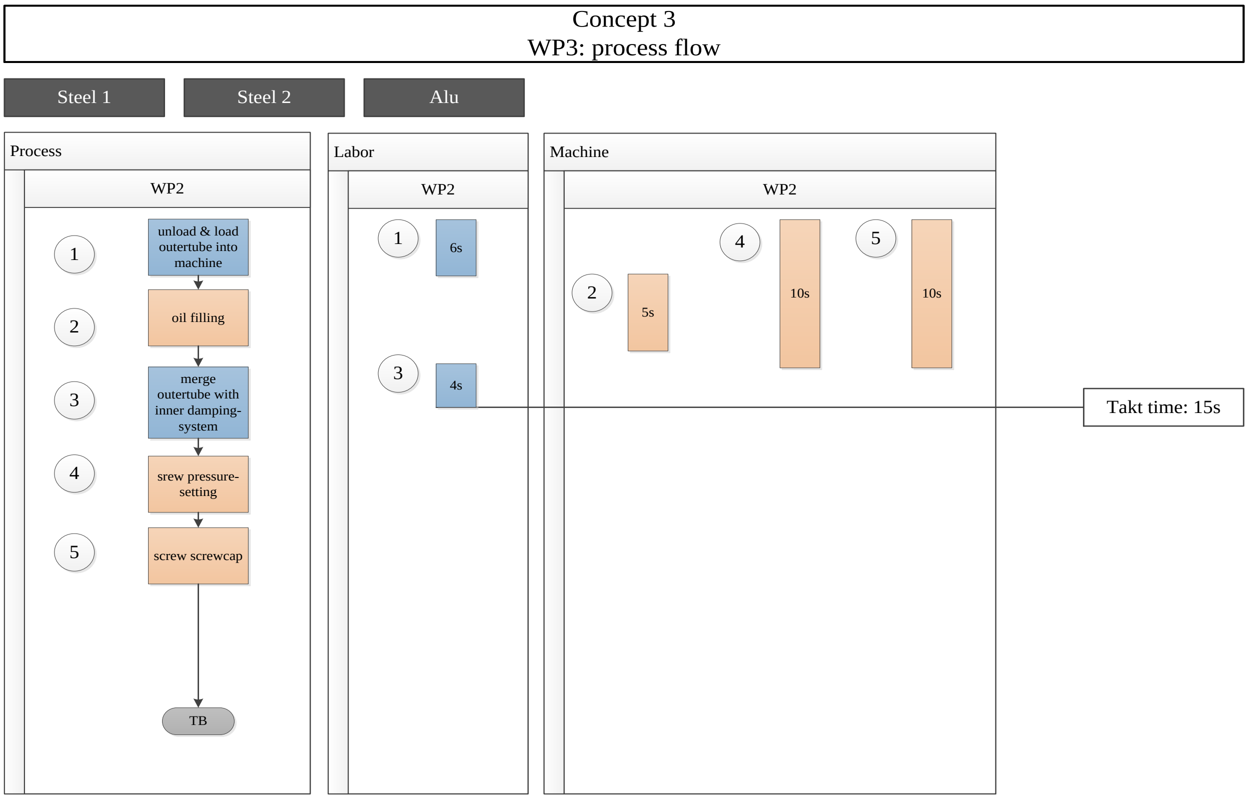


Figure 3.42: C3-process flow of WP3/ Steel 1, Steel 2 and Alu

In contrast to the previous concepts, for the realization of concept 3 the whole production system would be changed including machinery and equipment. This results in investment costs. The total required headcount for operating the offroad- and the onroad assembly line in parallel is nine workers. Though the additional required labor would only be two workers. In Table 3.19 the investment costs as well as the additional labor costs are listed. The labor costs are determined like mentioned in 3.8.1.

Table 3.19: Costs for implementing concept 3

Concept 3		
work place	investment costs [€]	additional annual labor costs [€]
WP1	43.000	131.031
WP2	80.000	
WPi3	1.000	
WP3	145.000	
SUM	269.000	131.031

3.8.4 Concept 4: Semi-Automated Production Line Stage 2

Concept 4 builds up on the idea of concept 3. The work places WP1, WP2, WPi3 and WP3 are identical compared to concept 3; the test bench is now fully automated. The fully automation of the test bench requires a new test bench and an industrial pick-and-place robot for loading and unloading the test bench. The technical design of the test bench could be copied form the existing test bench at the offroad assembly line. In Figure 3.43 the basic set up for this concept is displayed.

This concept would require only one additional worker to enable the parallel operation of the offroad and the onroad assembly line but accounts with the highest investment costs. The costs for implementing this concept are displayed in Table 3.20. The potential of this concept in terms of output, throughput time and takt time will be as well as all other concepts, investigated in a simulation run.

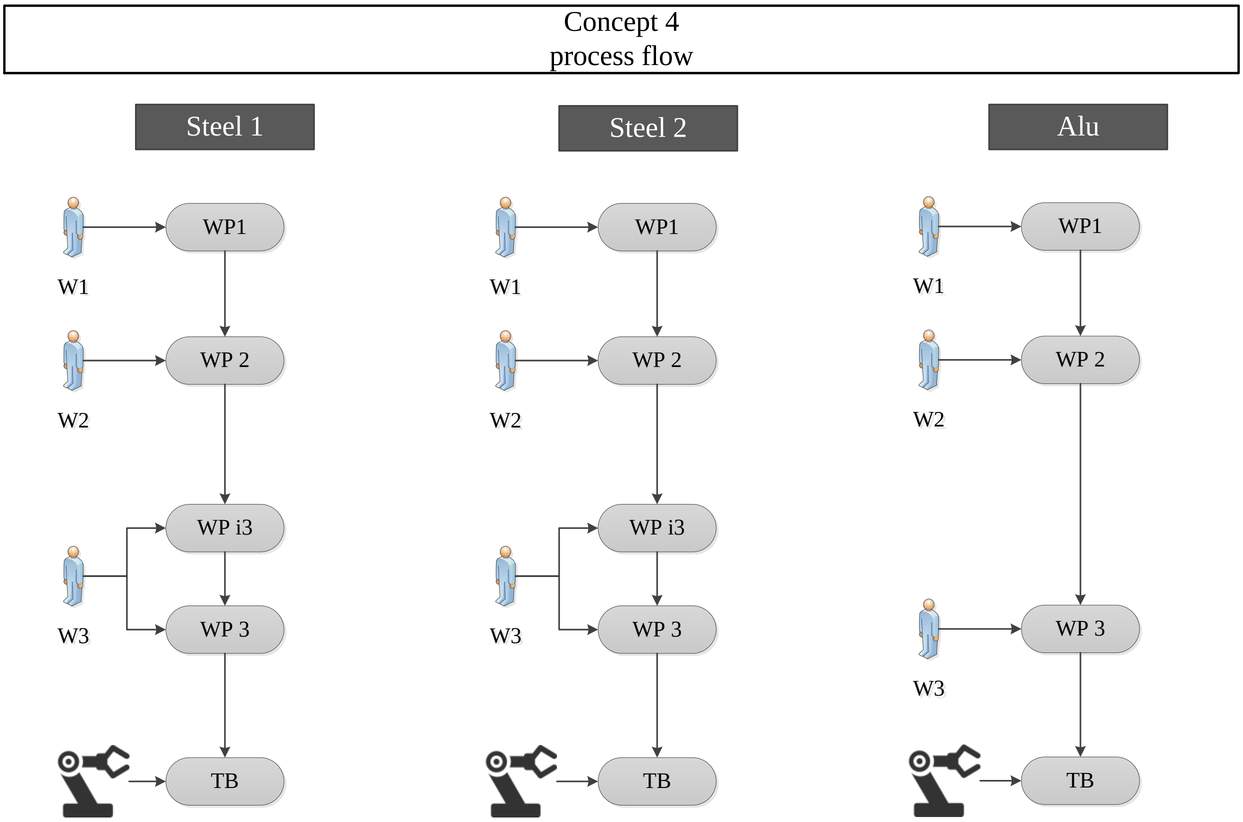


Figure 3.43: Process flow of concept 4

Table 3.20: Costs for implementing concept 4

Concept 4		
work place	investment costs [€]	additional annual labor costs [€]
WP1	43.000	65.516
WP2	80.000	
WPi3	1.000	
WP3	145.000	
TB	310.000	
SUM	579.000	65.516

3.9 Simulation of the Future Concepts

To gain data for the comparison of the different concepts, each concept is benchmarked by a computer simulation also realized with PlantSimulation®. The basic approach of the simulation follows the structure of the simulation of the current system, described in detail in 3.5. To make the different concepts comparable following input parameters are the same for each simulation run:

- *worker efficiency:* at the simulation of the current system it has been shown, that the simulation result was closer to the real system when the efficiency is set to 100%. Therefore the worker efficiency is set to 100% for all simulation runs.

