Atacan Ketenci, BSc

Strategic Site Planning for the Production of Agricultural Technologies

Master's thesis

to achieve the academic degree of

Diplom-Ingenieur

Master's degree program:

Production Science and Management

submitted to

Graz University of Technology

Institute of Innovation and Industrial Management
Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

Graz, June 2019

Affidavit

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 indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis dissertation.

……………………………   ….………………………………………………

Date   Signature

Acknowledgement

I would like to express my sincere thanks to Univ.-Prof. Dipl.-Ing. Dr. techn. Christian Ramsauer, head of the Institute for Innovation and Industrial Management, for giving me the opportunity to write this thesis in a very exciting subject area as part of an industrial project.

Special thanks is due to the supervisor of this project, Mr. Dipl.-Ing. Elias Auberger. As a result of his ongoing support, the project, and thus this thesis, could be successfully completed.

In addition, I would like to pay tribute to the entire team of the Institute, leaded by Mr. Dipl.-Ing. Hugo Karre, for their uninterrupted support and motivation during the work.

My special gratitude goes to my friends, flat mates and colleagues for various activities outside the university. Especially Mr. Thomas Reim MSc and Ms. Katharina Schneider BSc contributed to the fact that I was able to leave everyday life again and again. At this point I would also like mention Ms. Mag. Christina Hubich, for the proofreading of the entire work.

Finally, I would like to thank my parents and my sister, whose support made studying possible at all.

Atacan Ketenci,

Graz, May 2019

Abstract

An Austrian company manufactures products for environmental technologies as well as products for agricultural technologies at one of their two plants, located in Slovenia. Due to the high capacity utilization and the growing demand for the environmental technology products, this plant increasingly represents a bottleneck. For this reason, a *greenfield layout planning* for the agricultural products was carried out. However, the aim of this project is not only the elaboration and assessment of a LEAN-compliant production layout, but also a qualitative estimation of the impact of such a restructuring.

After the introduction, which contains information about the company and the goals of this project, an overview of the methods and techniques used is given.

In order to be able to identify weak points and derive optimization potentials of the current layout, the production processes, the current and planned production program and the flow of materials were examined. This analysis serves as the basis for the subsequent layout planning, in which the results and findings from the current state inspection are taken into account. Several different layout variants were created and subsequently evaluated by the entire project team. The planned annual throughput for the year 2025 and the utilization of the technologies used are then visualized for the selected variant by means of a simulation. Since the currently high lot sizes of the company represented a special challenge during this project, these are analyzed in depth with the use of the simulation. As a conclusion, a qualitative estimation of production costs and usage potentials of the existing plant is drawn.

As a result of this project, encountered problems and solutions are discussed.

Kurzfassung

Ein in Österreich gegründetes Unternehmen stellt in einem seiner zwei Werke in Slowenien sowohl Produkte für die Umwelttechnik, als auch Produkte für die Landtechnik her. Aufgrund der hohen Kapazitätsauslastung und der steigenden Nachfrage an Umwelttechnikprodukten stellt dieses Werk zunehmend einen Engpass dar. Aus diesem Grund soll für die Landtechnikprodukte eine Greenfield-Layoutplanung durchgeführt werden. Ziel der vorliegenden Arbeit ist allerdings nicht nur die Ausarbeitung und Beurteilung eines LEAN-konformen Produktionslayouts, sondern auch eine qualitative Abschätzung der Auswirkungen einer solchen Umstrukturierung.

Diese Arbeit gibt nach der Einleitung, welche Informationen über das Unternehmen sowie die definierten Ziele enthält, zunächst einen Überblick über die verwendeten Methoden und Techniken.

Im Anschluss erfolgt die Analyse des Ist-Zustandes. Die Prozesse zur Herstellung der Produkte, das aktuelle und geplante Produktionsprogramm und die derzeitigen Materialflüsse werden hier genauer betrachtet, um etwaige Schwachstellen herausfiltern zu können und Optimierungspotentiale abzuleiten. Diese Analyse dient als Grundlage für die Layoutplanung, in der die Ergebnisse und Erkenntnisse aus der Ist-Analyse berücksichtigt werden. Mehrere unterschiedliche Layoutvarianten werden erstellt, welche im Anschluss vom gesamten Projektteam bewertet werden. Die geplante jährliche Durchsatzmenge für das Jahr 2025 und die Auslastung der verwendeten Technologien werden anschließend für die ausgewählte Variante mittels einer Simulation visualisiert. Da die aktuell hohen Losgrößen eine besondere Herausforderung darstellen, werden auch diese mit Hilfe der Simulation weiter analysiert. Den Abschluss des praktischen Teils bildet die qualitative Abschätzung der Herstellkosten und der Nutzungspotentiale im existierenden Werk.

Als Ergebnis dieser Arbeit werden die aufgetretenen Probleme diskutiert und Lösungsvorschläge gegeben.

Table of Content

1 Introduction

This thesis was created in cooperation of an Austrian company with the institute of Innovation and Industrial Management (IIM). First, background information about the company is given. Afterwards the problem statement and goals of this project are explained. In the last two parts of this chapter an overview of the entire project and the structure of this thesis is stated.

1.1 The company

The company is a technology provider for both machines and systems for the mechanical and biological treatment of solid waste as well as for the processing of woody biomass as a source for renewable energy. By always keeping focus on innovative technologies and solutions that ensure a maximum value for their customers, the company has become one of the leading technology provider in the area of waste treatment. The enterprise was founded in 1992, in the same year as Styria, a region of Austria, started the separate collection of biodegradable waste. Beside their plant in Styria, Austria, the company has also several subsidiaries in Germany, Slovenia and the USA.

Within this work, we focus on the production facilities based in Slovenia, where machinery for agricultural and environmental purpose are produced. The following Figure 1 shows the location of this project's industry partner's subsidiaries. It is evident that the company operates globally. The mentioned manufacturing facility in Slovenia is marked with a pin.

Figure 1: Location of the company's subsidiaries

1.2 Task and Objectives

Currently, in one of their two plants in Slovenia parts for both environmental and agricultural technologies get produced. The high capacity utilization as well as the rising demand for products of environmental technologies contribute to the fact that this plant increasingly represents a bottleneck. A greenfield layout planning for the agricultural components should be carried out to reach the strategic goals of the company for the year 2025 which include, inter alia, 40 million € in sales and 8% EBIT margin.

If this project is to be realized, the free area in the existing plant should be used to manufacture products of the environmental technology line of the company.

The goals of this project can be summarized as follows:

- Identification of necessary production machines / technologies for the new plant
- Greenfield layout planning with focus on
    - Reduction of the current lot sizes, ranging from 20 to 40 pieces, to 5 pieces
    - Production according to LEAN-concepts
    - Balancing of a possible production line
    - Consideration of the number of required employees
- Estimation of the changes in the production costs of the agricultural technology products
- Showing possible potentials in the existing plant for the products of the environmental technology line after the restructuring

Due to the high quantity of the different product variations the analysis is carried out with nine previously chosen products of the company. Each of these products represents a specific variation of the standard product. Another constraint that has been taken for granted concerns the spreaders. They have to be pre-assembled and tested. An additional condition which has been assumed as given is that any kind of welding-pre-assembly does not take place. This fact makes it easier to analyze the manufacturing process of the sub-assemblies. As the company tries to avoid unnecessary loss of space in the distribution, the possibility of an “modular-system” has also been taken into account during this work.

1.3 Overview of the Project

To ensure a structured process during the entire project, this venture is divided into three work packages. Figure 2 gives a short overview of the phases, including the goal as well as some content of each phase. A detailed explanation of the phases is given at a later point.

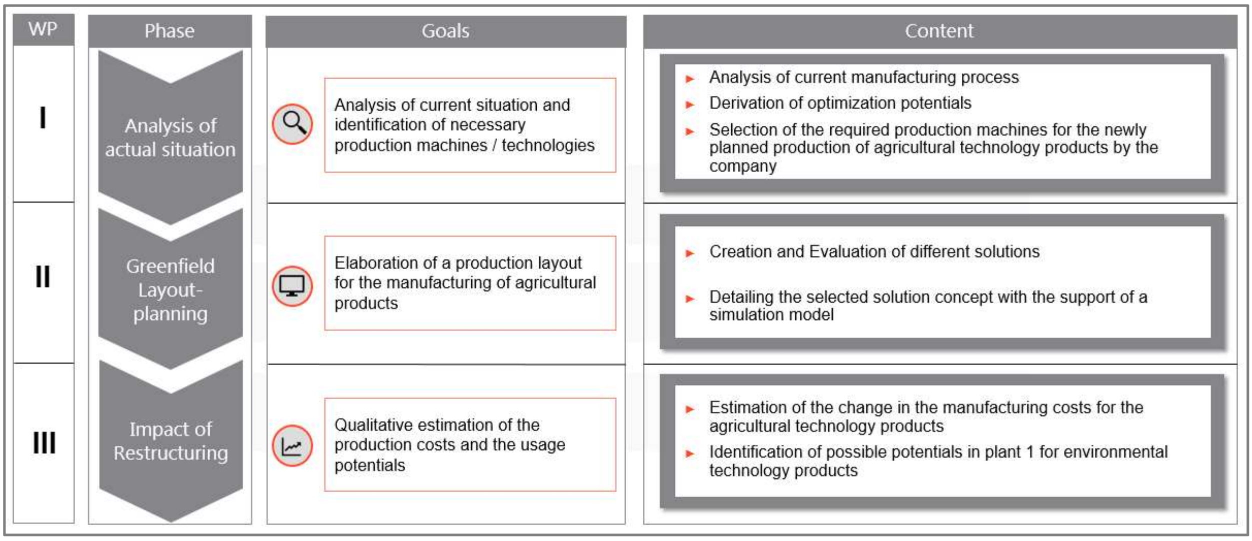


Figure 2: Overview of the project

Phase I starts with the analysis of the current situation in both plant one and plant two, which are both located in Slovenia. This is necessary in order to be able to derivate optimization potentials. Especially the impact of the change in the lot sizes are taken into account. The goal of this part is the identification of needed production machines / technologies for the new factory building.

Phase II deals with the greenfield layout-planning and includes the creation and evaluation of different solution variants. The elaborated layout for the manufacturing of agricultural products should then also be simulated for a given demand and lot size of each product.

The last part of the project is about the impact of the restructuring. To be able to assess the measures, an estimation of the change in the manufacturing costs for the agricultural technology products is carried out. Additionally, the identification of possible usage potentials in plant one for the remaining products of the environmental line will be executed.

1.4 Thesis' Structure

This project report is divided into the following chapters:

1. Introduction
2. Methodology
3. Practical Part
4. Discussion
5. Conclusion and Outlook

After providing background information about the company and the project in the first chapter, methods used during the different work phases will be introduced in the chapter of methodology. The corresponding subchapters also deal with the effects and causes of different lot size problems. The third chapter deals with the detailed explanation of all three work phases including the achieved results. The discussion of these results, as well as advantages or disadvantages, follows in a later chapter. The fifth section, which completes this report, contains the conclusion. Additionally, recommendations for future works are provided.

2 Theoretical Input

To understand the way of proceeding during the various work phases of the project, this chapter provides explanations of all used methods. Since this chapter forms the foundation for the practical part, it is of great importance to the entire project.

2.1 Literature Review

A literature review has been carried out continuously through the entire study. The gathered information helps to understand the achieved results after using the different methods, especially when analyzing the current situation of the company. By using books, journals, dissertations and other kinds of literature, the review served as a basis to form the structure of the report.

2.2 Factory Planning

Before the term *"factory planning"* is explained in more detail, it seems to be necessary to get an understanding about the two words that compose that term.

A *"factory"* is commonly referred to a commercial plant or manufacturing facility for the production of products that is based on both machines and labor. In order to gain a detailed understanding of a factory, it is useful to consider the aspects of location, plant structure, factory building, production logistics, and the organization.[1]

"Planning" can be described as an intellectual approach towards a desired result, including the sequence of actions required to achieve this result.[2]

"Factory planning" then can be defined as a systematic, target-oriented and methodized process. Planning occurs by the usage of different tools and methods, starting with the first idea and ending with the ramped-up production.[3]

Even though there are different interpretations of the term factory planning today, the work content is generally the same. It includes a strategical part, which deals with outsourcing, cooperation and other strategies. In addition to that, factory planning also deals with structural aspects, considering for example site locations on the one hand, but also the flow of materials within the sites on the other hand. The system project, as the

---

[1] Cf. Erlach (2010), p.5
[2] Cf. VDI 5200 (2011), p.4
[3] Cf. VDI 5200 (2011), p.3

last part to mention, pays attention to facilities that may contain for example stocking or transportation systems.[4]

2.2.1 Reasons for Factory Planning

Factory planning projects differ in terms of importance, scope, and duration. These types of projects are influenced significantly by the occasion, the area to be planned, and the intended use of the planning results.[5]

The constant need for rationalization is among the most common occasion for the planning of a factory. The increase in the volume of sales or the inclusion of new products in the production program may also trigger a factory planning project. In contrast, the sales volume may also decrease. This circumstance can cause the factory to be scaled down and thus the re-planning of the factory and the adaption of all areas accordingly.[6]

2.2.2 Types of Factory Planning

The VDI 5200 distinguishes between the following four types of factory planning:[7]

a.) Development Planning

The first type refers to the so-called greenfield planning. This means that the planning itself requires the consideration of the ground and the infrastructure but not of any building structure.

Due to the globalization of markets and locations, an increase of the number of this type of factory planning is recognizable.[8]

b.) Re-planning

If the task is to re-plan an already existing factory, factors regarding the production have to be taken into account. The re-planning also requires the consideration of the existing building structure.

c.) Demolition

Demolition describes the process of preparing a site for a new use if a factory is shut down and demolished. This case can be caused by a decline in sales, the reduction of the production depth or the outsourcing of entire production levels.[9]

---

[4] Cf. Pawellek (2008), p.14
[5] Cf. Wiendahl (1999), p. 9-2
[6] ibidem
[7] Cf. VDI 5200 (2011), p.4
[8] Cf. Grundig (2012), p. 18
[9] Cf. Grundig (2012), p. 19

d.) Revitalization

Revitalization refers to greyfields, which are industrial wasteland sites. Making available this kind of sites for industrial use again is called revitalization planning.

2.2.3 Phases of Factory Planning

As mentioned, strategic factory planning is a structured process that starts with the preparation of the project and ends with the successful implementation in order to achieve the company-specific goals.[10] All required process steps are shown in Figure 3. Those phases, which represented a special challenge during this project, are indicated specially.

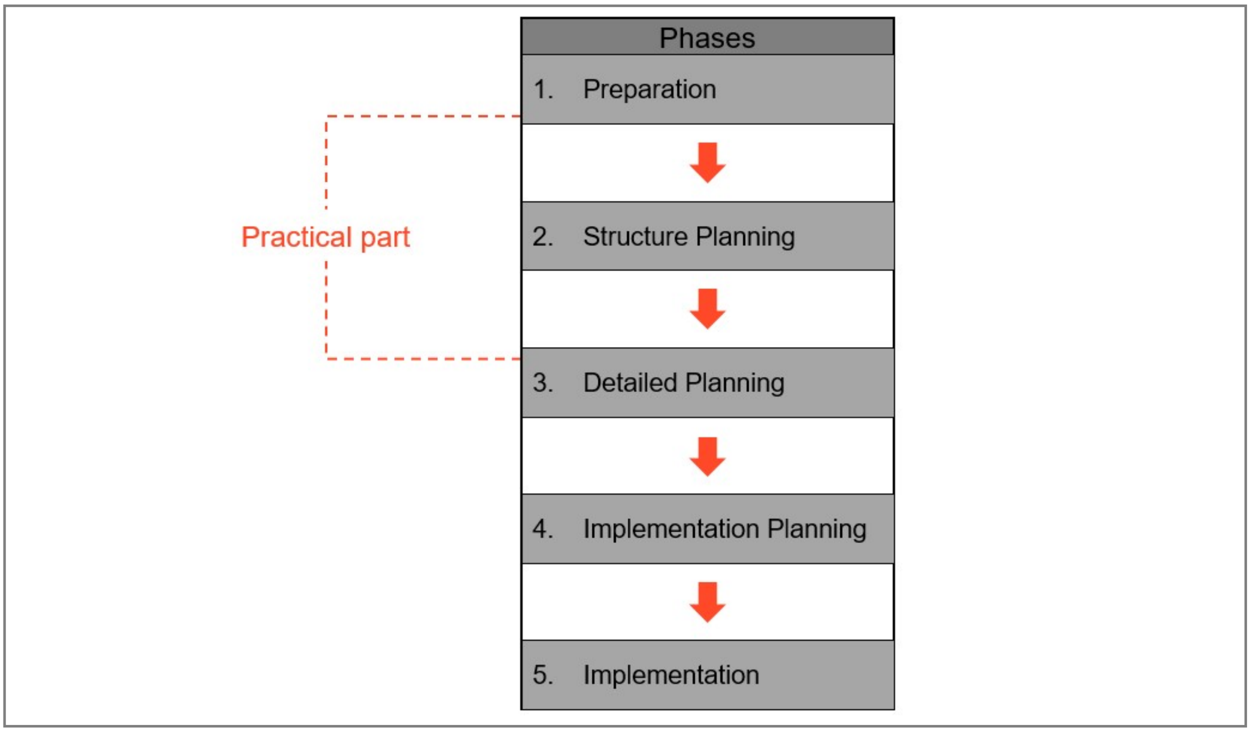


Figure 3: Process steps of factory planning[11]

In the following subchapters the different phases of a factory planning project are described, whereby a reference is made to the known six-phase-model. Since the first two ones had been the main tasks within this cooperation, targets and techniques needed to meet the objectives of the first two phases are explained in detail in the following.

[10] Cf. VDI 5200 (2011), p. 3
[11] Based on Schuh / Gottschalk / Lösch / Wesch (2007), p.195, own representation

2.3 Preparation Phase

The preparation phase considers both aspects the target planning and the preliminary planning.[12] Both are described in the following subchapters.

2.3.1 Target Planning

Target planning is the first phase within the factory planning procedure. To be able to carry out different factory planning tasks efficiently, both target specifications and planning principles get developed during this phase.[13] The aim of this part is to define goals by respecting the strategical objectives of the company which are mainly set by the management.[14] These objectives describe improvements in the fields of e.g. Financial, -Location- or Business Area developments.[15] As the target planning affects the other factory planning phases, a lot of influencing factors have to be considered.[16] Some of the key contents of this phase are listed in Figure 4.

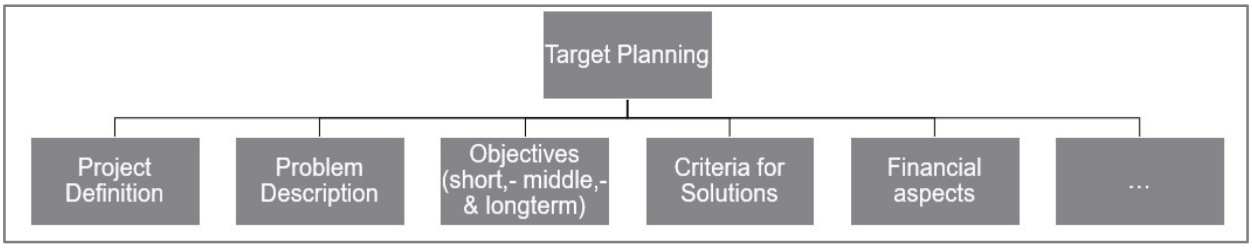


Figure 4: Key content of target planning[17]

The result of the target planning is an opportunity study, which represents a rough task. This study must be confirmed by the management of the company.[18]

Since this project concentrates more on the application of the methods of the following phases, the target planning is not discussed in more detail.

[12] Cf. Grundig (2012), p. 41
[13] Cf. Grundig (2012), p. 54
[14] Cf. Wiendahl / Reichardt / Nyhuis (2015), p.374
[15] Cf. Grundig (2012), p. 54
[16] ibidem
[17] Based on Grundig (2012), p. 56, own representation
[18] Cf. Grundig (2012), p. 57

2.3.2 Preliminary-Planning

Based on the results of the phase of target planning, the preliminary planning can start.[19] Some of the major work content is represented in the following Figure 5.

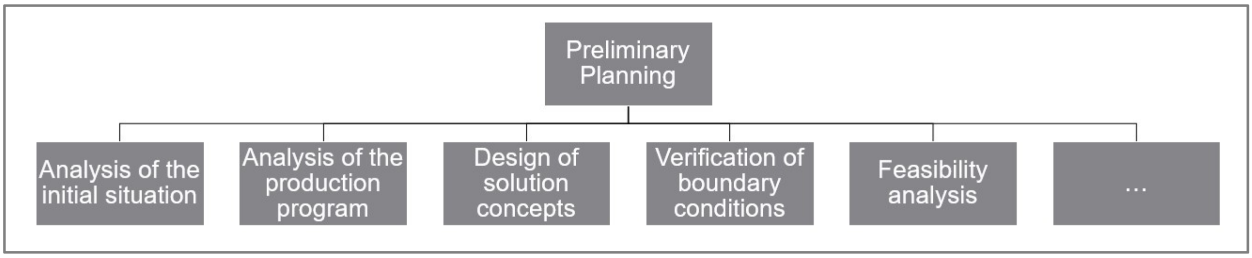


Figure 5: Key content of preliminary planning[20]

2.3.2.1 Analysis of the initial situation

The focus of this work step is the achievement of two main goals. First of all, the analysis of the initial situation should create the basis for further planning phases. Additionally, there is the necessity of the identification of any kind of weaknesses in order to be able to derivate optimization potentials.[21] Some of the methods used during the analysis are described below.

Methods of data acquisition

Basically, two different methods can be distinguished. While direct methods are used to collect data especially for the investigation purpose, the indirect ones are based on already existing documents of the company.[22]

Surveys (e.g. questionnaires), counts, observations or image captures (pictures or videos) can be named as some examples for direct methods of data acquisition. In contrast to this, the analysis of machine data, production documents (e.g. bill of materials, routing plans), production statistics or even the personnel statistics represents the indirect methods.[23]

The collected data can then be used to analyze the following *"flow"*-systems:[24]

- Flow of materials
- Flow of personnel (including traffic routes within the plant)
- Flow of energy

[19] Cf. Grundig (2012), p. 57
[20] Based on Grundig (2012), p. 57, own representation
[21] Cf. Grundig (2012), p.58
[22] Cf. Hömberg / Jodin / Leppin (2004), p.5
[23] Cf. Grundig (2012), p. 60
[24] Cf. Kettner / Schmidt / Greim (2011), p. 40

- Flow of information

Due to the fact that the bills of materials (BOM) of each product were the main source of information during the project, they should be briefly explained.

A BOM represents a list of parts and is necessary to make an assembly. The list should not only show the parts needed for the finished product, but also the part number, a description of the part, the needed quantity of the part and the information whether the part is produced in-house or purchased. The BOMs may also include additional information such as the price or weight of the part. If an assembly consists of several subassemblies, each of these subassemblies should have its own bill of materials.[25]

Material Flow Analysis (MFA)

The material flow can be described as a chain of all processes that are involved in the extraction, processing and the distribution of materials within defined areas.[26] The analysis of the material flow in the area of factory planning should ensure the achievement of two objectives. Firstly, the results of the analysis should provide an overview about the relations of each involved object to each other. In addition to that, the investigation should allow the drawing of a conclusion about the material flow intensity.[27] The different possibilities for both, the depiction and the evaluation of the materials flow, are shown in Figure 6. Methods used during this project are marked in red.

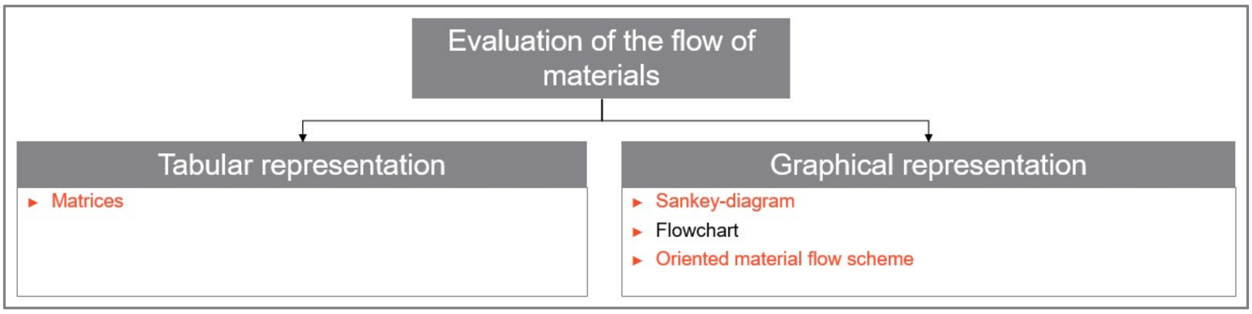


Figure 6: Methods for the evaluation of the material flow[28]

- Material Flow Matrix

This kind of matrix is also often called *"from-to-matrix"* in the literature. While the rows represent the sending station, the columns show the receiving areas. The numbers show the quantity, which is transported within a defined time period. A difference between input and output of the same station is possible, if not all work stations are recorded during the

[25] Cf. Sule (2009), p. 36
[26] Cf. VDI 3300 (1973), p. 2
[27] Cf. Grundig (2012), p. 119
[28] Based on Grundig (2012), p.121 ff., own representation

analysis.[29] The same is true if two or more objects are combined in an (pre-) assembling station (for example a welding process).

In order to find an arrangement of the different workstations, which shows a minimum effort regarding the transportation, it is necessary to create an intensity matrix. This matrix is the result of the multiplication of both the transport and the distance matrix. The second one mentioned shows the distances between the stations which are in relation to each other.[30]

An example for an intensity matrix is shown in Figure 7. As an example, the transport intensity from the drilling station to the painting station is 1.550 [#*m], which is one of the three maxima of the shown data.

Intensity Matrix	To	Stock	Milling	Press	Drilling	Painting	Drying	Outbound
From								
Stock			1200	350	800	0	567	1122
Milling		0		600	0	0	0	800
Press		0	200		750	0	0	0
Drilling		0	0	0		1550	0	0
Painting		0	0	0	0		1550	0
Drying		0	0	0	0	0		1550
Outbound		0	0	0	0	0	0	

Figure 7: Example of an intensity matrix[31]

- Oriented Material Flow Scheme

This visualization technique allows a qualitative assessment of the spatial arrangement of the different workstations. Even if the possibility of making relatively quick statements about the material flow is given by this method, the visualization can quickly become confusing. As one of the reasons for this, an inefficient material flow within the factory can be named.[32]

The visualization can be done in two different ways. The direct method shows the flow of materials by using arrows that connect the center of two working areas directly. Thus, the consideration of the transportation routes occurs only in the second method, which is called transport-related material flow representation.[33] During this project only the second mentioned method has been used. Figure 8 shows an example of this visualization technique.

---

[29] Cf. Wiendahl et al (2015), p. 393
[30] Cf. Grundig (2012), p. 125
[31] Based on Grundig (2012), p. 126, own representation
[32] Cf. Hartel (2015), p. 76
[33] Cf. Grundig (2012), p.129

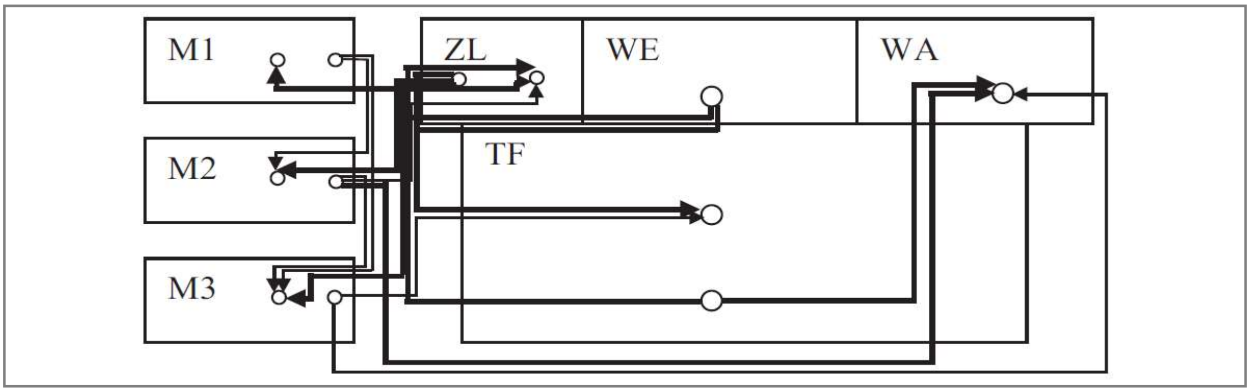


Figure 8: Example for an oriented material flow scheme[34]

- Sankey Diagram

The Sankey Diagram is an important tool in the topic of MFA and can be used to identify inefficiencies in a system.[35] The main disadvantage of this kind of visualization is that the locations of the working areas are not taken into account.[36] Nevertheless, it is a commonly used technique that represents the material flow in a directionally oriented way within a defined time period. The arrow-strength is directly related to the number of transportations, which in turn allows a quick conclusion about the intensities.[37] An example for a Sankey diagram is shown in Figure 9, which is based on the intensity matrix shown on the page before.

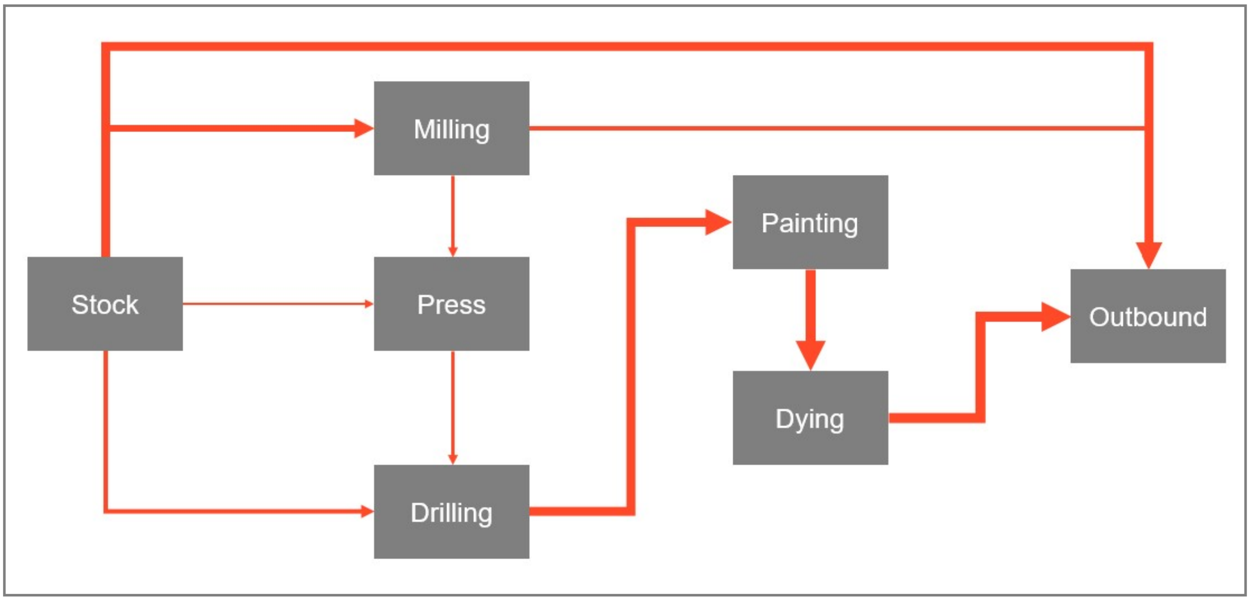


Figure 9: Example of a Sankey Diagram[38]

[34] Grundig (2012), p. 129
[35] Cf. Schmidt (2008), p. 1
[36] Cf. Hartel (2015), p. 76
[37] Cf. Grundig (2012), p. 127
[38] Based on Grundig (2012), p. 128, own representation

The example above shows that the smallest intensity occurs between the stock and the press, which is represented by the thinnest arrow.

Process Analysis

To be able to describe not only the flow of materials but also the communication and value flows, a process analysis needs to be executed.[39] This allows the determination of all product elements and production stages, which influence the process structure that needs to be developed.[40]

The use of charts to visualize the activities needed to manufacture a product is an often used practice in the field of engineering. The graphical representation enables a clear understanding of the different processes. Another advantage of the usage of charts is the possibility of identification of problems that are related to the production layout.[41]

One of these mentioned charts is the so called *"Gantt chart"*, in which the time needed to perform a specific activity is represented by horizontal bars. One of the aims is to reduce the throughput time of a process by allocating limited resources to different activities.[42] At this point it becomes important to mention that a time based overview plan as a single instrument for scheduling is not enough and would lead to wrong decisions. The reason for this is that the determination of the throughput time is based only on the critical path.[43]

The "*critical path"* can be described as a sequence of critical processes. The main indicator for this activity is that these processes have no buffer times. This means that the difference between the earliest and the latest start date of a process equals to zero. Therefore, it can be said that a delayed ending of a critical process delays the beginning of all successors, and thus, the increase of the total cycle time.[44]

An example for a Gantt-Chart can be seen in Figure 10. The red bars represent the critical path of the shown project. Also the buffer and the process times for each step can be seen. The final assembly consists of two parts which get connected in a welding process. It is also shown that this part will be finished at 4.30 pm if the starting time is 8 o'clock in the morning.

[39] Cf. Wiendahl et al. (2015), p. 389
[40] Cf. Grundig (2012), p. 83
[41] Cf. Sule (2009), p. 103
[42] Cf. Sule (2009), p. 110
[43] Cf. Adam (1998), p.559
[44] Cf. Fähnrich (2006), p. 20-21

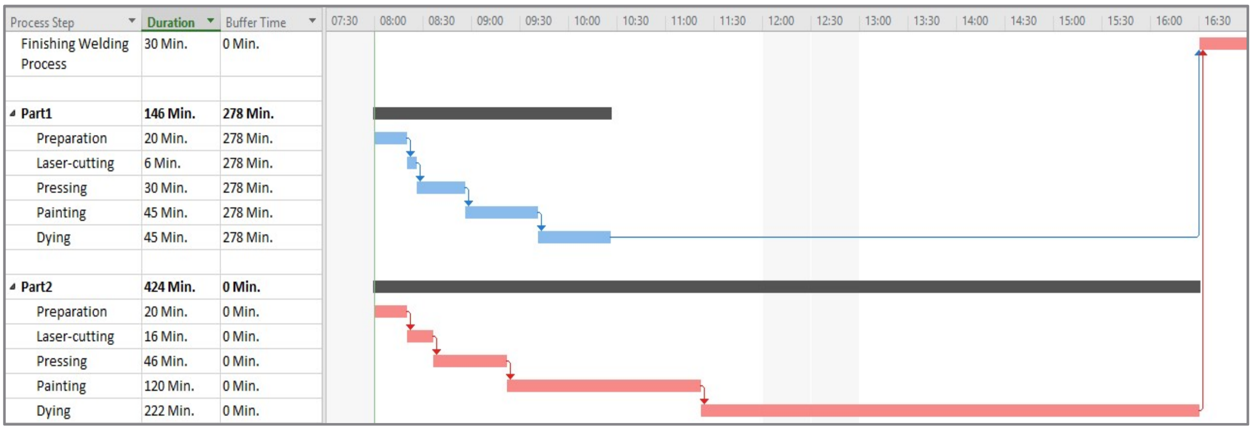


Figure 10: Example of a Gantt Chart[45]

2.3.2.2 Analysis of the Production Program

The production program serves as a base for determining the scope of the production according to factual, quantitative, temporal, and in terms of value aspects.[46] In the context of factory planning, the production program includes the definition of types and quantities of the products to be produced.[47]

During this analysis the production program has to be screened critically with respect to both production and business management.[48] The following figure gives a short overview of criteria for both aspects.