- *Buffer capacity*: the capacity of all buffers in the line is limited with 15 units. This constrain is set due to the requirements of the future system, described in chapter 3.7.

- *shift strategy:* all simulation runs are performed with a regular shift. The work times

3.9.1 Simulation of concept 1

As it is described in chapter 3.8.1, at concept 1 only the headcount is increased but no change of the production system or equipment is made. Therefore the simulation results of the current assembly system can be used for the comparison.

3.9.2 Simulation of concept 2

The simulation model for concept 2 is the same as for concept 1 and for the simulation of the current system. The new work times for an optimal balanced line, calculated in chapter 3.8.2, are loaded into the simulation model. At this simulation two different labor strategies are investigated. The first one is the same as at the current system with five workers who are allowed to switch workplaces between 3Gl2-10 and 3GL2-70 and two fixed workers for 3GL2-OELB and 3GL2-P. At the second strategy all workers are fulfilling theirs tasks at distinct workplaces and are not allowed to switch between workplace. Therefore eight workers are required in total.

3.9.3 Simulation of concept 3

For the simulation of concept 3 the existing simulation model has to be adopted. The main concept as well as many elements can be transferred form the model of the current assembly line. For modeling the work place WP2 and WP3 new sub-models are programmed. This sub-model simulates the behavior of the Hexagon machine, which is mentioned in chapter 3.8.3. In Figure 3.44 a screenshot of the sub-model in PlantSimulation is displayed.

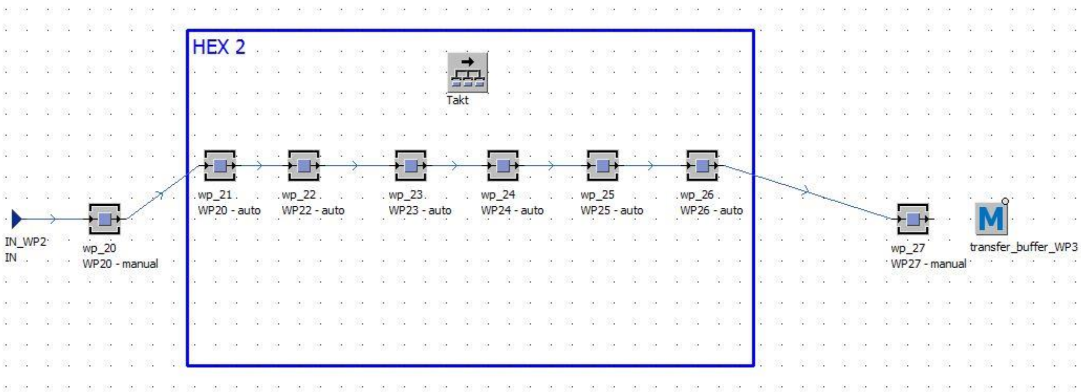


Figure 3.44: Screenshot of the sub-model for a Hexagon

The sub-model consists of automated assembly stations and manual stations. All automated stations are inside the blue rectangle. These stations are controlled by a takt-routine. This routine denies a handover to the successor as long as any of these stations are working. This means the takt time is determined by the longest process time. All other used elements of the simulation model are already used in the simulation of the current system. Tough some of them are rearranged in the model of concept 3. Figure 3.45 shows a screenshot of the model layout.

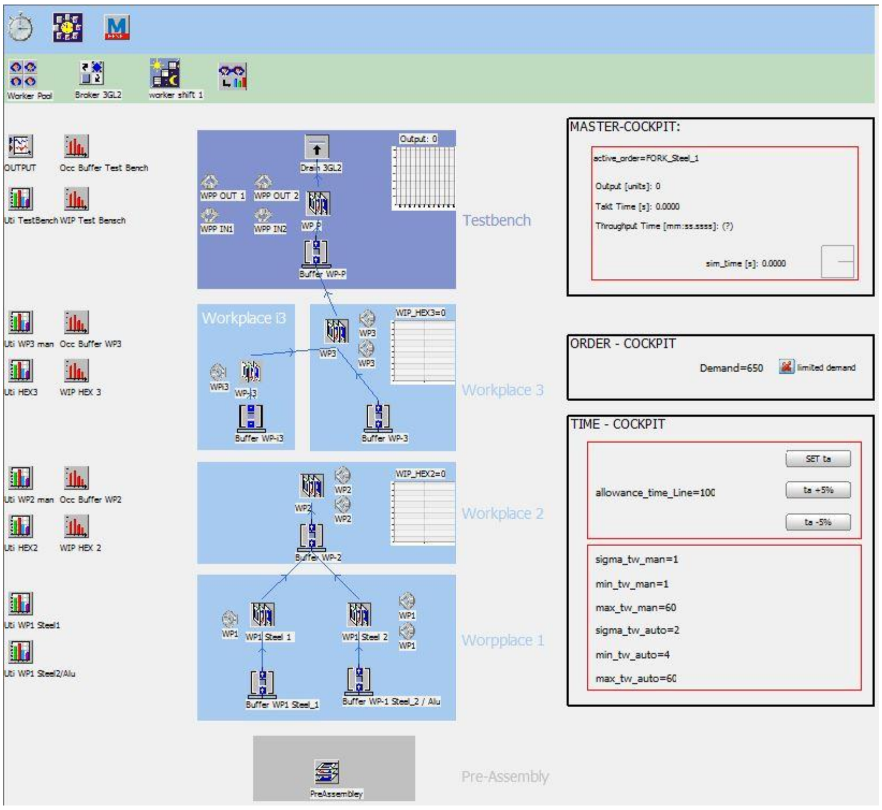


Figure 3.45: Screenshot of the simulation model layout of concept 3

The necessary time data for WP1, WP2, WPi3 and WP3 are listed in chapter 3.8.3 and implemented in the model. The time data for the test bench is the same as in the simulation of the current system.

3.9.4 Simulation of concept 4

The simulation model of concept 4 is very similar to the model of concept 3. The only difference is the test bench. As it is described in 0, the test bench is operating completely automated. To model the behavior of an industrial pick-and-place robot a robot element of PlantSimulation is used. In Figure 3.46 a screenshot of the test bench model layout is displayed.

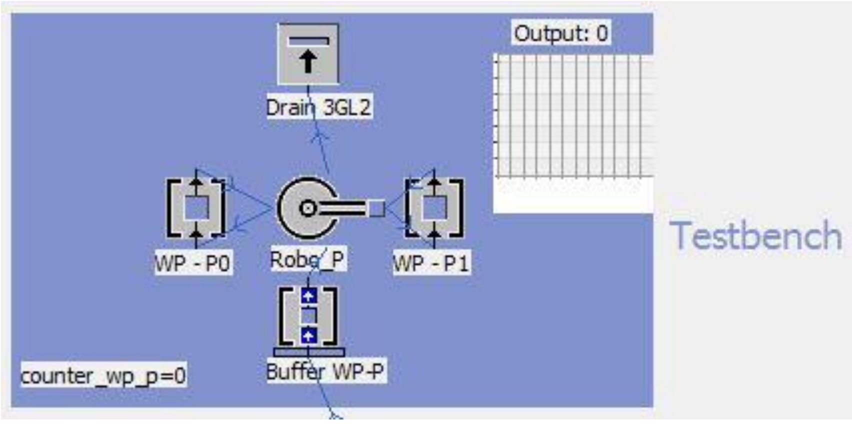


Figure 3.46: Screenshot of the test bench model-layout at concept 4

The time needed for loading and unloading the test bench is estimated with 6s for each cycle. This time is used in the robot model. The model is calculating the velocities to guarantee, that each cycle takes exactly 6 seconds. The modeled test bench is not requiring any worker and works fully autonomous.

3.10 Comparison of the different Concepts

The comparison of the simulation of all concepts is split up into two parts. The first part investigates the systems according their production performance. The second part compares the systems according their costs for implementing and operating each concept.