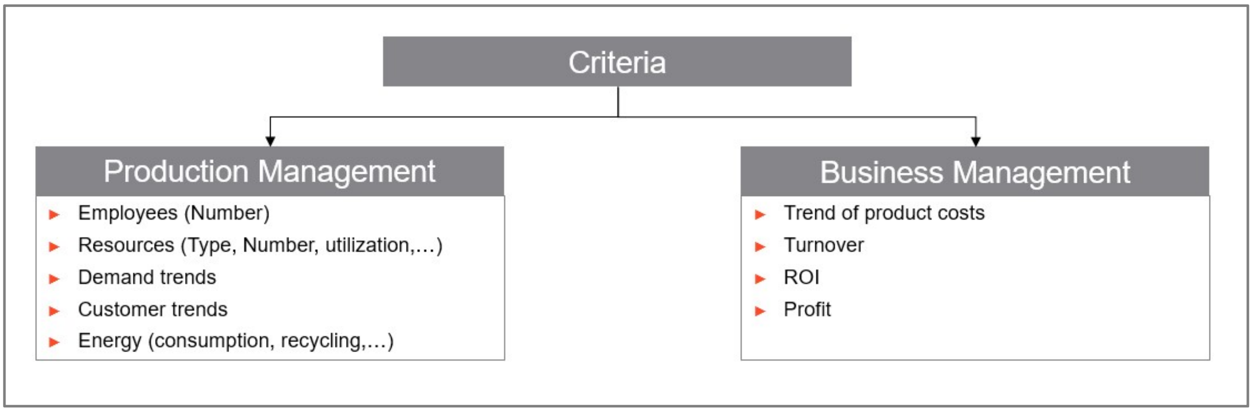


Figure 11: Aspects of interest for the analysis of the production program[49]

One of the methods for analysing the production program is the *"break-even analysis"* known from cost accounting, in which costs are taken into account.[50] Since the

45 Own representation
46 Cf. Grundig (2012), p. 64
47 Cf. Grundig (2012), p. 67
48 Cf. Kettner et al. (2011), p. 44
49 Based on Grundig (2012), p. 67, own representation
50 Cf. Grundig (2012), p. 69

determination of the production costs was one of the objectives during this work, these will be explained at this point.

Production Costs

The term *"costs"* can be defined as an input of values for the creation of output, which is related to both the business purpose and the time period.[51]

Based on this definition, the production costs of a product can be determined according to Zunk et al. (2016) using the following formula:[52]

$$\begin{aligned} & Production\ Costs \\ & \quad = Direct\ Material\ Costs + Indirect\ Material\ Costs \\ & \quad + Direct\ Manufacturing\ Costs + Indirect\ Manufacturing\ Costs \end{aligned} \tag{1}$$

Different costing procedures are available for determining costs. A basic distinction can be made between division costing and overhead costing procedures. The main difference between these two methods is that the former do not distinguish between direct costs and indirect costs. Since the overhead method is often used in lot-production[53], it is discussed in more detail below.

The following Figure 12 shows a possible subdivision of the different overhead costing procedures.

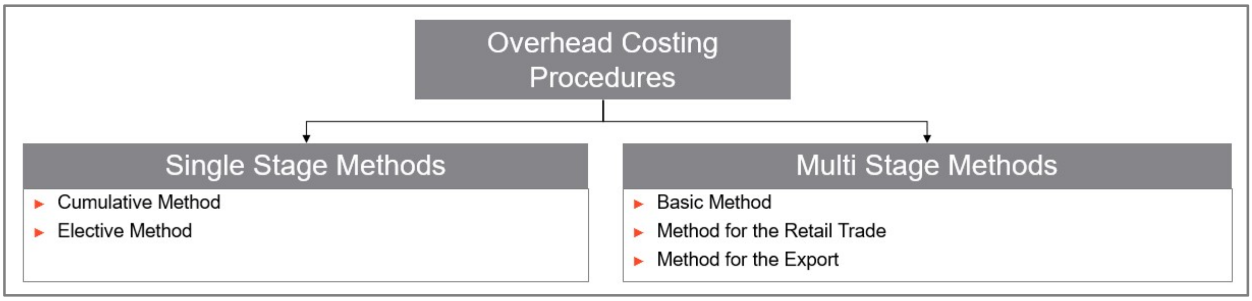


Figure 12: Subdivision of overhead costing procedures[54]

Within the framework of this project, a simplified calculation of production costs was carried out, based on the company's calculation method. As this corresponds to the single-stage method, the multi-stage method is not discussed in more detail.

---

[51] Cf. Zunk / Grbenic / Bauer (2016), p.17
[52] Cf. Zunk et al. (2016), p. 118
[53] Cf. Zunk et al. (2016), p. 122 ff.
[54] Based on Zunk et al. (2016), p. 128 ff., own representation

Although the single-stage overhead calculation is used in practice, it has problems with regard to inaccuracies in the results. These inaccuracies occur because no cost centre accounting is performed. It can therefore happen that a cost unit is assigned fewer indirect costs than it actually causes. This is, among other things, one of the reasons why this type of procedure is more likely to be carried out in small businesses.[55]

The two single-stage methods shown for determining the indirect costs differ in that point, that the cumulative overhead calculation method uses only one overhead absorption rate. This causes the disadvantage that the results obtained can be distorted, since it is assumed that the indirect costs are divided equally between the different direct cost elements. In reverse, a differentiated formation of overhead absorption rates takes place in elective single-stage costing. Therefore, an increase of the accuracy of the results can be observed, without losing the advantage of simplicity of this method.[56]

Since the impact of layout planning on revenue was estimated at the end of the project, the principle of the contribution margin will be explained here.

Contribution Margin

This is the amount available to cover the fixed costs. You can specify the contribution margin either for one piece or for an entire period. The latter one mentioned can be calculated by subtracting the variable period costs from the revenues of the same period.[57]

2.3.2.3 Feasibility Analysis

All results of the preliminary phase have to be presented in the Pre-Feasibility-Study, which clarifies those solutions which have an impact on the decision making.[58] Some of the main content of this analysis is shown in Figure 13. Since there was no need to carry out this kind of analysis during this project, the individual points are not discussed in more detail. Nevertheless, it can be seen that the content of the preliminary phase plays a major role for the entire project as well as for factory planning in general, since there is no possibility to carry out a feasibility analysis without information about e.g. the material flow.[59]

---

[55] Cf. Zunk et al. (2016), p. 128 f.
[56] ibidem
[57] Cf. Zunk et al. (2016), p. 177
[58] Cf. Grundig (2012), p. 79
[59] ibidem

Pre-Feasibility-Study

- Clarification of the project goals
- Specification of the production program
- Determination of demands
- Determination of logistical concepts
- Information about expenses
- Information about profitability

Figure 13: Content of the pre-feasibility-study[60]

2.4 Structure Planning

The task of this phase is the linkage of all factory elements in a functional, cost-effective and humane way.[61] The result of this association is then called the *"structure of a factory"*.[62] The planning of this structure and thus the arrangement of the different functional units occurs with respect to production, logistical, and organizational boundaries.[63] Functional units can be formed by production functions and logistic functions, which can be named as the main functions.[64] In addition, auxiliary areas (e.g. maintenance, supply) or administrative areas can also be regarded as functional units.[65]

2.4.1 Dimensioning

Structure Planning includes the dimensioning of the following different subsystems.[66]

- Resources (Equipment)
- Personnel
- Area
- Other Media

Due to the fact that this project only required the dimensioning of the needed areas, the other three subsystems will only be explained briefly. Exact calculation processes can be found in the corresponding literature.

---

[60] Based on Grundig (2012), p. 79, own representation
[61] Cf. Schulte (1984), p. 1201-1254
[62] Cf. Pawellek (2008), p. 115
[63] ibidem
[64] Cf. Grundig (2012), p. 80.
[65] Cf. Pawellek (2008), p. 115
[66] Cf. Grundig (2012), p.88

2.4.1.1 Dimensioning of Resources

"Resources" are defined as all technical equipment or machinery that is required in different manufacturing, assembly, and logistics processes.[67]

The determination of the required resources includes both the determination of the types of resources needed and the determination of the needed quantity of them. While the fixing of the resource types is based on the different technological processes and is determined by the work preparation, the estimation of the needed quantity is part of the dimensioning phase during the factory planning project.[68]

In case that there is a definitive production program and the results of the work preparation (such as type of needed resources) are known, the required resources can be determined by dividing the total capacity requirements by the available capacity of the chosen equipment. The detailed calculation takes factors like set-up times, processing times or the number of working days per year into account as well. If there is a batch production, the values must be given according to the product and the lot.[69]

Mistakes or inaccuracies during the dimensioning of the resources can cause the forming of queues of the orders. As a result, capacities have to be sufficiently adjusted when planning a factory.[70]

2.4.1.2 Dimensioning of Personnel

The determination of the required personnel occurs with respect to type (qualitative) and number (quantitative) of employees.[71]

<u>Qualitative required personnel</u>

To determine the right type of personnel it is necessary to create a job-related requirements profile first. If possible, it should include all requirements and activities that may occur during the work. The right personnel can then be chosen by use of, for example, the profile comparison method, where the skill profile of each individual applicant gets compared with the requirements profile.[72]

---

[67] Cf. Wiendahl et al. (2015), p.140
[68] Cf. Grundig (2012), p. 89
[69] Cf. Kettner et al. (2011), p.53 ff.
[70] Cf. Grundig (2012), p.93
[71] Cf. Grundig (2012), p. 94
[72] Cf. Grundig (2012), p. 94 ff.

__Quantitative required personnel__

In the context of factory planning, the number of employees needed in the future is of major interest. The methods for the determination of the quantity of the needed personnel can be grouped into the two categories gross and net required personnel.[73]

Due to the fact that the number of employees had not to be calculated, no further details are given but can be found in the given literature.

2.4.1.3 Dimensioning of Areas

Since the dimensioning of the areas has a huge influence on, among other things, the investment costs, the determination of the required areas represents a core task within a factory planning project. The basis for the calculation is an area classification in which partial areas are defined functionally.[74] Figure 14 shows an extract of such a classification according to the VDI-guideline 3644, in which a general distinction is made between areas with and without building.[75]

Within the scope of this work, special attention is paid to production areas, assembly areas, and storage areas.

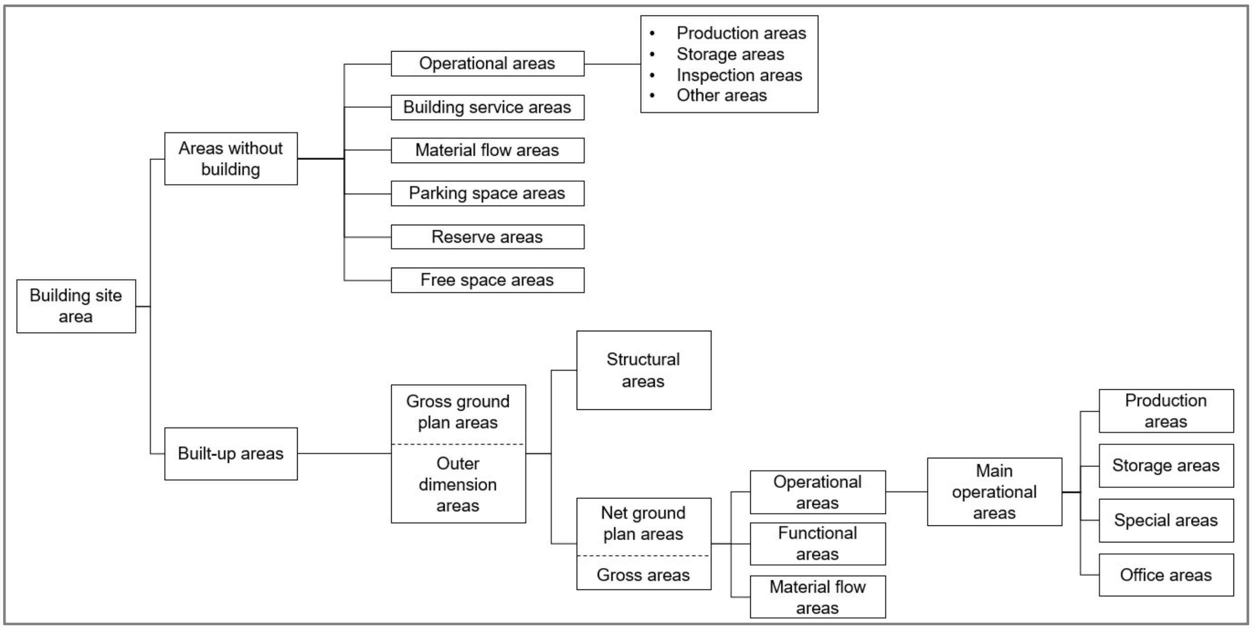


Figure 14: Extract of the area classification[76]

---

[73] Cf. Grundig (2012), p.95 ff.
[74] Cf. Grundig (2012), p.100
[75] Cf. VDI 3664 (2010), p. 6
[76] Cf. VDI 3664 (2010), p.7

Even though there are different methods to determine the required area, only those two that were used during the project are explained below.

Unless otherwise indicated, the reference given in point a.) refers to all formulae given within this subchapter.

a.) Method of functional area survey for mechanical workshops[77]

In this method, the workshop area A_{WA} is formed in a simplified manner from the following partial areas:

- Production area A_F
- Area for the interim stock A_{ZL}
- Area for transport and traffic A_T
- Additional area A_Z

By percentage additions to the production area, the other three mentioned are determined. Thus, the production area serves as a basis for calculating the entire required workshop area.[78]

If the machine workspace is A_{MA}, then the production area is calculated according to the following formula:

$$A_F = \sum A_{MA} \tag{2}$$

Figure 15 shows the definition of the machine workspace.

[77] Cf. Nestler (1968)
[78] Cf. Grundig (2012), p. 103

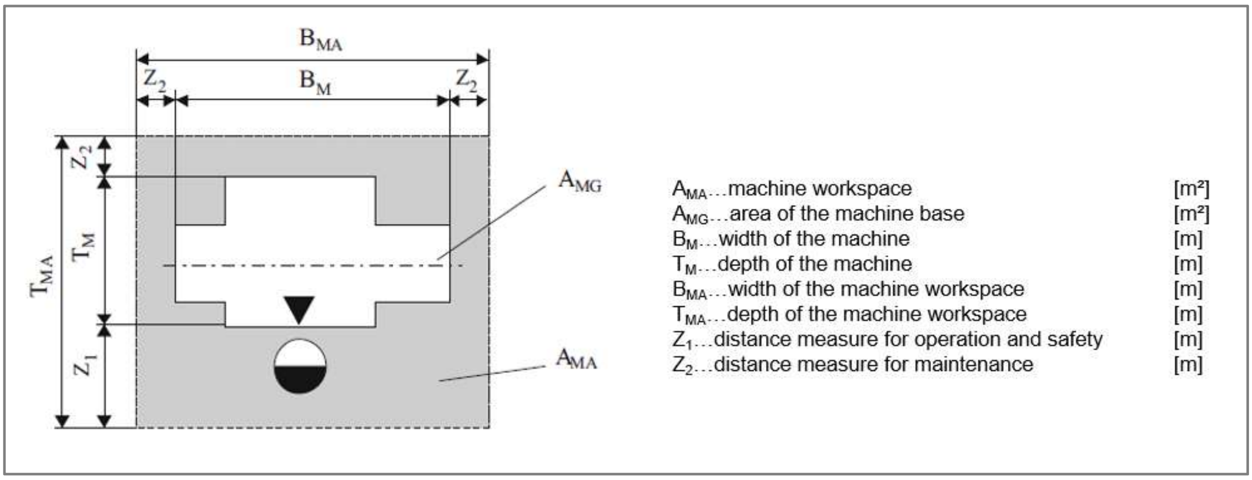


Figure 15: Structure of the machine workspace[79]

While the distance measure for operation and safety is expected to be one meter, a surcharge of 0.4m is assumed for the maintenance. Taking into account these two values, the machine workspace can be calculated as follows:

$$A_{MA} = B_{MA} * T_{MA} = (B_M + 0.8) * (T_M + 1.4) \tag{3}$$

With this formula the machine workspace for every machine can be calculated, if the dimensions of the machines are known. Therefore, this is a prerequisite that must be met to use this method.[80]

As mentioned, the other sub-areas are considered with percentage additions. Investigations have shown that the area for the interim stock and the area for transport and traffic each account for 40% of the production area. The additional area, on the other hand, is included in the calculation with a 20% allowance. Thus, the workshop area according to Nestler (1968) can be calculated as follows:

$$A_{WA} = A_F + 0.4 * A_F + 0.4 * A_F + 0.2 * A_F = 2 * A_F \tag{4}$$

For the determination of the area, it is not necessary to know the arrangement of the individual machines. In addition to that, the required equipment can be accommodated within the calculated area, as long as it does not exceed the normal level.[81]

[79] Cf. Grundig (2012), p. 104
[80] Cf. Grundig (2012), p.105
[81] Cf. Kettner et al. (1984), p. 78

b.) Calculation of the assembly production area

In general, a distinction can be made between the following types of assembly areas:[82]

- Assembly on the ground
- Work at assembly benches
- Work in testing areas
- Work on conveying equipment
- Work at workbenches
- Workstations on machines and plant

All six types are shown in Figure 16, in which also the position of the assembly unit or the machine is shown.