3.10.1 Performance

For a performance-comparison of all different concepts the same result parameters are used as at the benchmark analysis of the current system, described in 3.5.5. These parameters are:

- *output per shift:* represents the mean value of the produced units, calculated on all simulation-runs for each experiments

- *takt-time:* represents the mean time-period between two units exit the system, calculated on all simulation-runs for each experiments

- *throughput-time:* represents the mean time-period between entering and exit the system for one distinct unit, calculated on all simulation-runs for each experiments

For all concepts, the mean value, the standard deviation, the minimum value and the maximum value of each result parameter and each assembly type is displayed in chapter additional information in the tables: Table 6.5, Table 6.6, Table 6.7, Table 6.8 and Table 6.9. For a better comparison of the concepts, the values of the result parameters are displayed graphically in Figure 3.47, Figure 3.48 and Figure 3.49.

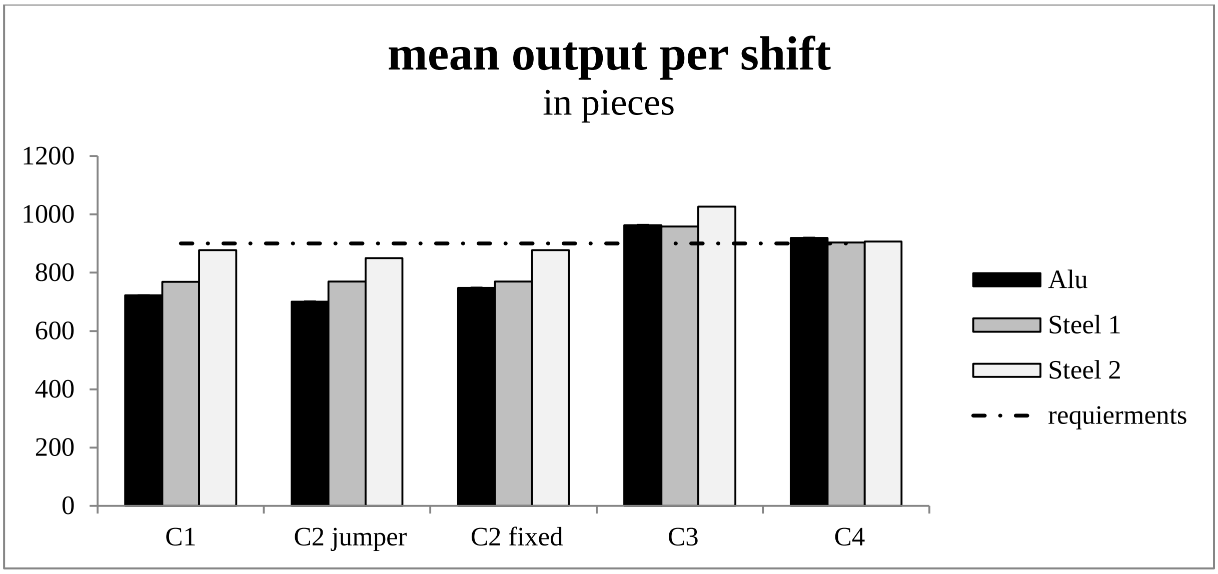


Figure 3.47: output per shift comparison

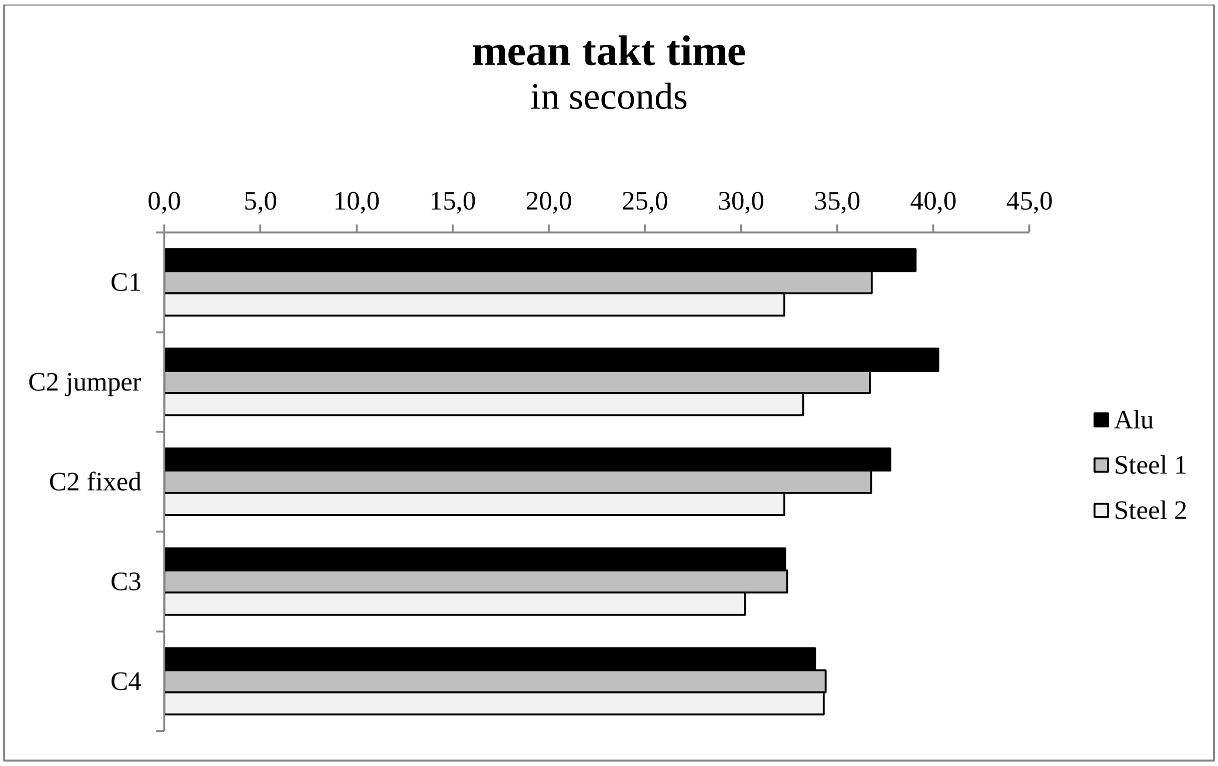


Figure 3.48: takt time comparison

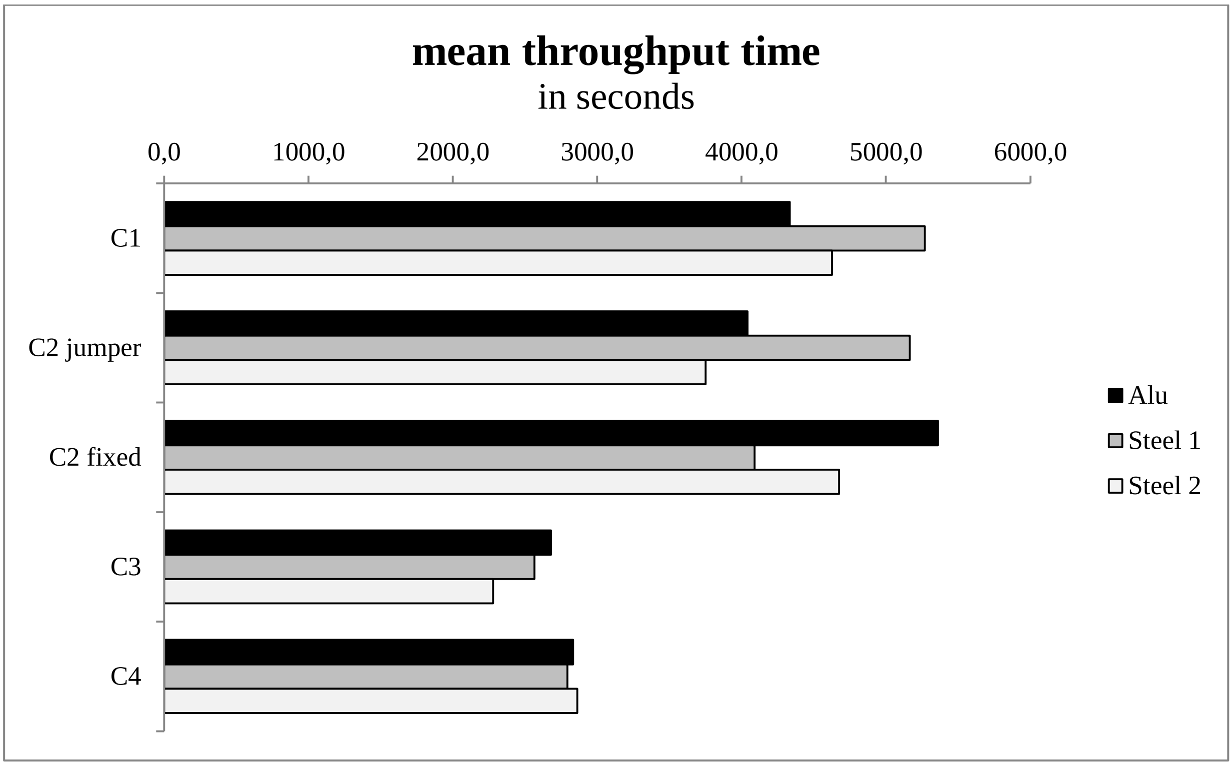


Figure 3.49: throughput time comparison

As it can be easily seen in Figure 3.47 and Table 6.5, Table 6.6 and Table 6.7, with concept 1 as well as with both variants of concept 2 the system is not capable to produce 900 units per shift. The line balancing investigated at concept 2 brings no real improvement compared to concept 1. A further investigation of feasibility of the balancing is not necessary due to the only very slight improvement of concept 2 compared to the current state.

The concept with the highest output per shift is concept 3. Of course also the takt time of concept 3 is the shortest. Concept 4 is also fulfilling the requirement of producing 900 pieces per shift. The throughput times of concept 3 and concept 4 are about 40% shorter.

Because the required labor for the onroad assembly line ranges from only three workers at concept 4 up to 6 workers at concept 2 (fixed workers) an objective comparison of the different system is only possible when taking the required labor also in account. Therefore the produced units per worker and shift are summarized for all concepts and assembly types in chapter additional information in Table 6.10. Figure 3.50 illustrates the difference in productivity by comparing the output of each worker per shift for each concept. As Figure 3.50 shows, the productivity of labor is the highest at concept 4. At this concept the productivity of labor doubled compared to the current state. In figures this means between 306 and 301 pieces per worker in every shift. At concept 3 the productivity of labor is better than at the current state, but not as good as at concept 4.

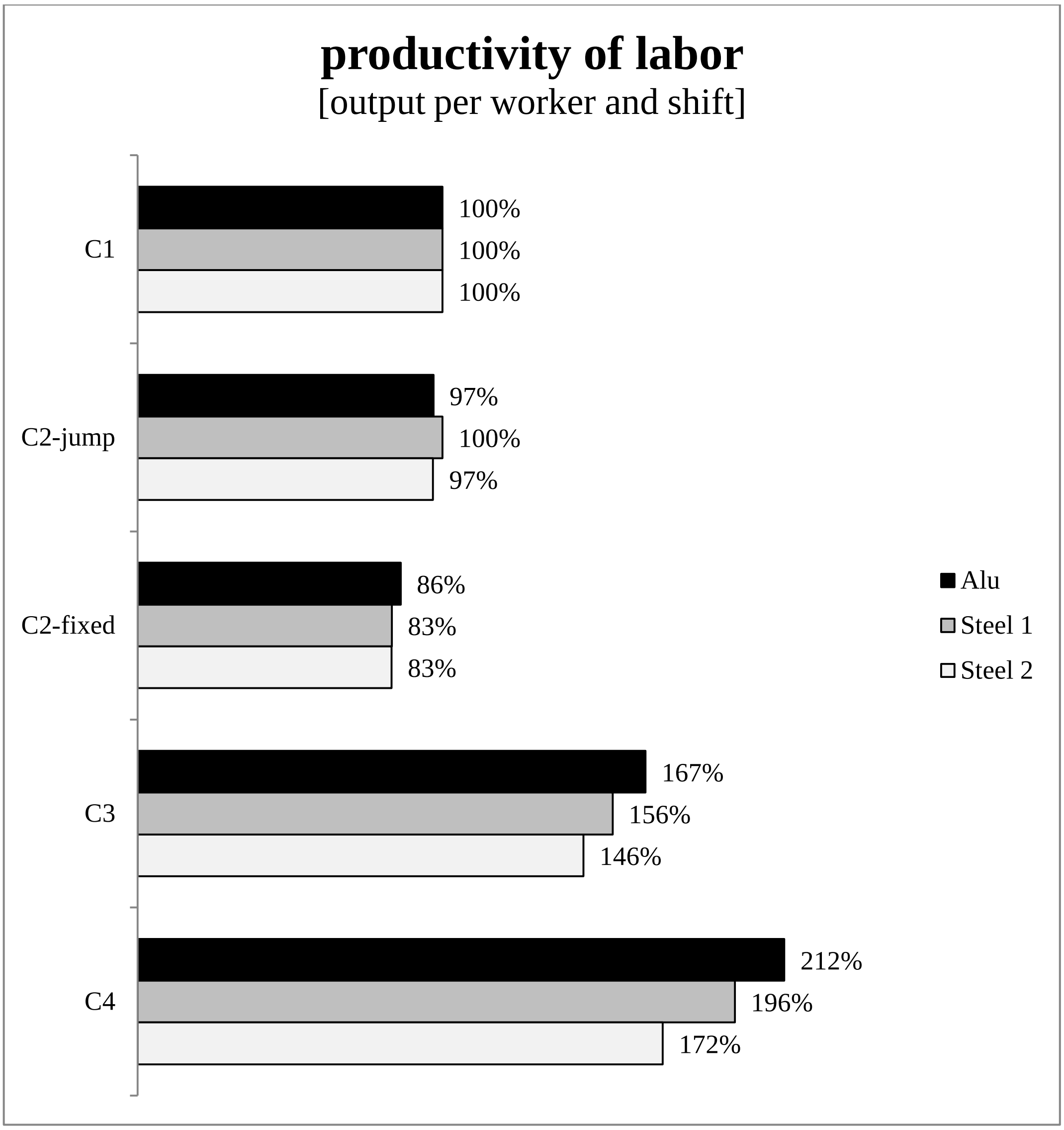


Figure 3.50: Productivity of labor at the onroad assembly line

3.10.2 Costs

Next to the performance, the costs are the second important criteria to rate the concepts. The different costs for implementing each system are already explained in chapter 3.8.1, 3.8.2, 3.8.3 and 3.8.4. To compare all concepts the additional annual labor costs and the investment costs are cumulated for a period of 10 years. These costs are listed in Table 3.21. Figure 3.51 displays the individual cost functions over a time period of 10 years.

Table 3.21: Cumulated costs for each concept

cumulated costs					
years after implementation	**C1** [€]	**C2-jump** [€]	**C2-fixed** [€]	**C3** [€]	**C4** [€]
0	0	0	0	269.000	579.000
1	327.578	327.578	393.093	400.031	644.516
2	655.156	655.156	786.186	531.062	710.032
3	982.734	982.734	1.179.279	662.093	775.548
4	1.310.312	1.310.312	1.572.372	793.124	841.064
5	1.637.890	1.637.890	1.965.465	924.155	906.580
6	1.965.468	1.965.468	2.358.558	1.055.186	972.096
7	2.293.046	2.293.046	2.751.651	1.186.217	1.037.612
8	2.620.624	2.620.624	3.144.744	1.317.248	1.103.128
9	2.948.202	2.948.202	3.537.837	1.448.279	1.168.644
10	3.275.780	3.275.780	3.930.930	1.579.310	1.234.160