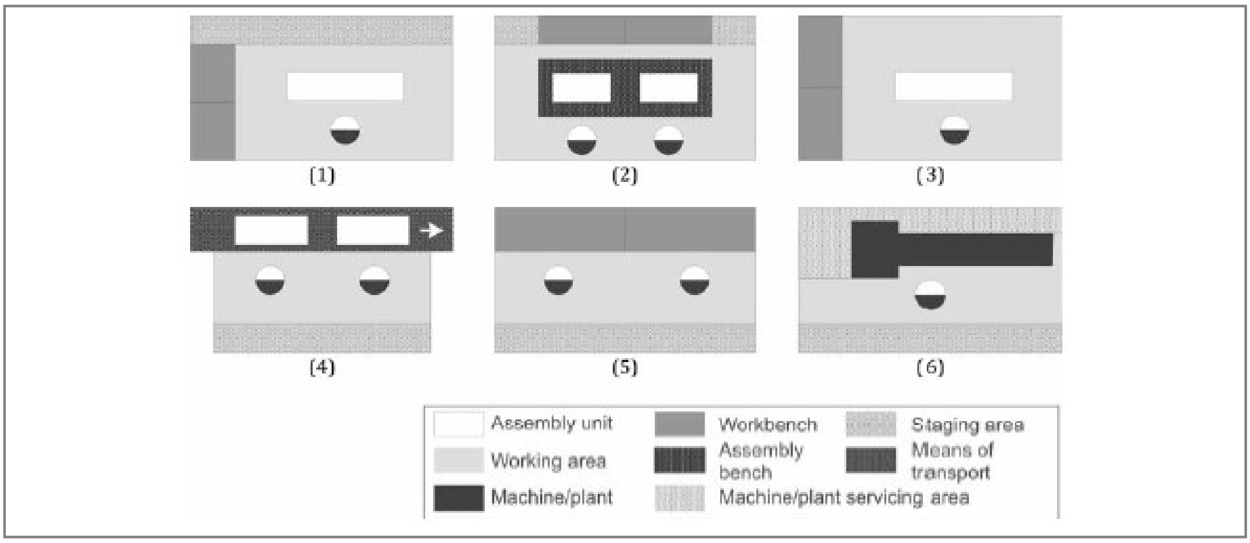


Figure 16: Six types of assembly areas[83]

Since only type 1 was of interest during this project, the calculation of this area will be discussed in more detail.

Type 1 is characterized by the fact that the assembly unit is located directly on the ground. In addition to that, it can be seen that an access to the unit is possible from all sides.[84]

The use of Formula 5[85] allows the calculation of the required floor space for the assembly area type 1.

[82] Cf. Rockstroh (1982), p. 56
[83] Schenk et al. (2010), p.111
[84] Schenk et al. (2010), p.111
[85] Schenk et al. (2010), p. 112

$$A_{AA1} = A_{AU} + A_{WB} + A_{SA} + A_R \tag{5}$$

A_{AA1}…assembly area type 1 [m²]
A_{AU}…assembly unit floor space [m²]
A_{WB}…workbench floor space [m²]
A_{SA}…staging area floor space [m²]
A_R…residual floor space [m²]

The dimensions of the area are design dependent. Assuming that there is one primary working side, up to three secondary working sides are possible. This leads to a further division of the assembly area type 1 into six different assembly area types. All of them can be seen in the next figure.[86]

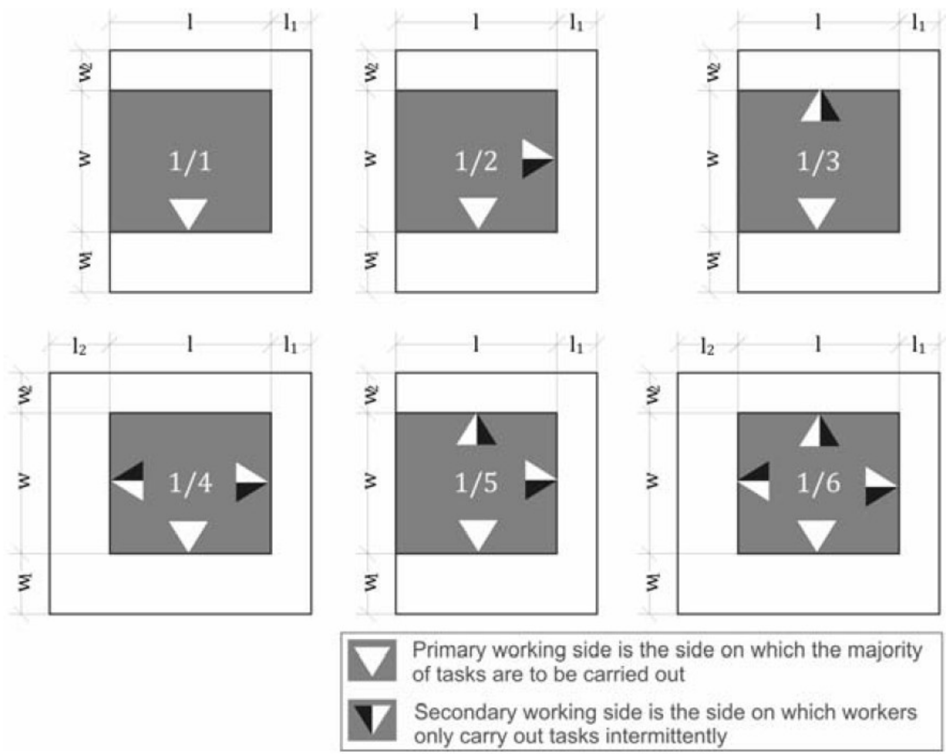


Figure 17: Sub-types of the assembly area type 1[87]

Due to the fact that the employees in the assembly area of the company the layout was planned for has to have access to the unit from all sides, type 1/6 has been used during this project.

To calculate the required floor space for the assembly unit, Formula 6[88] can be used.

[86] ibidem
[87] ibidem
[88] Schenk et al. (2010), p.113

$$A_{AU} = (l_{AU} + l_1 + l_2) * (w_{AU} + w_1 + w_2) * f_1 + N_{AU} \quad (6)$$

l_{AU}…length of the assembly unit [m]
w_{AU}…width of the assembly unit [m]
l_1, l_2, w_1, w_2 …assembly area additions [m]
f_1…plus factor according to the number of workers
N_{AU}…number of assembly units

The area of the assembly unit depends on the dimensions of the unit that is to be assembled. Additionally, this formula considers also the number of employees, that are working in the area and the number of units that are to be assembled. The plus factor f_1 can be taken from tables. Its range is usually between 0.5 and 1.[89]

The additions for the assembly area, which depend on the different sub-types, can be seen in the following Table 1.

Type	Secondary operating sides		Working height [m]	Assembly area additions [m]			
	opposite	at the side		l_1	l_2	w_1	w_2
1/1			≤1.3	0.6		1.2	0.6
			>1.3<3	0.6		1.6	0.6
1/2		1	≤1.3	0.85		1.2	0.6
			>1.3<3	1.6		1.6	0.6
1/3	1		≤1.3	0.6		1.2	0.85
			>1.3<3	0.6		1.6	1.6
1/4		2	≤1.3	0.85	0.85	1.2	0.6
			>1.3<3	1.6	1.6	1.6	0.6
1/5	1	1	≤1.3	0.85		1.2	0.85
			>1.3<3	1.6		1.6	1.6
1/6	1	2	≤1.3	0.85	0.85	1.2	0.85
			>1.3<3	1.6	1.6	1.6	1.6

Table 1: Additions for the assembly unit area[90]

The workbench floor space A_{WB} for the assembly area type 1 gets calculated as follows[91]:

$$A_{WB} = 1.2 * N_{AU} * N_{WAU} \quad (7)$$

It can be seen that also the workbench area considers the number of the assembly unit. In addition to that, the number of workers per assembly unit N_{WAU} is taken into account as well.[92]

89 ibidem
90 ibidem
91 Schenkt et al. (2010), p. 113
92 ibidem

To calculate the staging area A_{SA}[93] the areas of both the large and the small / medium parts have to be taken into account.[94]

$$A_{SA} = (A_{LP} + A_{MSP}) * N_{AU} \quad (8)$$

A_{LP}…area of the large parts [m²]
A_{MSP}…area of the medium and small parts [m²]

The last sub-area that is necessary to determine for the assembly area type 1 is the residual area A_R which can be calculated as follows[95]:

$$A_R = \left(w_{AU} + 1.4 + \frac{1}{N_R}\right) * 0.6 * N_R \quad (9)$$

2.4.1.4 Dimensioning of the other media

As a rule, the dimensioning of any "other media" (such as waste disposal) is handled by a special project developer. However, the factory planning team has to provide a detailed scope of tasks as a basis to meet all requirements.[96]

2.4.2 Structuring

The results of the structure planning phase lead to an idealized solution concept, which can be called *"ideal layout"*. This layout is the basis for the following planning of the real layout. The planning of the structure is, inter alia, possible through the determination of workplace, space and internal building structures. The goal of this phase is an arrangement of workplaces within areas and an arrangement of areas within buildings that is both spatial and functional.[97]

A distinction between the following objects that have to be arranged can be made:[98]

- Workplace level: considers elements of the workplace and the equipment which are in the immediate workplace environment
- Area level: workplaces, production islands, elements of logistics, …
- Building level: Areas, workshops, production stages

Basically, it can be said that the design of solutions in the context of the structure planning is significantly influenced by the material's flow. The reason for this is the fact that these

[93] Schenk et al. (2010), p.114
[94] ibidem
[95] ibidem
[96] Cf. Grundig (2012), p. 108
[97] Cf. Grundig (2012), p. 112
[98] ibidem

flows make up between 15 and 60% of the costs of production. Therefore, the arrangement of the objects is taking the operations and work sequences of the individual products into account.[99]

In order to design the ideal layout, both the material flow and the manufacturing form must be known.[100] Since the material flow has already been discussed in an earlier chapter, only the production forms will be explained in the following subchapter. Before describing the different forms of manufacturing it is useful to understand what types of manufacturing exist in general. A short overview is given accordingly.

2.4.2.1 Manufacturing types

A company's manufacturing type can be derived from the production program. Possible forms of manufacturing can then be deduced.[101]

Basically, companies can be divided into single-product companies and multi-product companies. Based on this, a classification can be made between single-item production, serial production, batch production, and mass production.[102]

In the following the types are to be described. Since the lot sizes posed a special challenge during this project, the corresponding manufacturing type and its challenges will be explained in more detail.

a.) Single-item production

This is the production of individual products. Although the number of products to be produced may differ from one, in general it is talked about a few products. This type of manufacturing often follows the "make-to-order" principle, meaning that an attempt is made not to build up a stock.[103]

b.) Mass production

Mass production refers to the production of large quantities of identical or similar products. In order to avoid a lack of materials, a precise planning of the material flow is necessary. The effort of this planning is great, but it only has to be done once.[104]

c.) Batch production

This manufacturing type is similar to the mass production. A similarity of the products, which exists because of different conditions, is present. It can be caused by the use of

---

[99] Cf. Grundig (2012), p. 114 ff.
[100] Cf. Grundig (2012), p. 115
[101] Cf. Dolezalek (1973), p. 129
[102] Cf. Gutenberg (1983), p. 109
[103] Cf. Dolezalek (1973), p. 129
[104] Cf. Dolezalek (1973), p. 131

the same raw material, or the presence of the same work sequences of different products.[105]

d.) Serial production

The production of several different products occurs in temporal succession. However, same products are combined in each case. Therefore, the change of a series leads to an interruption of the production.[106]

The interruption occurs due to the fact, that the change of the lot requires a re-equip. This, in turn, causes a reduction of the performance. Many companies are confronted with this problem, above all because serial production is the most common used manufacturing type in the mechanical engineering industry.[107]

In the following the term lot size will be discussed in more detail. In addition to that, the calculation of the optimal lot size is shown.

The Lot Size

Normally, the lot sizes are not based on the customer demand and represent therefore an optimization potential. However, the achievement of the goals depends not only on the size of the lots, but also on their sequences.[108]

The problem of the lot sizes can also be considered from a cost technical point of view. First of all, costs that are independent from the lot size have to be defined. These are called lot-fixed costs. In contrast to this are those costs that increase with a rising lot size. These are the costs for storage and the costs of interest. The ideal situation is reached when the costs per produced quantity is at a minimum. This amount is called the optimum lot size.[109]

In the following the classical calculation formula according to Harris (1913) is presented.

This formula is applicable only if the following listed conditions are fulfilled:[110]

- Demand per time unit is known and constant
- No storage incapacities of materials
- No bottlenecks regarding the liquidity
- Any kind of discounts are not taken into account
- Only one storage is used

[105] ibidem
[106] Cf. Dellmann (1980), p.45
[107] Cf. Dolezalek (1973), p. 130
[108] Cf. Erlach (2010), p. 18
[109] Cf. Pack (1964), p. 9
[110] Cf. Arnolds / Heege / Tussing (1996), p. 64

- No dependencies between different products

The goal of the optimum lot size is the minimization of both the costs of ordering and the costs of warehousing. While the first ones decrease with increasing lot sizes, the costs for warehousing increase the higher the lot size becomes.[111]

This situation is illustrated in the following Figure 18.

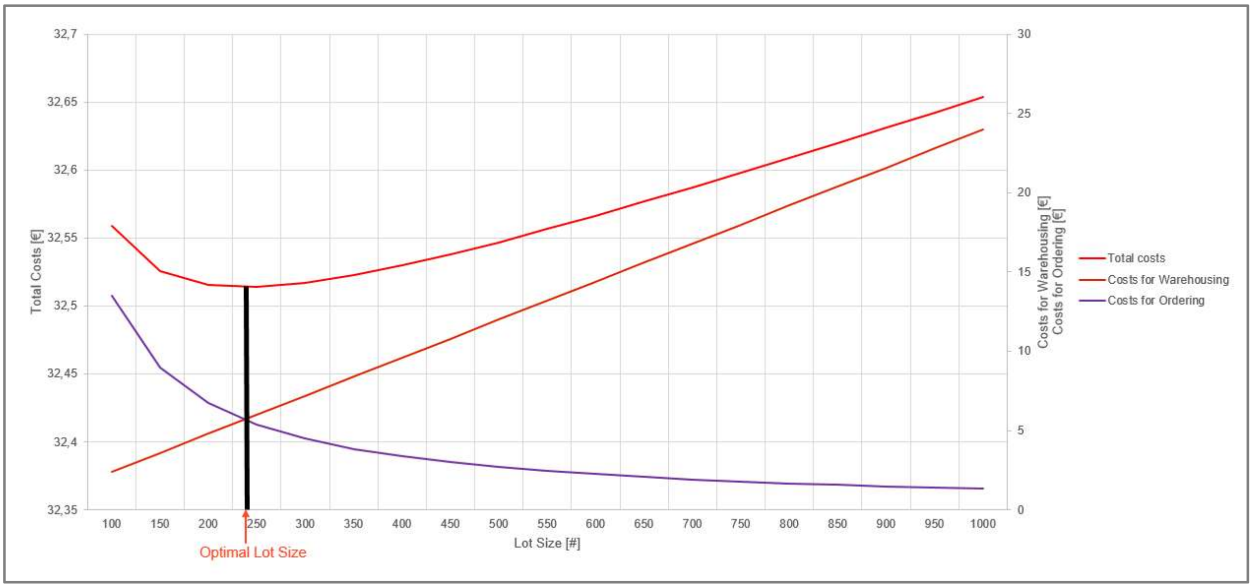


Figure 18: Cost curves for the Harris formula[112]

The formula according to Harris to compensate the costs which are mentioned above is as follows:[113]

$$Optimal\ Lot\ Size = \sqrt{\frac{200 * Annual\ Demand * Fixed\ Order\ Costs}{Price\ per\ Unit * Cost\ Rate\ of\ Interest\ and\ Inventory}} \tag{10}$$

Since the individual lot sizes of the products which had been analyzed during this project were specified by the company, other calculation methods are not discussed in more detail.

2.4.2.2 Manufacturing forms

A manufacturing form describes not only the spatial arrangement of the workplaces, but also the organizational structure and procedure of the production.[114] A distinction can be

[111] Cf. Arnolds et al. (1996), p. 66
[112] Based on Arnolds et al. (1996), p. 66, own representation
[113] Cf. Arnolds et al. (1996), p. 65
[114] Cf. Henn et al. (1999), p. 9-66

made between manufacturing forms in parts production processes and those in assembly processes.[115]

The fundamental manufacturing forms in parts production processes according to Dolezalek (1973) are the following:

a.) Stationary production

As the name already implies, the product is stationary. This means, that all work on the product is done in the same place.[116] Both the labor force and the necessary work equipment are mobile.[117]

b.) Workshop production

The use of workshop production means that all machines that carry out the same activities are spatially grouped. However, a workshop manufacturing may also be present if machines of the same size or with the same required environmental conditions are grouped together. This form is also characterized by the missing of a constant material flow. Major disadvantage are the high space requirements for an intermediate storage at the machines and the difficult overview of both the production process itself and the work pieces.[118]

c.) Group production

Here, functionally cooperative machines and manual workstations are locally combined.[119] A comparison with the workshop production shows that not only the transportation efforts are lower, but also that there is a better overview of the production. Based on this, it can be concluded that the possibility of shorter cycle times exists.[120]

d.) Flow production

The individual workstations are arranged in such a way, that they correspond to the production sequence of the product. In addition to that, a flow production is also characterized by a clocking (timely balance) of each machine. The second one mentioned represents the biggest challenge of the flow production. The cycle time corresponds to the longest production time of a component. Therefore, all stations with lower processing times show loss times.[121]

---

[115] Cf. Grundig (2012), p. 133
[116] Cf. Dolezalek (1973), p. 133
[117] Cf. Grundig (2012), p. 135
[118] Cf. Dolezalek (1973), p. 135
[119] Cf. Henn et al. (1999), p. 9-66
[120] Cf. Dolezalek (1973), p. 138
[121] Cf. Dolezalek (1973), p.139

These four manufacturing forms are shown graphically in the following Figure 19.