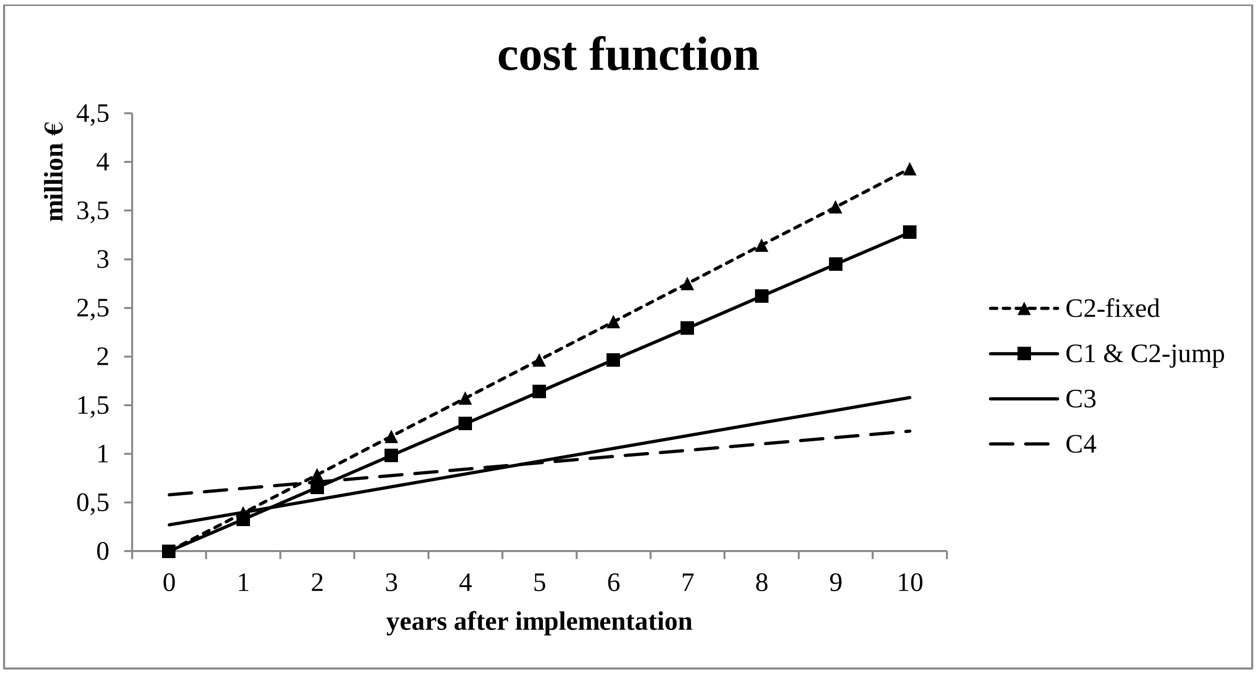


Figure 3.51: Cost function of all concepts

Due to missing investment cots, concept 1 and concept 2 are the cheapest for the first year. But already after one year, concept 3 is as expensive as the concepts 1 and 2. Until year five, concept 3 is the cheapest. After five years, concept 4 is the cheapest. Therefore the planned time period for using the assembly system is important to rate the different concepts in terms of costs.

4 Summary and Outlook

Solving the overall problem of increasing the output of the onroad fork assembly turned out to be more complicated then it seemed at the beginning. Many different influences have been evaluated. Due to the specific labor strategy, explained in chapter 3.3.1, and the not consistently available production report a simulation of the current state was necessary. Even by evaluating a rather small area of a factory many different analysis have to be made. The great amount of different products which have to be assembled with one single assembly line was another factor which made the investigation more complicated. After analyzing all this factors different concepts for a possible future system were created.

In chapter 3.10 the different concepts are compared according their performance as well as their costs for implementing the system. In terms of performance, concept 3 and concept 4 are both meeting the requirements on the future state of roughly 900 pieces per shift. To reach the targeted output with the other two concepts, extended shifts would be necessary. An interesting fact is that there is hardly any increase in output by balancing the assembly line. This means, even though the balance efficiency of the line is not 100%, as it is explained in chapter 2.2.3.2 by switching between workplaces the workers reach a much higher output than theoretically calculated. On the other hand this means that the current system cannot be optimized in terms of productivity without any investment. Only with high increase of labor costs a solution without any investment could be realized. Due to the fact that such assembly lines are planned to be operated for several years at WP, such big increase in labor costs would harm the company as a long-term effect.

Concept 3 and concept 4 are following the approach of automation. By separating assembly time from operating time, a drastic improvement in productivity can be seen. The basic principle is to automate tasks where the experience of a worker is not necessary. As it can be seen in chapter 3.10.1, concept 3 has a slightly higher output per shift but requires one worker in addition, compared to concept 4. This is why concept 4 is the concept with the best productivity of labor. The productivity increase, while implementing concept 4, ranges from 72% to 121%. By implementing concept 3 the productivity increase ranges from 46% to 67% .

The second important decision factor is the costs. As mentioned in 3.10.2, there are basically two different types of costs: the investment costs and the additional annual labor costs. Even when the investment costs for concept 3 and concept 4 seem to be high, it turns out that by drastically lower additional labor costs both of these concepts amortize during two to five years. In Figure 3.51 it can be seen, that concept 3 amortizes after two years and concept 4 after five years. These time periods are not longer than the assembly line is expected to be operated. The current system is now operated for 10 years. Assuming the same time period for operating the future system, WP would save over 2 million Euro by implementing concept 4 and over 1,5 million Euro by implementing concept 3, as the cost function diagram, Figure 3.51, shows . Therefore one of these two concepts is strongly recommended by the author.

Which of these two concepts is ideal for WP depends on the willingness to take the risk of a higher amortization period.

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6 Additional Information

					ABC Analysis:					
goodID	Customer	Type	Code		annual production	%	cumulative %	share of product range	cumulative SOPR	class
05067L01	BMW	Bleed Adjuster	111111		10.922	7,98%	7,98%	1,82%	1,82%	A
14289O06	Triumph	EDS	114211		10.550	7,70%	15,68%	1,82%	3,64%	A
14188N22	KTM	Split	112211		10.232	7,47%	23,15%	1,82%	5,45%	A
14181P26	KTM	Cross	000000		8.049	5,88%	29,03%	1,82%	7,27%	A
14188N10	KTM	Split	112121		6.570	4,80%	33,82%	1,82%	9,09%	A
14188N12	KTM	Split	112121		6.450	4,71%	38,53%	1,82%	10,91%	A
14187P63	KTM	Bleed Adjuster	223121		6.136	4,48%	43,01%	1,82%	12,73%	A
14187P67	KTM	Bleed Adjuster	223121		6.052	4,42%	47,43%	1,82%	14,55%	A
05288O05	Triumph	Split	112211		6.040	4,41%	51,84%	1,82%	16,36%	A
14181P23	KTM	Cross	000000		5.586	4,08%	55,92%	1,82%	18,18%	A
05187M05	KTM	Bleed Adjuster	223121		5.420	3,96%	59,88%	1,82%	20,00%	A
14189M24	KTM	EDS	114211		5.034	3,68%	63,56%	1,82%	21,82%	A
05538O02	CFMOTO	Split	112211		4.920	3,59%	67,15%	1,82%	23,64%	A
14158P12	Husqvarna	Split	112121		4.840	3,53%	70,68%	1,82%	25,45%	A
07187L04	KTM	Bleed Adjuster	000000		4.098	2,99%	73,68%	1,82%	27,27%	A
05188M11	KTM	Split	112211		4.095	2,99%	76,67%	1,82%	29,09%	A
14188N25	KTM	Split	112121		4.068	2,97%	79,64%	1,82%	30,91%	A
14527L01	Sherco	Bleed Adjuster	223121		2.900	2,12%	81,75%	1,82%	32,73%	B
14187P69	KTM	Bleed Adjuster	223121		2.271	1,66%	83,41%	1,82%	34,55%	B
05187N42	KTM	Bleed Adjuster	223121		1.880	1,37%	84,78%	1,82%	36,36%	B
07186Q03	KTM	Free	000000		1.855	1,35%	86,14%	1,82%	38,18%	B
05067L02	BMW	Bleed Adjuster	111111		1.850	1,35%	87,49%	1,82%	40,00%	B
05288O07	Triumph	Split	112211		1.638	1,20%	88,69%	1,82%	41,82%	B
14289O08	Triumph	EDS	114211		1.520	1,11%	89,80%	1,82%	43,64%	B
07181L03	KTM	Cross	000000		1.473	1,08%	90,87%	1,82%	45,45%	B
07186Q02	KTM	Free	000000		1.391	1,02%	91,89%	1,82%	47,27%	B
05187N40	KTM	Bleed Adjuster	223121		1.350	0,99%	92,87%	1,82%	49,09%	B
14288O06	Triumph	Split	112211		1.340	0,98%	93,85%	1,82%	50,91%	B
05186O08	KTM	Free	111111		1.280	0,93%	94,79%	1,82%	52,73%	B
14187P61	KTM	Bleed Adjuster	223121		1.243	0,91%	95,69%	1,82%	54,55%	C
05538N01	CFMOTO	Split	112211		960	0,70%	96,39%	1,82%	56,36%	C
14527P63	Sherco	Bleed Adjuster	000000		866	0,63%	97,03%	1,82%	58,18%	C
07181Q01	KTM	Cross	000000		640	0,47%	97,49%	1,82%	60,00%	C
05287L04	Triumph	Bleed Adjuster	114211		630	0,46%	97,95%	1,82%	61,82%	C
07181L01	KTM	Cross	000000		622	0,45%	98,41%	1,82%	63,64%	C
14527L04	Sherco	Bleed Adjuster	223121		438	0,32%	98,73%	1,82%	65,45%	C
14187O03	KTM	Bleed Adjuster	000000		378	0,28%	99,00%	1,82%	67,27%	C
14157P08	Husqvarna	Bleed Adjuster	000000		297	0,22%	99,22%	1,82%	69,09%	C
14547P08	Alta Motors	Bleed Adjuster	000000		224	0,16%	99,38%	1,82%	70,91%	C
14527P69	Sherco	Bleed Adjuster	000000		201	0,15%	99,53%	1,82%	72,73%	C
05187N41	KTM	Bleed Adjuster	223121		155	0,11%	99,64%	1,82%	74,55%	C
14027P01	Armstrong/CCM	Bleed Adjuster	000000		138	0,10%	99,75%	1,82%	76,36%	C
14188Q22	KTM	Split	000000		50	0,04%	99,78%	1,82%	78,18%	C
14188Q25	KTM	Split	000000		42	0,03%	99,81%	1,82%	80,00%	C
14027P02	Armstrong/CCM	Bleed Adjuster	000000		41	0,03%	99,84%	1,82%	81,82%	C
14188Q67	KTM	Split	000000		40	0,03%	99,87%	1,82%	83,64%	C
14188Q69	KTM	Split	000000		36	0,03%	99,90%	1,82%	85,45%	C
14181Q26	KTM	Cross	000000		36	0,03%	99,92%	1,82%	87,27%	C
14188Q63	KTM	Split	000000		34	0,02%	99,95%	1,82%	89,09%	C
14158Q12	Husqvarna	Split	000000		20	0,01%	99,96%	1,82%	90,91%	C
14187M08	KTM	Bleed Adjuster	000000		20	0,01%	99,98%	1,82%	92,73%	C
14158Q63	Husqvarna	Split	000000		8	0,01%	99,98%	1,82%	94,55%	C
14158Q67	Husqvarna	Split	000000		8	0,01%	99,99%	1,82%	96,36%	C
14158Q69	Husqvarna	Split	000000		8	0,01%	100,00%	1,82%	98,18%	C
14158Q61	Husqvarna	Split	000000		6	0,00%	100,00%	1,82%	100,00%	C
SUM					136.951					