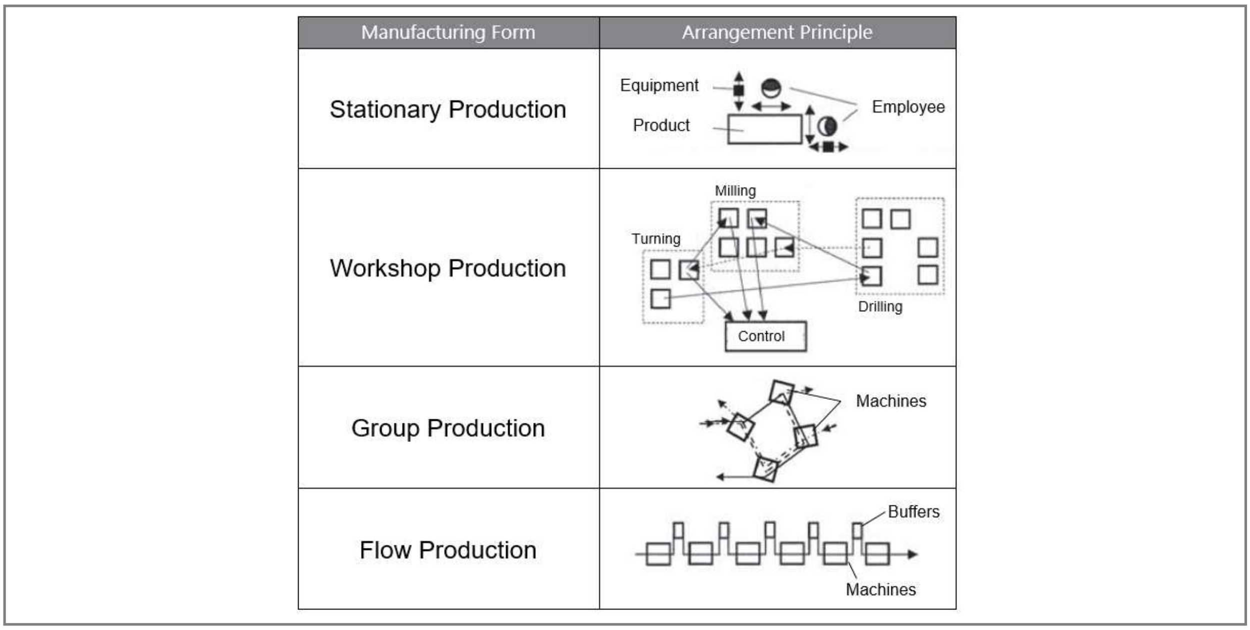


Figure 19: Manufacturing forms[122]

In the following, those manufacturing forms in assembly processes according to Grundig (2012) will be explained, which reflect the assembly processes of the company the layout is planned for:

e.) Row assembly

The assembly stations are arranged in a stationary manner, which creates a flow direction. With this type of manufacturing form, it is permissible to skip individual assembly stations, if necessary. This is the case, for example, if a specific product does not require an operation step.[123]

f.) Assembly in cycle lines

This type of assembly line avoids the occurrence of buffer formation. An explanation for this is provided by the consideration of the material flow. This flow is bound to the specified cycle time. The cycle line assembly requires a synchronization of the individual workstations.[124] The total workload that is required to mount a product is the sum of the operation times. Finding a practicable balance within the line is the aim of any type of *"assembly line balancing problem"*. This can be achieved by assigning the operations to the different station in such a way, that any kind of priority conditions or other restrictions are fulfilled. Although there are different approaches for solving the problem mentioned

[122] Based on Grundig (2012), p. 135, own representation
[123] Cf. Grundig (2012), p. 154
[124] ibidem

above, one rule can generally be stated. A balancing of the line is only attainable if the station time of neither station is higher than the cycle time. This applies in those cases, where a fixed shared cycle time exist.[125]

2.4.2.3 Designing the ideal layout

The ideal layout is also called a restriction-free layout. The reason for this is that any kind of restrictions are not taken into account yet. This layout only displays the arrangement of the functional units in a material-flow optimized way.[126]

A variety of data are required to plan the ideal layout. This includes, for example, the transport matrix or the needed space per workstation.[127] This basis has already been discussed in previous chapters. Therefore, only the models for planning the ideal layout are mentioned in the following.

Even if there are different methods for the designing of an ideal layout, they all have the same goal. They try to minimize the total transport intensity, which is calculated as shown in the following:[128]

$$T = \sum \sum t_{ij} * e_{ij} \tag{11}$$

t_{ij}…number of transports between i and j [#]
e_{ij}…distance between i and j [m]

Figure 20 shows the classification of the solution methods to optimize the transport intensity.

[125] Cf. Boysen et al. (2007), p. 511
[126] Cf. Grundig (2012), p. 159
[127] Cf. Grundig (2012), p. 161
[128] Cf. VDI 3595 (1999), p.5

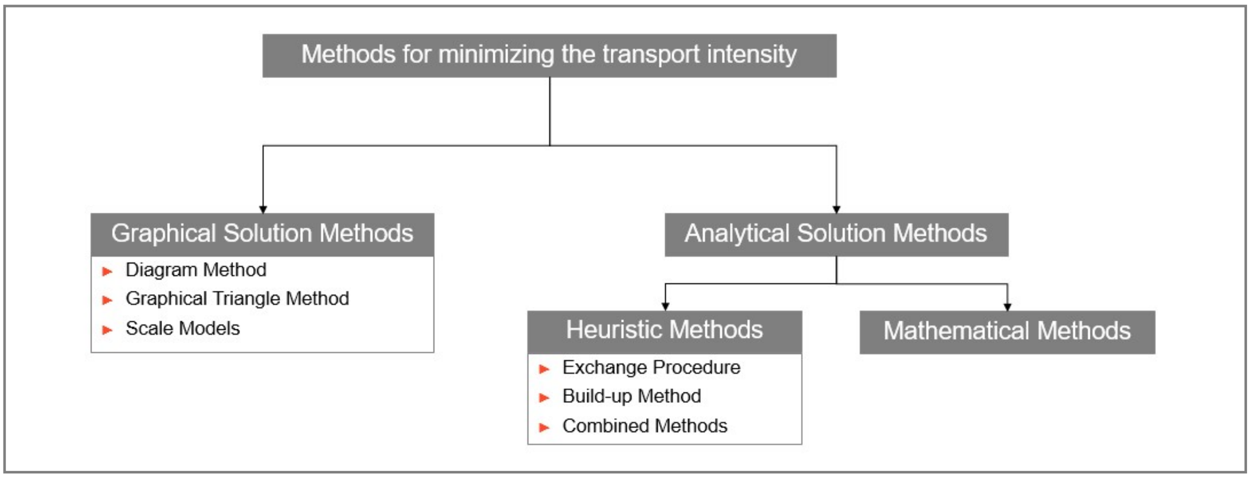


Figure 20: Solution Methods for the ideal layout[129]

Graphical methods are based on the visualization of the material flow. A step-by-step improvement can be achieved by changing the arrangement of the individual stations.[130] Due to the fact that neither graphical nor mathematical methods had been used during this project, these two solution methods are not discussed in detail.

In the following the heuristic build-up method is explained, which has been used to find an ideal layout.

Modified triangular method according to Schmigalla (1995)

A defined grid of equilateral triangles is used for the arrangement of the stations. Firstly, those two operation resources with the greatest intensity are arranged centrally. These stations are also referred to as the core of the layout.[131]

Afterwards, those stations which have the highest intensity to the already placed ones have to be determined. The placement of these is then carried out on the point that shows the minimum of transport intensity. This step is repeated until all stations have been worked through.[132]

This method delivers an initial solution, which has to be revised in the following step of the structure phase within the factory planning.[133]

Particularly noteworthy is the influence of the amount of operating resources in this process. An increase of this amount leads not only to a decreasing possibility of finding

[129] Based on Grundig (2012), p. 164 f., own representation
[130] Cf. VDI 3595 (1999), p. 5
[131] Cf. Arnold / Furmans (2007), p. 291
[132] Cf. Grundig (2012), p. 165
[133] Cf. Grundig (2012), p. 166

an optimal layout, but also to an increasing calculation effort. These are the reasons for a computer-aided layout planning in practice.[134]

Finally, the grid is to be dealt with briefly. Even if the name of the method contains the word “triangle”, the possible grids are not limited to that geometrical form. Square grids can also be used.[135] These have been the ones used for the design of the ideal layout within this project. The reasons for this are listed in the corresponding chapter.

2.4.3 Design of Solution Variants

A spatial and realizable arrangement of units under consideration of function, material-flow, space, practice as well as official influencing factors is called real layout.[136]

This section of factory planning deals with the revision of the ideal layout. This means, that a planning “into the reality” occurs. Thus, this phase is based on the previously described sub-phases within the structuring. Taking into account the real areas, different layouts are designed firstly. Subsequently, not only the selection but also the arrangement of various elements of logistics takes place. The final stage of this sub-phase is the selection of a designed variant.[137]

Since the part with the logistic elements had no significance during the project, only the other two mentioned stages are explained below.

2.4.3.1 Design of the real layout

To avoid any planning errors, restrictions have to be specified firstly. These can be divided into governmental and operational constraints. The first of these must be complied with by law.[138]

After the specification of the restrictions, different real layouts can be developed. A distinction between manual and computer-aided planning techniques can be made. With the manual procedure, which can also be described as the trial procedure, variants with different arrangements are processed by rearranging the individual objects. Computer-aided methods use CAD-systems for the draft of layout variants.[139]

---

[134] Cf. Arnold et al. (2007), p. 294
[135] Cf. Grundig (2012), p.165
[136] Cf. Schenk / Wirth / Müller (2014), p. 341
[137] Cf. Grundig (2012), p. 167
[138] Cf. Schenk et al. (2014), p. 341
[139] Cf. Grundig (2012), p. 175 ff.

2.4.3.2 Selection of a variant

In this sub-phase the individual variants are evaluated by comparison. The goal is to find the layout which delivers an overall optimum. As the evaluation is carried out under uncertainties, it should take place within a team of experts.[140]

In order to determine the preferred variant, the evaluation is carried out on the basis of both criteria that can be quantified and criteria that cannot be quantified. For the latter, the so-called value benefit analysis is suitable.[141]

Value-Benefit-Analysis

The value benefit analysis generally considers those target figures that are of relevance for the upper management. Firstly, the degree to which the individual target criteria have been met by the individual variants has to be measured. This is then given as a partial value benefit. Taking into account the weightings of the criteria, these partial values are then combined to form an overall value for each variant. This value is then called the value benefit.[142]

The following steps are necessary to carry out the value benefit analysis:[143]

- Definition of evaluation criteria
- Determination of weightings of these criteria
    - A simplified comparison of pairs has been carried out for this purpose within the framework of this project. The relative significance of a criterion is determined by a direct comparison of two criteria.[144]
- Determination of the partial value benefit
- Determination of the value benefit
    - Multiplication of the weightings with the partial value benefit[145]
- Evaluation of the advantageousness

In addition to this method, there are of course others, such as the simple scoring method. It represents a very simplified selection principle and is therefore not explained in detail.[146]

In addition to the evaluation methods mentioned above, the factory planning also includes profitability calculations, which, in turn, are purely monetary in nature. Based on the

---

[140] Cf. Grundig (2012), p. 201
[141] Cf. Schenk et al. (2014), p. 343 f.
[142] Cf. Götze (2006), p. 180 f.
[143] Cf. Blohm / Lüder / Schaefer (1995), p. 177
[144] Cf. Götze (2006), p.188
[145] Cf. Grundig (2012), p. 203
[146] Cf. Grundig (2012), p. 204

available data, these calculations can be divided into static and dynamic methods.[147] These methods are briefly explained below. However, due to a simplified calculation during the project, no further details on various formulas or derivations are given.

Static investment calculation procedures

Static methods differ mainly in the fact, that an economic situation is considered only for a single period. However, this decisive disadvantage of these methods also derives a number of advantages. It simplifies not only the calculation itself, but also the procurement of the necessary data. Some of these methods are the cost comparison calculation, profit comparison calculation, profitability comparison calculation, and the static amortization calculation. These methods can be used, inter alia, to make comparisons between different alternatives.[148]

Dynamic investment calculation procedures

These methods are characterized by the consideration of different payments with a fixed interest rate. This is the reason why these procedures reflect the reality in a much better way than the static ones. The net present value method, the internal rate of return method, and the annuity method are, among others, used methods. They all have in common that each of them can be used to evaluate the absolute advantageousness of investment alternatives.[149]

The following Figure 21 shows the different methods in a simplified form.

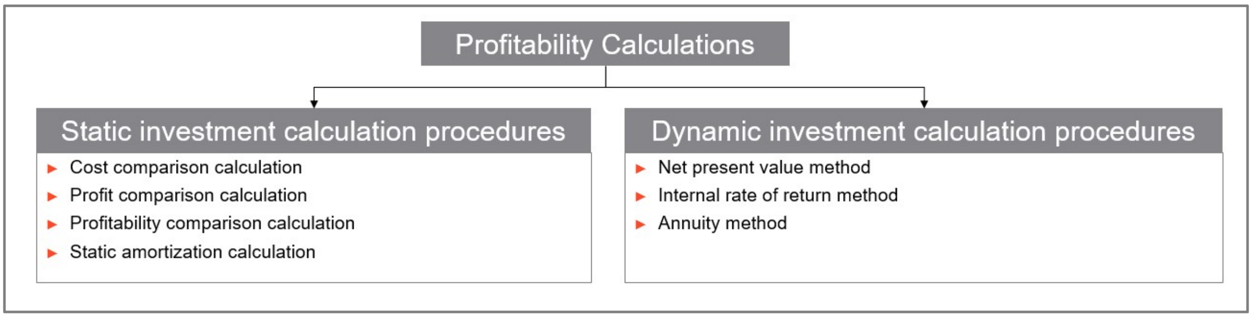


Figure 21: Profitability calculations within the factory planning[150]

The phases of factory planning described so far were the main tasks within this project. Therefore, the remaining phases will only be explained briefly.

[147] Cf. Grundig (2012), p. 206
[148] Cf. Poggensee (2009), p. 39 ff.
[149] Cf. Poggensee (2009), p. 108 f.
[150] Based on Grundig (2012), p. 206 f., own representation

2.5 Detailed Planning

The aim of this phase is to develop detailed extensions based on the results of the structure phase and, consequently, also based on the preparation phase. The goal is to achieve a fair interaction between people, equipment and materials at each workplace.[151] Some selected tasks within this phase are:

Machine placement

In this phase of the factory planning project the arrangement of the machines gets specified with respect to the different transportation routes. In addition to the required areas and the manufacturing forms, other aspects regarding the material flows and the production itself are taken into account. For example, any necessary conveying means (such as a required portal crane for certain work areas) are considered.[152]

Workplace design

The design of workplaces taking into account human factors not only reduces manufacturing errors but also accidents during the use of the products. For this and other reasons, an ergonomic design should be planned right from the start.[153]

Information and Communication technologies

Here, data preparation and data generation are taken into account. Software solutions for planning and control have to be selected accordingly. Based on this, room allocation is then necessary. This includes for example, the processor rooms which have to be planned. In addition, also communication systems are to be provided. Beside telephone and monitoring systems, alarm techniques (as an example) will also be used and have to planned accordingly.[154]

Development of the detailed layout

During the development of the detailed layout, spatial and ground plan geometries are depicted true to scale. However, all conveying and storage technologies are also drawn in the detailed layout. In addition to that, the assignment of the workers to the workplaces is also marked. After drawing in the main material flow streams, a very precise layout is then obtained.[155]

---

151 Cf. Grundig (2012), p. 208 f.
152 Cf. Grundig (2012), p. 209 f.
153 Cf. Anderson (2014), p. 129 f.
154 Cf. Grundig (2012), p. 215
155 Cf. Grundig (2012), p. 216

All results achieved so far, as well as calculations for the success of these results, have to be documented. This is then referred as the project definition. This document forms the basis for the next phase within the factory planning project, the implementation phase.

2.6 Implementation Planning

This phase can be described as the first one, within the implementation. In addition to the definition of required tasks, also schedules are created, and responsibilities are assigned.[156]

An essential part of this phase is the tendering procedure, in which not only tenders are requested, but also contracts are awarded. Care should be taken to obtain a sufficient number of orders. Negotiations should be well documented and, ideally, signed by both parties. After the tendering process, a decision for a provider should be made as fast as possible, to avoid any delays in the project.[157]

Contents related to the commissioning of the factory are also taken into account during this phase. For example, the start-up of the production is planned in advance. The reason for this, is to be able to guarantee the first supply with material. The planning of the personnel is also taken into account. This includes not only the recruitment but also the qualification of the future employees.[158]

The systems of project management will often be used to help with large projects. “Large” does not refer to the size of the factory to be planned, but rather to the degree of the complexity of a project.[159]

2.7 Implementation

This phase begins with the execution and ends with the commissioning of the factory. In between, however, the handover takes place.[160] These three tasks will be briefly explained here.

<u>*Execution*</u>

This involves, inter alia, the controlling and the monitoring of the companies, which were commissioned to carry out the work during the previous phase. The execution also includes the compliance with safety regulations and quality standards. The adherence to

[156] Cf. Grundig (2012), p. 217
[157] Cf. Pawellek (2008), p. 263 f.
[158] Cf. Grundig (2012), p. 218 f.
[159] Cf. Pawellek (2008), p. 271
[160] Cf. Grundig (2012), p. 219

deadlines plays an important role as well. Any necessary corrections are carried out before the next sub-phase, the handover, starts.[161]

Handover

This sub-phase is about, as the name already implies, the handover of complete or partial buildings to the client, who is the owner of the factory. It is primarily about the pursuit of administrative tasks. In addition to checking invoices, for example, a final documentation that contains all relevant project-related records must be prepared.[162]

Commissioning

The time span from the start of production to the achievement of various, defined targets (e.g. capacity utilization, throughput, or turnover) is referred to as commissioning and can be divided into the following phases, as shown in Figure 22.[163]

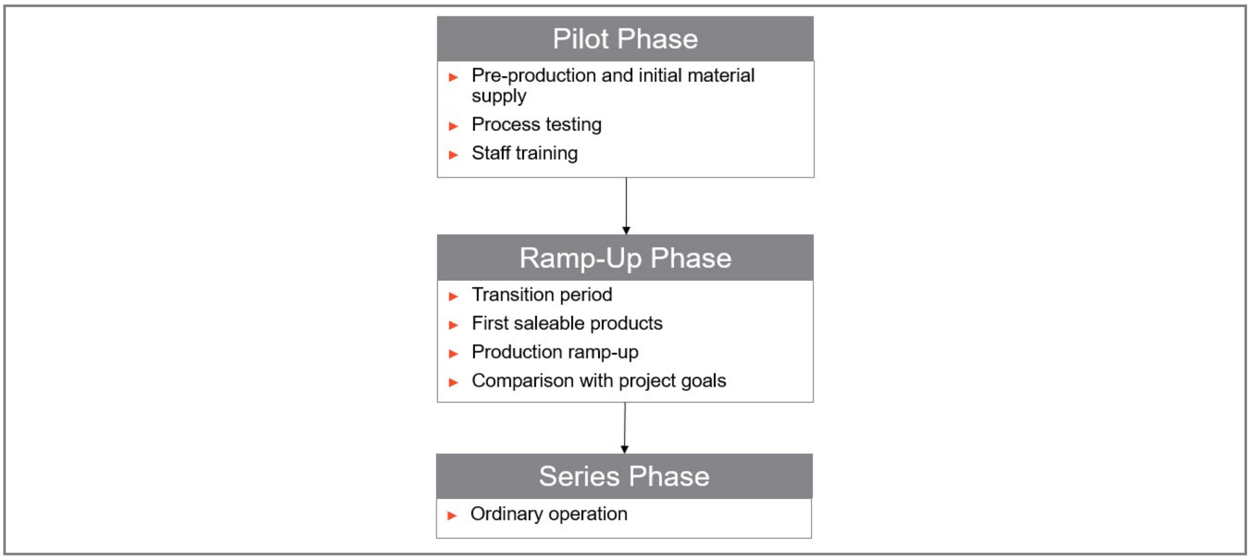


Figure 22: Phases of commissioning[164]

The achievement of the series phase and thus the stable production can be interpreted as the completion of the project. Nevertheless, an analysis of the causes for various deviations (such as the costs) is necessary.[165]

Since this project was carried out with the help of a simulation, the use of modern tools will be discussed as the last part of the methodology.

[161] Cf. Grundig (2012), p. 220
[162] ibidem
[163] Cf. Grundig (2012), p. 220 f.
[164] Based on Grundig (2012), p. 220 f., own representation
[165] Cf. Grundig (2012), p. 221

2.8 IT-support in Factory Planning

If one considers the facts that nowadays the life cycles of products are not only shorter (compared to the past) but also that these products are more varied and that orders are getting more and more adapted to the customer's requirements, it becomes clear that the production has to be designed more and more product and order (customer) oriented. Flexible factory planning concepts are necessary to meet these requirements. The use of EDP (electronic data processing) systems is a suitable tool for this. These tools can not only be used for analysis, they are also suitable to carry out evaluations, optimizations, and simulations.[166]

Within this project, a simulation has been used to deal with the complexity of the optimal lot size (see chapter 2.4)

2.8.1 Dynamic Factory Planning

The use of a simulation within a factory planning project, allows consideration of process behaviours which are both time-dependent and dynamic. Thus, if a simulation is used, it can be called dynamic factory planning. This type of factory planning allows the visualization of complex systems that either already exist or are to be planned. The main advantages of a dynamic factory planning approach are the increased accuracy of the project result and the limitation of various project uncertainties.[167]

2.8.2 Simulation in Factory Planning

Before the structure and procedure of a simulation will be discussed in the following, different types of simulations will be introduced first.

2.8.2.1 Types of Simulation

Simulations can be applied in different areas. Accordingly, there are different types of simulations.[168]

Monte Carlo-Simulation

This simulation is based on two assumptions. The distributions of the probabilities must be known. In addition to that, successive events are independent from each other. In the Monte Carlo-simulation static, stochastic systems are analysed. For this purpose,

---

166 Cf. Pawellek (2008), p. 275 f.
167 Cf. Grundig (2012), p. 239
168 Cf. Domschke / Klein / Drexl / Scholl (2015), p. 234

sampling experiments are carried out in which different scenarios are simulated with different parameter selection.[169]

Discrete Event Simulation

This is the simulation of dynamic systems, which are described by variables that are time-dependent. These variables change due to events. A distinction can be made between period-oriented and event-oriented time control. With the latter, those events are skipped which are uneventful. This leads to a saved computing time and is also the reason why this type of discrete simulation is more common than the period-oriented simulation.[170]

Continuous Simulation

Continuous simulation, like discrete ones, also deals with dynamic systems. Systems in which the condition variables change continuously over time are analysed. The behaviour of the model is described by so-called feedback models, whereby a distinction is made between positive and negative feedback.[171]

Agent-Based Simulation

Once again it is a question of the analyses of dynamic systems. The difference being, that this simulation focuses on complex interdependencies that arise through heterogeneous and networked interactions between the actors. As a rule, it is not possible to determine functional relations between the behaviour of the system and the actions of the actors. During the simulation, a period-oriented transformation of the initial state into a final state takes place. Within this period, actions are taken by the agent.[172]

An in-depth discussion can be found in Domschke et al. (2015). The necessity of a systematic procedure for a simulation study which was carried out will be focus in the next paragraph.

[169] Cf. Domschke et al. (2015), p. 234 f.
[170] Cf. Domschke et al. (2015), p. 235
[171] Cf. Domschke et al. (2015), p. 235 f.
[172] Cf. Domschke et al. (2015), p. 236

2.8.2.2 Procedure of a simulation study

In general, a simulation study is structured as follows:

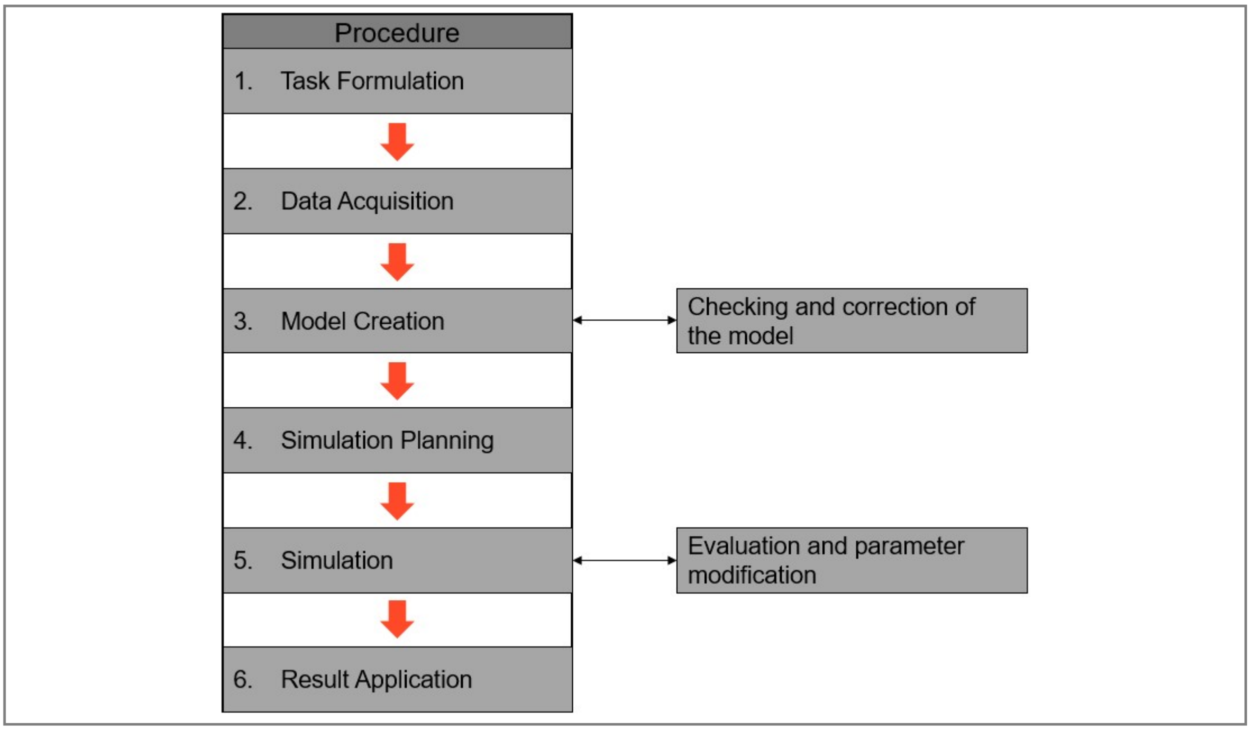


Figure 23: Systematic structure of a simulation study[173]

First, the data must be collected and made available. This is done in the data acquisition phase after the task formulation has been completed. Since the reliability of a simulation study is essentially dependent on the data, attention must be paid for appropriate quality of the data. As soon as all information is available, the model creation can begin. The model will represent the reality in the computer. In this phase of the study, the model is also validated and checked for correctness and meaningfulness. This is followed by several simulation runs. These are carried out by changing the parameters, which are changed by the planner. Although this enables the optimization of the system, it also states that simulation systems are not optimizations systems in principle, but helpful tools for the planning project. In order to be able to make statements about the behaviour of the system, the results have to be interpreted at the end.[174]

[173] Based on Pawellek (2008), p. 294, own representation
[174] Cf. Pawellek (2008), p. 294 f.

2.8.2.3 Simulations in the different phases of factory planning

After the more general discussion about simulations, the use of this technique in factory planning will now be explored.

A large number of IT-systems are already used within factory planning projects. These systems are used for analysing and planning production processes with the aim of creating a logistics-oriented factory.[175]

In the following Figure 24 the categorization of simulation studies within the factory planning is illustrated and explained.

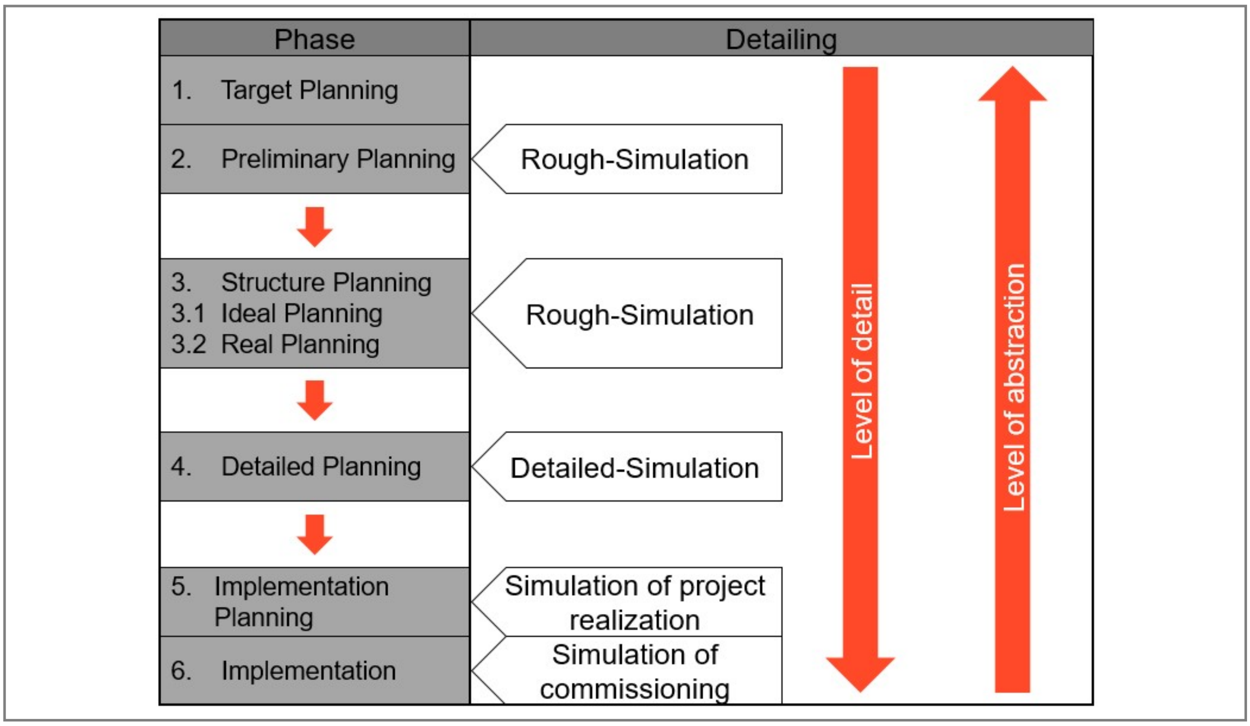


Figure 24: Categorization of simulation studies within a factory planning project[176]

Simulation in the Preliminary-Planning-Phase

The use of a simulation in this early phase of the project allows statements to be made about both production scenarios and strategies. Logistics principles and solution concepts are tested. In addition to that, it is possible to determine requirements with regard to investments.[177]

---

[175] Cf. Pawellek (2008), p. 281
[176] Based on Grundig (2012), p. 240, own representation
[177] Cf. Grundig (2012), p. 241

Simulation in the Structure-Planning-Phase

With a still high degree of abstraction, the simulation of interdependencies of operating areas is carried out under consideration of the material flow. In addition, not only the arrangement of the machines and/or work stations, but also the dimensioning of the internal infrastructure can be carried out. Different system loads are taken into account to be able to assess the factory structure. This includes, inter alia, the evaluation of the production program, which influences the production form (see chapter 2.4.2) and thus also, if the need arises, on the lot size.[178]

Simulation in the Detailed-Planning-Phase

Now the system behaviour is analysed. Throughput times and utilizations as well as the flexibility of the system are checked. The influence of disturbance variables is taken into account which allows additional statements about the failure behaviour of the system.[179]

Simulation in the Implementation-Planning- and Implementation-Phase

A cost-optimum assembly sequence of the factory is determined. Subsequently, the optimum commissioning gets checked by simulating the start-up and ramp-up behaviour.[180]

With this, well-known methods and techniques from the literature were explained, which are applied in the field of factory planning and were used in the context of this project. The application of the techniques described in chapter two occurs in the following part of this documentation.

[178] Cf. Pawellek (2008), p. 296
[179] Cf. Grundig (2012), p. 242
[180] Cf. Grundig (2012), p. 242

3 Practical Part

The following chapter provides information of all three work phases of the project. The methods described in the previous chapter were used to fulfill the required goals given by the company. Additionally, the achieved results are explained in this chapter.

3.1 Situational Analysis

The goal of the first work phase has been the collection, evaluation, and the preparation of the existing data of the actual production of the agricultural technology products. The analysis has been carried out for nine products, which were chosen by the company. These products are shown in the next subchapter.

To carry out the analysis, the necessary data had to be prepared first. The following list shows the required data base.

- Product structure, including the assemblies for each of the selected products
- Actual production data of the selected products (production program, order structure including order forecasts for the next years)
- Order times and current target times (lead times, work schedules, and process sequences)
- Actual deployed technologies and capacities or utilizations of them (machinery / manual workstations and machine data)
- Layout from the factory (CAD)

The procedure of the analysis can be seen in the following Figure 25. After finishing the data collection and preparation of the data sheets, it was possible to carry out the analysis of the production program. Afterwards the flow of materials and the processes needed to produce the products were analyzed, and an estimation of the capacity utilization was carried out. These insights gained from these four main tasks served as a base for both the identification of optimization potentials and the derivation of a catalogue of requirements. The last part of this work phase was about a voting on the required manufacturing machines that are needed in the new plant to produce the products of the agricultural line. For this purpose, checklists have been created, which are shown at the end of this chapter.