Figure 6.1: List of all onroad-fork products

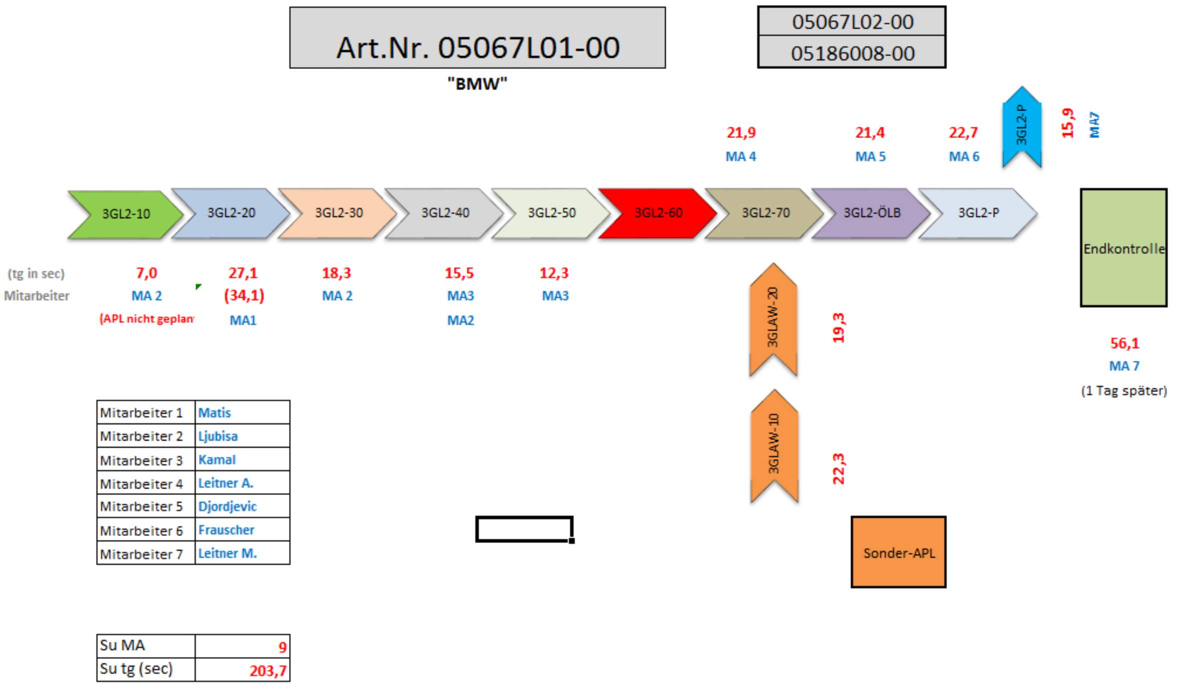

Figure 6.2: MTM-analysis of 05067L01-00

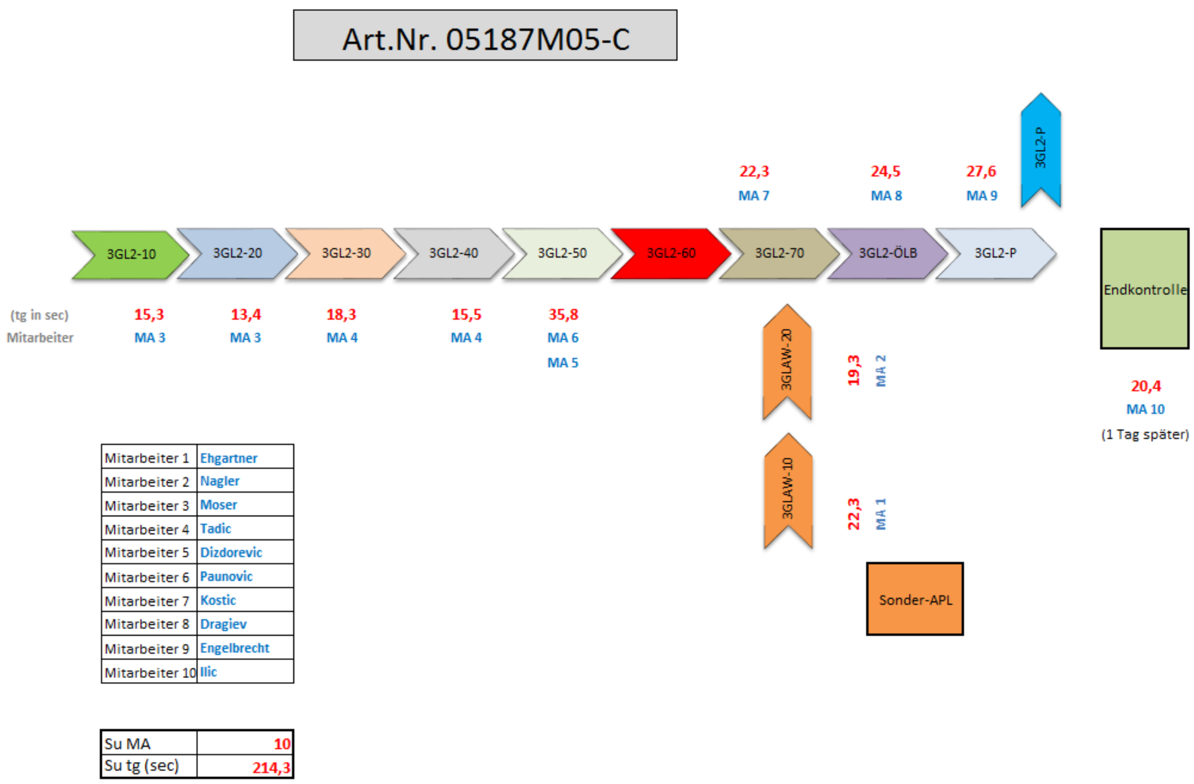

Figure 6.3: MTM-analysis of 05187M05-C

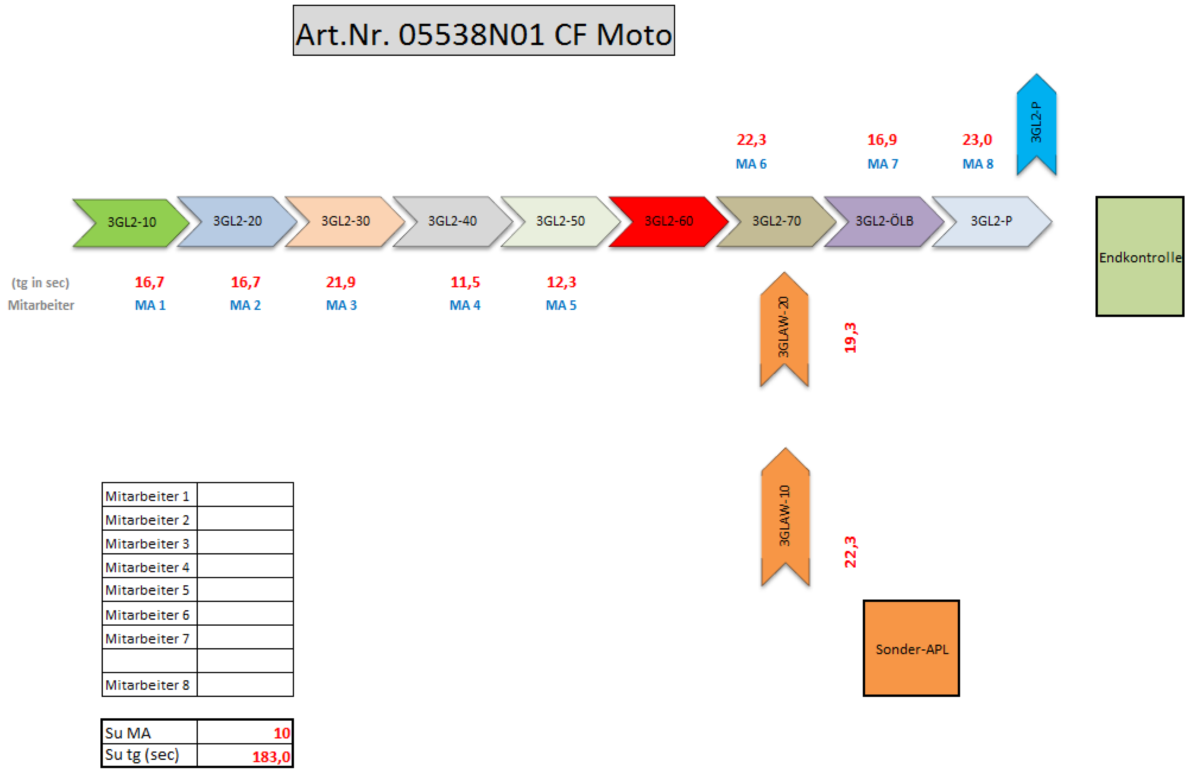

Figure 6.4: MTM-analysis of 05538N01

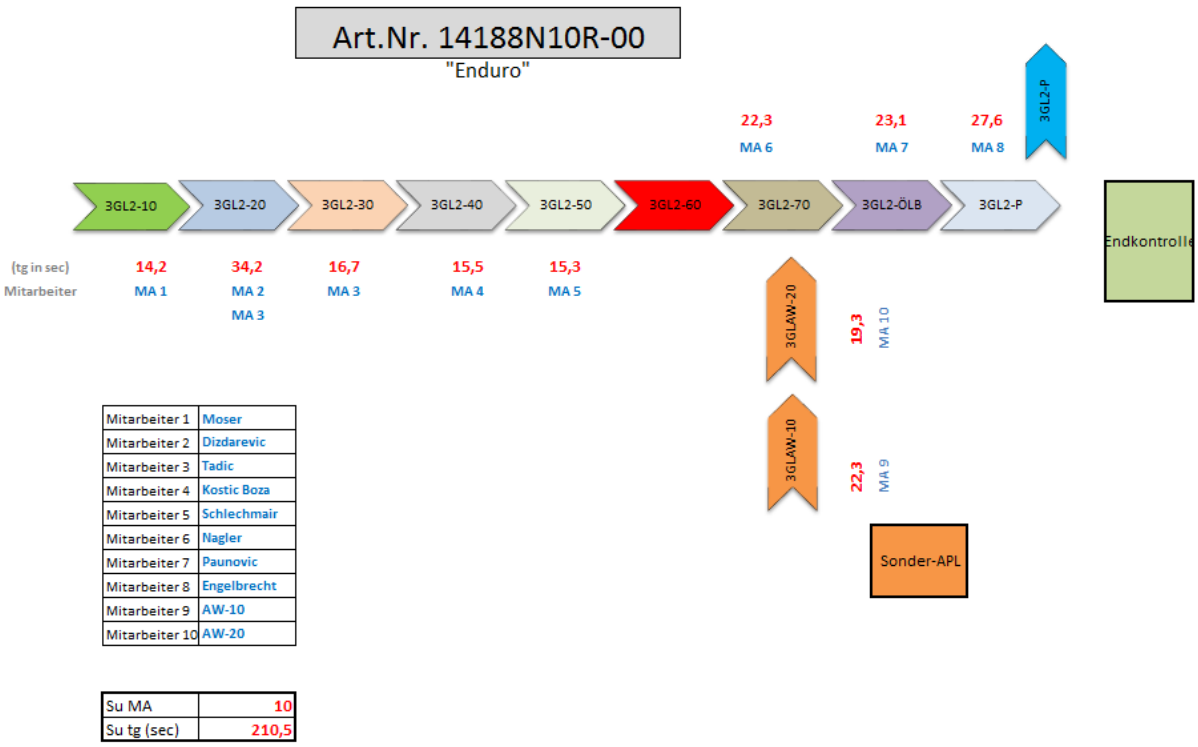

Figure 6.5: MTM-analysis of 14188N10R-00

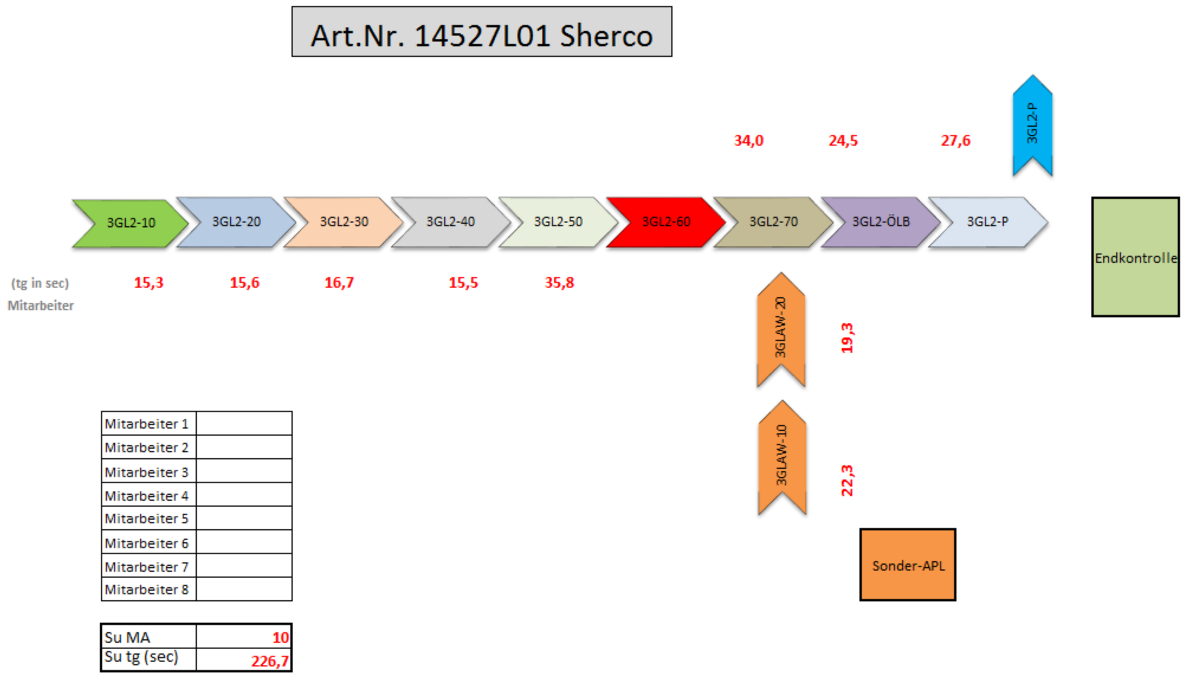

Figure 6.6: MTM-analysis of 14527L01

Table 6.1: Result-parameters of the current system simulation: output per shift

Results of the simulation – output per shift							
assembly type	experiment	output per shift					
		mean - value [#]	standard deviation [#]	minimum [#]	maximum [#]	quartile left interval border [#]	quartile right interval border [#]
alu	**1**	689,80	11,87	662,00	704,00	681,30	698,30
	2	707,00	9,36	693,00	721,00	700,30	713,70
	3	544,30	7,29	530,00	554,00	539,08	549,52
	4	558,70	6,68	530,00	569,00	553,91	563,49
steel_1	**1**	768,60	22,77	729,00	800,00	752,30	784,90
	2	770,00	21,77	729,00	800,00	754,42	785,58
	3	670,10	19,23	631,00	695,00	656,34	683,86
	4	671,80	18,89	631,00	695,00	658,28	685,32
steel_2	**1**	869,40	23,77	829,00	902,00	852,38	886,42
	2	877,30	25,58	829,00	912,00	858,99	895,61
	3	737,00	15,96	708,00	754,00	725,58	748,42
	4	751,30	18,77	708,00	778,00	737,86	764,74

Table 6.2: Result-parameters of the current system simulation: takt time

Results of the simulation –takt time							
		takt time					
assembly type	**experiment**	**mean - value** [ss,s]	**standard deviation** [ss,s]	**minimum** [ss,s]	**maximum** [ss,s]	**quartile left interval border** [ss,s]	**quartile right interval border** [ss,s]
alu	**1**	40,88	0,55	40,16	41,96	40,50	41,28
	2	39,92	0,46	39,07	40,54	39,59	40,25
	3	50,43	0,65	49,56	51,54	49,97	50,89
	4	49,14	0,63	48,11	49,99	48,69	49,60
steel_1	**1**	36,80	1,03	35,41	38,80	36,06	37,53
	2	36,74	0,98	35,41	38,80	36,03	37,44
	3	41,10	1,18	39,54	43,58	40,25	41,95
	4	41,00	1,17	39,55	43,60	40,16	41,84
steel_2	**1**	32,53	0,84	31,38	34,10	31,93	33,13
	2	32,24	0,89	31,07	34,09	31,60	32,88
	3	37,35	0,80	36,53	38,81	36,78	37,92
	4	36,66	0,92	35,32	38,81	36,00	37,31

Table 6.3: Result-parameters of the current system simulation: throughput time

Results of the simulation – throughput time							
		throughput time					
assembly type	**experiment**	**mean - value** [s,ss]	**standard deviation** [s,ss]	**minimum** [s,ss]	**maximum** [s,ss]	**quartile left interval border** [s,ss]	**quartile right interval border** [s,ss]
alu	**1**	3411,69	247,03	3041,99	3934,19	3234,84	3588,55
	2	5325,87	355,04	4980,64	6099,92	5071,69	5580,06
	3	4192,13	235,50	3829,90	4626,45	4023,52	4360,73
	4	6235,99	230,86	5951,27	6550,70	6070,72	6401,27
steel_1	**1**	3736,09	137,84	3539,00	3955,65	3637,40	3834,77
	2	6511,35	216,60	6289,45	6897,90	6356,28	6666,42
	3	4193,00	151,38	3973,59	4430,63	4084,62	4301,37
	4	7198,37	264,75	6795,85	7684,19	7008,83	187,91
steel_2	**1**	2918,97	336,89	2267,24	3400,78	2677,78	3160,15
	2	4718,64	598,86	3981,24	5933,85	4289,90	5147,38
	3	3092,69	303,61	2618,02	3636,82	2875,32	3310,05
	4	5106,38	428,21	4552,88	5868,39	4799,81	5412,94

Table 6.4: Work times for the simulation run of concept 2

Concept 2			
work place:	work time [s]:		
	Alu	Steel_1	Steel_2
3GL2_10	22,16	15,88	16,91
3GL2_20	22,16	15,88	16,91
3GL2_30	22,16	15,88	16,91
3GL2_40	22,16	15,88	16,91
3GL2_50	22,16	15,88	16,91
3GL2_60	0,00	0,00	0,00
3GL2_70	22,16	15,88	16,91
3GL2_OELB	24,48	21,38	16,86
3GL2_P_load	7,00	7,00	7,00
3GL2_P	31,46	29,8	22,26
3GL2_P_unload	6,00	6,00	6,00

Table 6.5: Simulation result of concept 1

Concept 1												
Assembly type	output per shift [#]				takt time [s]				throughput time [s]			
	mean	stand dev	min	max	mean	stand dev	min	max	mean	stand dev	min	max
Alu	722	15	708	742	39,1	0,7	38,1	39,9	4333,4	306,5	4007,1	4950,2
Steel 1	769	22	729	800	36,8	1,0	35,4	36,0	5270,4	156,6	5093,4	5364,5
Steel 2	877	26	829	912	32,3	0,9	31,1	34,1	4627,2	165,4	4436,2	4893,5

Table 6.6: Simulation result of concept 2 - line jumper