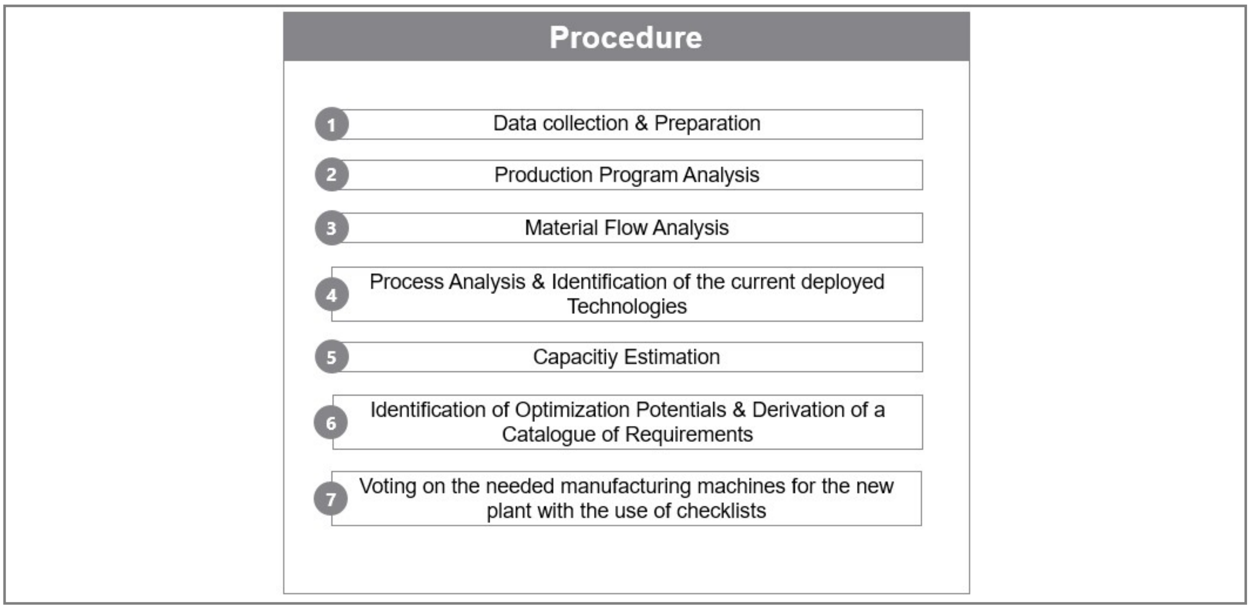


Figure 25: Procedure during the situational analysis

3.1.1 Analysed Products

Not all of the products that are manufactured in Slovenia were taken into account during this project. As already mentioned, analysis has been carried out only for the agricultural product line of the company. For this reason, the company has compiled a list of those products that should be used for the analysis. The list of the products can be seen in Figure 26.

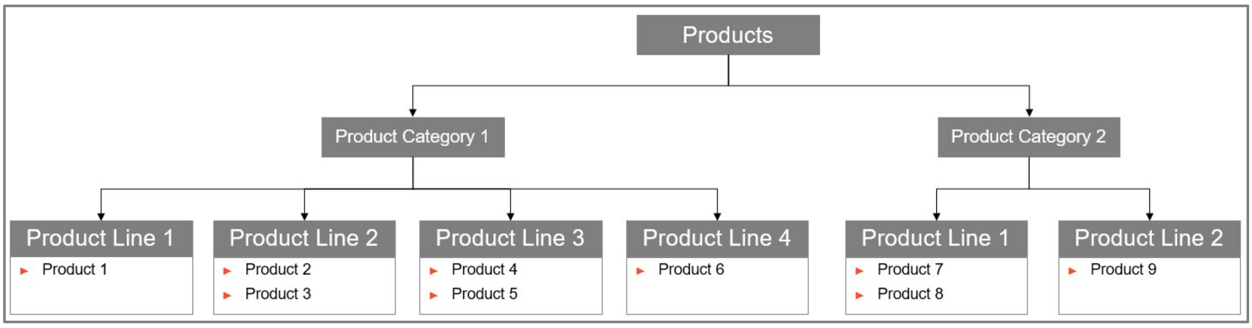


Figure 26: List of products for the analysis

It can be seen, that within the products that have to be analysed also a distinction can be made between two different product categories. These two categories differ in possibilities of usage and basic structure of the finished products. It is also noticeable that more than half of the products that have been analysed, are part of the first product category. These products simply show a higher demand than the others. At this point it should also be mentioned that the assembly process (see chapter 2.4.2.2) of the products six and nine is fundamentally different than the process from the remaining products. While the mentioned two products are assembled in a raw assembly station, the others are mounted within a cycle line. Two reasons can be named for this. The products six and nine do not only differ in the larger dimensions, also the demands for these are considerably smaller compared to the other seven products (see chapter 3.1.3).

3.1.2 Data Collection & Preparation

Most of the data has been collected by the use of an indirect data acquisition method. In particular, the bill of materials provided a large information base throughout the entire project. These lists contained not only the number and type of required components, but also the process sequences of each component and the associated setup and processing times. To use the data, that has been provided by the company effectively, it was necessary to structure the bills of materials firstly, meaning that the data sheets had to prepared for the specific purposes. The following Figure 27 shows the basic structure of the products. The first level is the finished product, in this case the product one. The second level shows one of the main subassemblies of the finished goods needed to produce the final product. The levels three or higher, in turn, can be either again subassemblies, single components of the subassemblies or raw materials which are necessary to produce the level two assemblies.

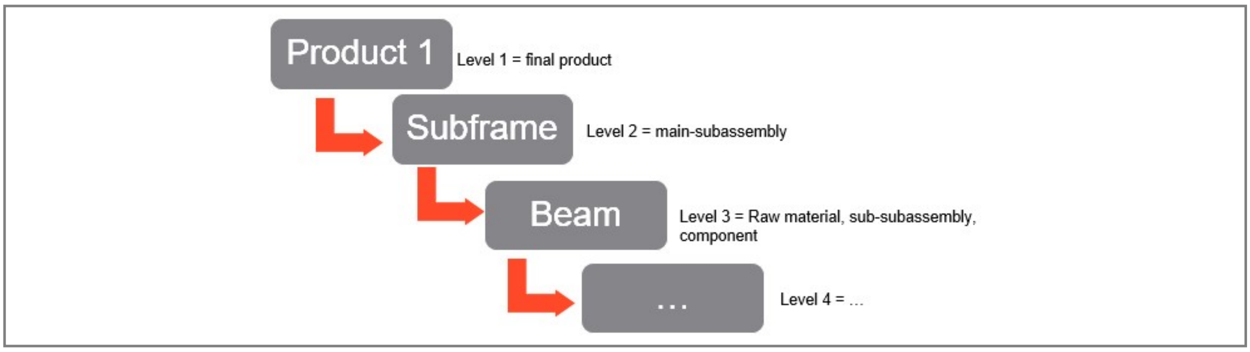


Figure 27: BOM structure of the products

3.1.3 Production Program Analysis

The goal of this analysis was to gain knowledge about the order structure, including also the order distribution for the years 2019 and 2025.

During the production program analysis, the current and the planned quantities were taken into account. The analysis has been carried out only for the nine products mentioned in the previous chapter. Due to the high differences regarding the quantity and lot size of each product, the table shown on the next page shall give an overview about the changes within the years 2019 and 2025.

-	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7	Product 8	Product 9
Quantity 2019 [#]	139	177	166	113	225	78	154	92	96
Current Lot size [#/Lot]	26	27	26	36	21	3	38	19	3
Quantity 2025 [#]	285	400	360	355	500	135	315	185	165
Planned Lot size [#/Lot]	5	5	5	5	5	5	5	5	5

Table 2: Changes in quantities and lot sizes for each product

An increase of the total amount of products to be produced by 118% is expected. To put it more precisely, an increase from 1240 to 2700 pieces is anticipated.

The stated quantity for 2025 is based on a forecast of the company. It can also be seen that a lot size of five for each product is expected for 2025. This information was also provided by the enterprise and served, like the other data given in the table, as a basis for further calculations. The result of the first analysis can be seen in Figure 28. While the grey bars show the quantity for 2019, the amount of products for 2025 is represented by the orange ones. The actual lot sizes are shown by the bars on the right side of the products.

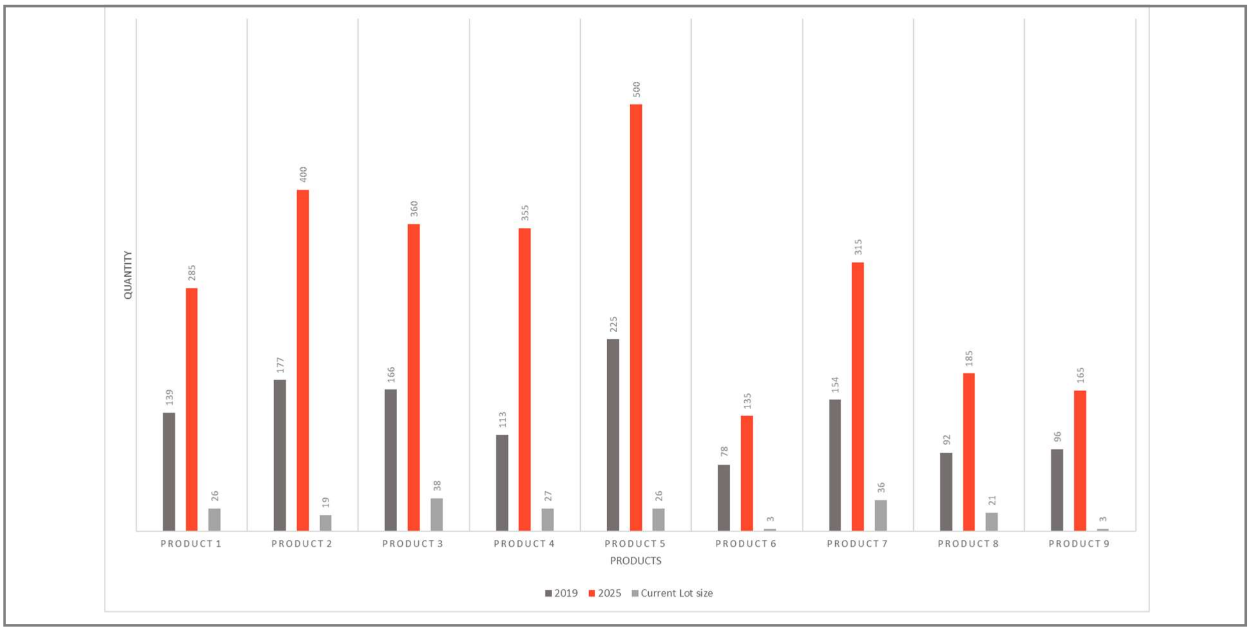


Figure 28: Result of the production program analysis

3.1.4 Material Flow Analysis

The basis for the greenfield layout planning is an overall analysis of the current situation. This also includes the analysis of the material flows within production site. Therefore, a complete workflow scheme has been created and the flow of materials has been visualized.

3.1.4.1 Procedure

The data collection occurred by using both direct and indirect methods of data acquisition. Especially those data gathered via observations or surveys were helpful in determining weaknesses regarding the material flow. After the required data was collected, the product structure was analyzed. Each of the products has been structured on the way described in Figure 27. This made it possible to differentiate main assemblies from individual components and to determine the required number of production stages. Afterwards, the working plans were examined. This included the detailed analysis of both the work processes and the work sequences. This provided not only insights about the working areas which are in relation to each other, but also made it possible to create a transportation matrix for each product. The material flow analysis (MFA) was finalized by visualizing the material flows with both a Sankey diagram and an oriented material flow scheme.

3.1.4.2 Assumptions

Due to the fact that no accurate information regarding type and number of the transportation containers was available in the company, the following assumptions had to be made:

- The production program for the year 2019 served as a basis for the transportation matrices
- Before the parts get to the welding line, an intermediate storage takes place
- One transport per container for the small parts
- Large parts were considered as single transport directly to the welding line
- Three transportations of bulk goods per lot size take place into the welding line

3.1.4.3 Results

a.) Transport Intensity Matrix

To create the intensity matrix, the creation of both the transportation and the distance matrices had to be done firstly. Both can be seen in Appendix A. Those cells that are filled yellow represent entries between workspaces that are in relation to each other. To figure out the total number of transportations between work stations during the year 2019 the transportation matrices for each product was created in a first step. Afterwards the sum of each cell was calculated which lead to the total number of transportations.

Table 3 shows the intensity matrix for the plant 1 in Slovenia for the year 2019.

Transportmatrix (Von \ Nach)	Lager innen	Lager-Bordwände	Lager-Bleche	Lager-Rohre	Lager-Zelt	1305-Presse Exzentrisch	1312-Presse hydraulisch	1422-CNC Abkantpresse Trumpf	1425Abkantpressse 650T	2311-Bandsäge OK320	2313-Bandsäge OK410	2581-Hand Plasma	2593-Plasma	2595-Laser	2600-Schleifen manuell	3111-konv. Drehmaschine	4111-konv. Fräsmaschine	4300-CNC Werkzeugmaschine	61000-Säulen bohrmaschine	6105-Säulen Bohrmaschine	6501-Radial Bohrmaschine RB40	6502-Radial Bohrmaschine RB70	7205-Schweißen Laserzelle	7223-Schweißarbeitsplätze	7602-Schweißlinie U	7602-Schweißlinie P/M	7602-Schweißlinie B	Warenausgang
Lager innen	0	0	0	0	0	567	1122	554,4	638	0	0	0	0	0	5842,4	3410,4	0	0	4498,2	429	0	1360	0	48436,7	41523,2	28492	35280,4	11125
Lager-Bordwände	0		0	0	0	0	0	0	0	0	0	0	0	0	50300	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Bleche	0	0		0	0	0	0	2770,2	7463,9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Rohre	0	0	0		0	0	0	0	0	0	0	1306,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Zelt	0	0	0	0		3857	0	0	0	1161	0	5845,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1305-Presse Exzentrisch	1764	0	0	0	0		0	509,2	0	0	0	0	0	0	0	0	0	0	220,4	0	0	0	0	6054,4	0	0	0	882
1312-Hydraulische Presse	5967	0	0	0	0	0		202	352	0	0	0	0	0	666	360,5	0	0	4353,9	0	7115,5	0	0	10472	414	0	0	3825
1422-CNC Abkantpresse Trumpf	17991,6	0	0	0	0	341	66,5		1007,6	0	0	915,2	0	0	1219,2	0	0	0	0	116,2	839,3	0	715,5	68290,5	0	0	0	10626
1425-Abkantpresse 650T	12281,5	0	0	0	0	943,8	448	641,2		0	0	2338,4	0	0	0	0	0	0	0	0	0	0	0	10964,8	684	807	684,2	3700,4
2311-Banksäge OK320	18400,4	0	0	0	0	1380,6	3944	0	0		0	0	0	0	10624,9	9680	0	0	0	0	1394	3111,1	0	4175,2	0	0	0	219,8
2313-Bandsäge OK410	3774,2	0	0	0	0	346	0	0	0	0		772,9	0	0	1287,7	7560	1216	0	1850,8	0	1519,2	855,4	0	2599,4	424,6	147,5	0	1336
2581-Hand Plasma	162,4	0	0	0	0	0	306	0	177,6	0	0		0	0	18	0	0	0	0	0	0	0	0	1175,4	3491,1	1156	1782	5765,2
2593-Plasma	10428	0	0	0	0	0	0	2336,1	3237,6	0	0	200		0	10753,6	0	0	0	0	0	0	0	0	296	0	0	0	0
2595-Laser	20433,6	0	0	0	0	858	4925,9	23562	9773,4	0	0	0	0		14690	4408,6	0	0	1630	1903,2	2525,9	0	0	30830,8	0	0	0	420
2600-Schleifen manuell	23805,6	0	0	0	0	2481,6	14208	27533,6	10758	0	0	60	0	0		2263,5	3912,1	1843,2	6303,6	1988	12892,5	900,9	0	14479,6	737,6	0	30221,4	4578
3111-konv. Drehmaschine	10054,8	0	0	0	0	0	1081,5	0	0	0	0	0	0	0	0		395,2	0	4207,4	0	224,1	0	0	11636,2	0	0	0	2881,2
4111-konv.Fräsmaschine	2193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	808,4	0	0	2162,4	0	0	0	0
4300-CNC-Werkzeugmaschine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
6100-Säulen Bohrmaschine	15850,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	13118,6	0	0	718,2	8996,4
6105-säulen bohrmaschine	4433	0	0	0	0	0	891,8	2755,6	0	0	0	0	0	0	2499,2	0	0	0	0		0	0	0	3844	0	0	0	442
6501-Radial Bohrmaschine RB40	18659,2	0	0	0	0	0	0	0	0	0	0	445,9	0	0	0	0	0	0	0	0		0	0	8050,1	0	0	0	12423,4
6502-Radial Bohrmaschine RB70	2880	0	0	0	0	0	0	0	0	0	0	0	0	0	275,2	0	0	0	0	0	0		0	3224	0	0	0	3333
7205-Schweißen Laserzelle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		2025	1375,4	1357,8	791	0
7223-Schweißarbeitsplätze	15184,8	0	0	0	0	1651,2	1632	0	0	0	0	0	0	0	0	0	0	5419,2	1787,4	0	0	0	0		15059,7	7095,6	17265,4	27346,7
7602-Schweißlinie U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
7602-Schweißlinie P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
7602-Schweißlinie B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Warenausgang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 3: Intensity matrix for the year 2019

In order to be able to make a comparison between the developed layouts and the current state in the second work phase, the total intensity number was calculated. This is the sum of all cell entries of the intensity matrix and amounts to 1. 966.189 [#*m] in the year 2019.

b.) Sankey Diagram

Based on the transportation matrix a Sankey diagram, which can be seen in Figure 29, has been created. It can be seen that nearly all work stations are in relation to each other. This fact made it very difficult to define a clear flow direction. Nevertheless, it can be seen that especially the laser, the press brake, the welding line, the line where pre-assembly occurs, and the stock itself show a very high quantity of transportations for the year 2019. The mentioned work places are specially marked in the following diagram.