Concept 2 - line jumper												
Assembly type	output per shift [#]				takt time [s]				throughput time [s]			
	mean	stand dev	min	max	mean	stand dev	min	max	mean	stand dev	min	max
Alu	701	10	684	715	40,3	0,5	39,6	41,0	4041,0	458,5	3504,0	4994,6
Steel 1	769	21	729	798	36,7	0,9	35,5	38,8	5165,8	178,2	5038,1	5461,3
Steel 2	850	15	821	866	33,2	0,5	32,7	34,4	3751,0	356,9	3241,2	4386,2

Table 6.7: Simulation result of concept 2 - fixed workers

Concept 2 - fixed workers												
Assembly type	output per shift [#]				takt time [s]				throughput time [s]			
	mean	stand dev	min	max	mean	stand dev	min	max	mean	stand dev	min	max
Alu	748	21	709	779	37,8	1,0	36,9	37,1	5361,2	156,3	5164,9	5613,3
Steel 1	770	22	729	800	36,8	1,0	35,4	38,8	4090,9	149,8	5110,2	5780,2
Steel 2	877	26	829	912	32,3	0,9	31,1	34,1	4675,6	145,7	4508,3	4914,9

Table 6.8: Simulation result of concept 3

Concept 3												
Assembly type	output per shift [#]				takt time [s]				throughput time [s]			
	mean	stand dev	min	max	mean	stand dev	min	max	mean	stand dev	min	max
Alu	963	27	930	1007	32,3	0,9	30,8	33,4	2680,6	93,7	2522,9	2809,7
Steel 1	959	24	928	1017	32,4	0,8	30,5	33,5	2565,3	85,4	2413,9	2675,3
Steel 2	1026	24	986	1057	30,2	0,8	29,1	31,5	2279,3	74,7	2194,5	2403,7

Table 6.9: Simulation result of concept 4

Concept 4												
Assembly type	output per shift [#]				takt time [s]				throughput time [s]			
	mean	stand dev	min	max	mean	stand dev	min	max	mean	stand dev	min	max
Alu	919	10	895	927	33,9	0,4	33,6	34,8	2832,7	37,6	2766,0	2879,9
Steel 1	904	16	880	926	34,4	0,6	33,6	35,1	2793,3	66,9	2656,4	2887,5
Steel 2	907	14	886	926	34,3	0,5	33,6	35,1	2862,7	60,3	2771,4	2958,3

Table 6.10: Productivity of labor at the onroad assembly line for each concept

productivity of labor [units / worker and shift]					
assembly type	**C1** 5 workers	**C2-jump** 5 workers	**C2-fixed** 6 workers	**C3** 4 workers	**C4** 3 workers
Alu	144	140	125	241	306
Steel 1	154	154	128	240	301
Steel 2	175	170	146	257	302