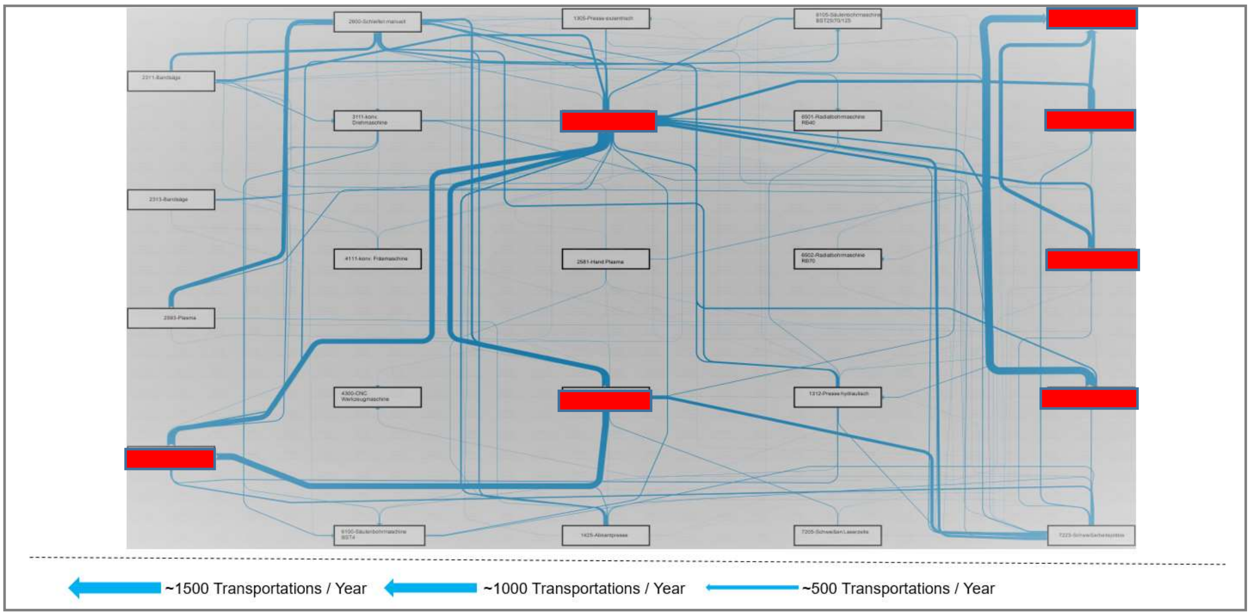


Figure 29: Sankey diagram for the current situation

c.) Oriented Material Flow Scheme

Since the Sankey Diagram shows the flow of materials without considering the locations of the single work stations[181], it was helpful to visualize the material's flow with another technique, too. Figure 30 shows that the current material flow does not follow a precise pattern. This can be justified by the number of work stations that are related to each other. As a result, the entire process seems to be more complex than well-regulated. It was also possible to identify a node, which is marked in the following figure as an intersection.

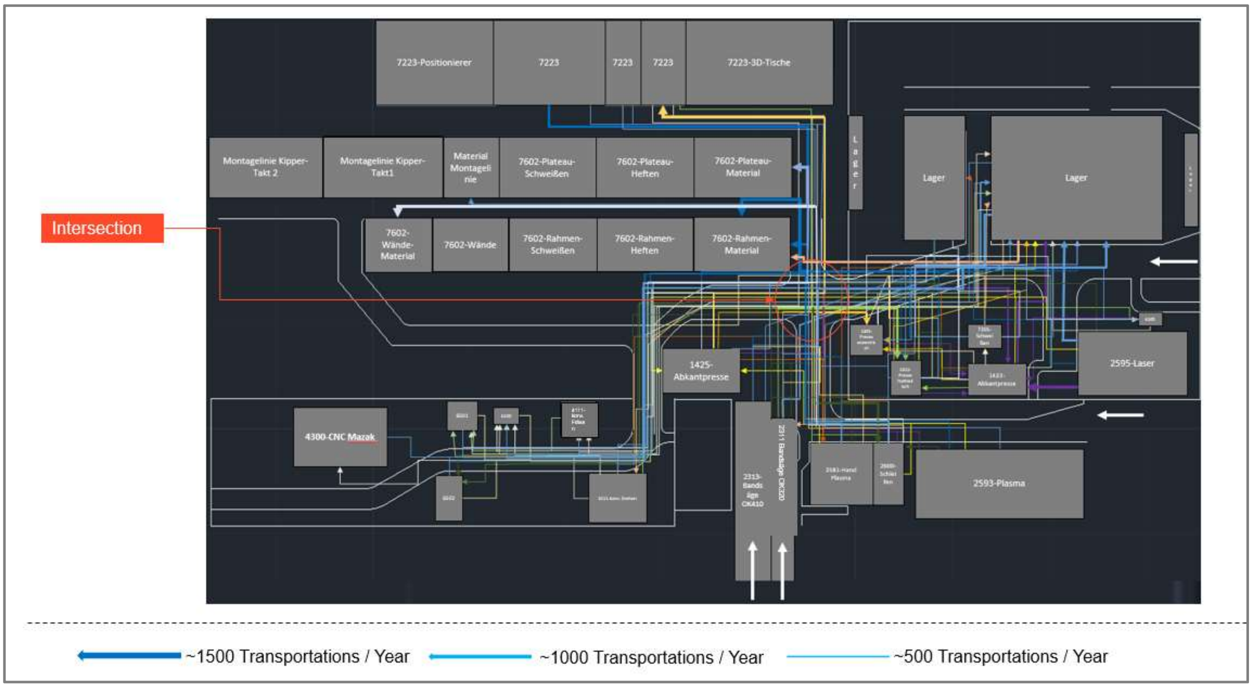


Figure 30: Oriented material flow scheme for the current situation

The use of the two different visualization techniques was not only helpful to derivate optimization potentials, they also served as a basis to arrange the different work stations in the new plant.

For better legibility, both diagrams shown above are enlarged in Appendix B.

d.) Top 10 Transportation Relations

One result of the material flow analysis was the identification of the top 10 transportation relations which are represented in Figure 31. It can be seen that most of the transportations are done from the stock to the welding line. The reason being that all parts pass an intermediate storage process, as already mentioned in the assumptions. In second place is the number of transports from the laser to the press brake. The fact, that the storage plays a major role in the processes can also be seen when having a view on

[181] Cf. Hartel (2015), p. 76

places three and four. Additionally, the ranking shows that the welding stations have a huge impact to the flows of materials, since those stations are placed three times in the top ten relations.

Rank	From	To	Number of transports in 2019 [#/year]
1	Stock	Welding line	1948
2	Laser	Press Brake small	1683
3	Laser	Stock	1419
4	Press Brake small	Stock	1363
5	Plasma	Manual Grinding	1144
6	Press Brake small	Welding station	859
7	Bandsaw small	Manual Grinding	743
8	Stock	Welding station	689
9	Welding station	Welding line	613
10	Bandsaw small	Stock	586

Figure 31: Top ten transportation relations

3.1.4.4 Optimization Potentials

After finishing the MFA, it was possible to deviate optimization potentials with respect to the flow of materials in plant 1. These potentials can be summarized as follows:

- Relief of the identified node (see Figure 30)
    - The MFA has shown that 8.029 transportation occur through the intersection in the year 2019
- Arrangement of working areas with high dependencies to each other
    - Reduction of transportation distances
- Provision of sufficient resources for the transports in the new plant
    - Considering also the number of gantry cranes
- Structuring the transport containers
    - Note: Currently partially different components in a single transportation unit

3.1.5 Process Analysis

After finishing the MFA, the analysis of the processes for each product has been carried out. Goal of this phase was the obtainment of knowledge about actual cycle times, process sequences, and the current technologies used. In addition, vulnerabilities at the item level should be identified.

3.1.5.1 Procedure

Firstly, again the needed databases had to be prepared. The required bases for the process analysis were mainly production documents, such as the product structure or the work schedules for each product. Subsequently, the processes for all products had been visualized. Taking into account both the actual and the planned lot sizes two Gantt-charts for every product had been created. The process analysis has been completed by the identification of critical components and working stations.

3.1.5.2 General Results

General results of the situational analysis of the processes can be summarized as follows:

- 18 Gantt-Charts
  - 9 Products
  - Current lot size, planned lot size
- Identification of the critical path, depending on the different lot sizes
- Clocking components, depending on the different lot sizes
- Identification of work places with remarkably high setup times
- Derivation of recommended actions

3.1.5.3 Assumptions

Also for the process analysis some assumptions had to be made. These were necessary mainly because of the high number of single components of the products. The assumptions are listed below:

- The production of all level three components starts at the same time
  - As already mentioned, these components are those needed for the production of the main sub-assemblies (level two assemblies required for the final product)
- The setup times of the work stations are based on the data sheets of the received bills of materials
- Both the stitching and welding process have the same setup and processing times in the welding line for the agricultural products

3.1.5.4 Results

By creating the Gantt- charts it was possible not only to identify the critical paths but also the critical components of each product and the critical machines. An extract from the Gantt chart of the product 1 is shown in the following figure. This Gantt chart consists of the final product and the main sub-assemblies. Since the number of single components for each assembly is very high, they are not shown in this representation. While the dark grey bars show summary tasks, which means that two or more process steps are summarized into one big process, the blue ones represent single process steps. The red bars show the critical path. It can be seen that the base for this path is a component needed for the plateau. Therefore, the buffer time, which is shown in the last column, for the plateau equals to zero. Also the duration needed for the production can be seen in the third column.

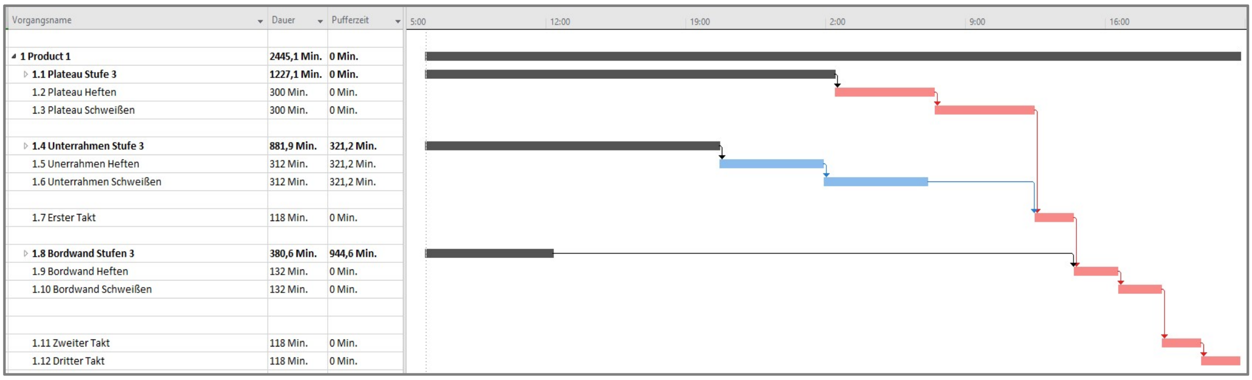


Figure 32: Extract from the Gantt chart of product 1

The Gantt- charts for all products with respect to the changes in the lot sizes between the years 2019 and 2025 can be seen in Appendix C.

The next page summarizes the results of the process analysis. The first column shows the individual products. Since the results were created as a function of the different lot sizes, these are shown in the second column. The third one then shows the critical components that are based on the critical paths of the respective Gantt-charts. Afterwards, the critical workstations / machines needed to produce the components are listed. In order to be able to make concrete statements, the entire process time has been divided into setup and processing time for these machines. The percentage of each time is shown within the square brackets. To see how great the influence of the critical component actually is, the time proportion of the component with respect to the total cycle time of the products was determined last. This percentage is shown in the last column. The figure also shows the influence of the different lot sizes. For example, in the case of product 2, it can be seen that different critical components arise, when the lot size changes.

Product	LS	Critical Components	Critical Workstations	Setup	Processing [min]	Time proportion related to the cycle time[%]
Product 1	5	Rear locking pin	Bandsaw Welding Station	9 [36%] 49,4 [18%]	16,2 [64%] 220,2 [82%]	4,8
	26	Rear locking pin	Bandsaw Welding Station	9 [10%] 49,4 [4%]	84,2 [90%] 1145 [96%]	5,8
Product 2	5	Rear central locking system	Milling machine Radial drilling machine Bandsaw	90 [83%] 42,1 [52%] 6 [42%]	18 [17%] 38,4 [48%] 8,4 [58%]	3,6
	27	Base plate	Manual plasma Press brake	4 [2%] 27 [12%]	218,7 [98%] 191,1 [88%]	2,7
Product 3	5	Rear closure	Welding station Laser	60 [22%] 0	212,7 [78%] 11,4 [100%]	5,3
	26	Rear closure	Welding station Laser	60 [5%] 0	1106 [95%] 59,2 [100%]	6
Product 4	5	Tube	Welding Station Bandsaw Hydraulic Press Turning machine Radial drilling machine	28,2 [59%] 4 [32%] 9 [75%] 7 [39%] 30 [63%]	19,5 [41%] 8,4 [68%] 3 [25%] 11,1 [61%] 18 [37%]	2,8
	36	Cylindrical carrier	Bandsaw Welding Station	4 [2%] 33,7 [4%]	162 [98%] 827,2 [96%]	3,2
Product 5	5	Longitudinal girder	Welding Station Plasma Press brake	61,2 [8%] 0 20 [44%]	740 [92%] 64,8 [100%] 25,2 [56%]	12,6
	21	Longitudinal girder	Welding Station Plasma Press brake	61,2 [2%] 0 20 [16%]	3108 [98%] 272,1[100%] 105,8[84%]	14,5
Product 7	5	Brace	Welding Station Hydraulic Press Plasma Manual Grinding Press brake	56,2 [25%] 18 [58%] 0 0 10 [44%]	167,1[75%] 12,9[42%] 11,4[100%] 12,6[100%] 12,6[56%]	5,1
	38	Brace	Welding Station Hydraulic Press Plasma Manual Grinding Press brake	56,2 [4%] 18 [25%] 0 0 10 [9%]	1270 [96%] 54,2[75%] 86,6[100%] 95,7[100%] 95,7[91%]	5,6
Product 8	5	Chain strip	Bandsaw Eccentric Press Manual Grinding	96 [40%] 312 [65%] 0	144 [60%] 168 [35%] 80,1[100%]	7,5
	19	Chain strip	Bandsaw Eccentric Press Manual Grinding	96 [15%] 312 [33%] 0	547,2 [85%] 638,4 [67%] 304,4 [100%]	6,5
Product 9	3	Lateral Reinforcement	Press brake small	56 [72%]	22 [28%]	2
	5	Lateral Reinforcement	Press brake small	56 [60%]	36,6 [40%]	2,9
Product 6	3	Mounting bracket	Welding Station Plasma Manual Grinding Turning machine	76 [12%] 0 0 14 [41%]	545,4 [88%] 3,4 [100%] 4 [100%] 20 [59%]	10,8
	5	Mounting bracket	Welding Station Plasma Manual Grinding Turning machine	76 [8%] 0 0 14 [30%]	909 [92%] 5,7 [100%] 6,6 [100%] 33 [70%]	12,9

Figure 33: Results of the process analysis

3.1.6 Capacity Estimation

During this work phase the capacities for the years 2019 and 2025 with current as well as planned quantities and lot sizes had been considered. By doing so it was possible to identify weaknesses in the technology level.

3.1.6.1 Procedure

In comparison to the other evaluations in the situational analysis, the evaluation of the capacities and utilizations of the machines and work stations did not require any direct data collection. The only data base needed was the work schedules for each product. After analyzing them with respect to the demands for 2019 and 2025 as well as the current and planned lot sizes it was possible to make statements for each working station and to identify critical machines and manual workstations.

3.1.6.2 Assumptions and Boundary Conditions

- During the analysis only the 9 agricultural products were taken into account
- The increasing demand from 1.240 to 2.700 products had been considered as well (see chapter 3.1.3)
- For 2025, a lot size of 5 pieces was again accepted for each product
- Critical are those work stations that have an overall equipment efficiency (OEE) above 75%

3.1.6.3 Results

The analysis of the capacities and utilizations served as a basis for both the identification of critical machines and the selection of machines and workstations needed in the new plant for the production of the agricultural products.

The following two tables show the utilization of the machines and the workstations, respectively. The first two columns show the different stations and the current number of shifts used for the production of both environmental and agricultural products. The next ones show the results for 2019 and 2025 based on the current lot sizes. The green lights signalize that the utilization and thus the OEE is below the described 75%. Therefore, those stations are not critical. As a logical consequence, red lights signal those workstations that require special attention, as they have to be considered as critical for the strategic planning. Additional information has been provided for the year 2025. The columns after the lights is about the working time for each station. The calculation was carried out by considering the lot sizes and is composed as the sum of the required set-up and working times. Afterwards the utilization is indicated. The calculation respects the number of both shifts and identical work stations. The basis was 220 working days per year. This number has been provided by the company and takes into account both public and employees' holidays as well as possible sick leaves. The number of productive hours that can be worked per shift was assumed to be 7.5. With reference to the working days per year and the hours per shift, the possible working hours per year could be calculated. These can be found in the following Table 4.

# of Shifts	Possible Hours
1	0 – 1.650
2	1.651 – 3.300
3	3.301 – 4.950

Table 4: Possible working hours per year

To make it easier to explain, one hundred percent utilization equals three shifts multiplied by the number of identical work stations.

To clarify the influence of the different lot sizes, additionally the theoretically required number of shifts for the year 2025 had been calculated and listed in the last column of both figures.

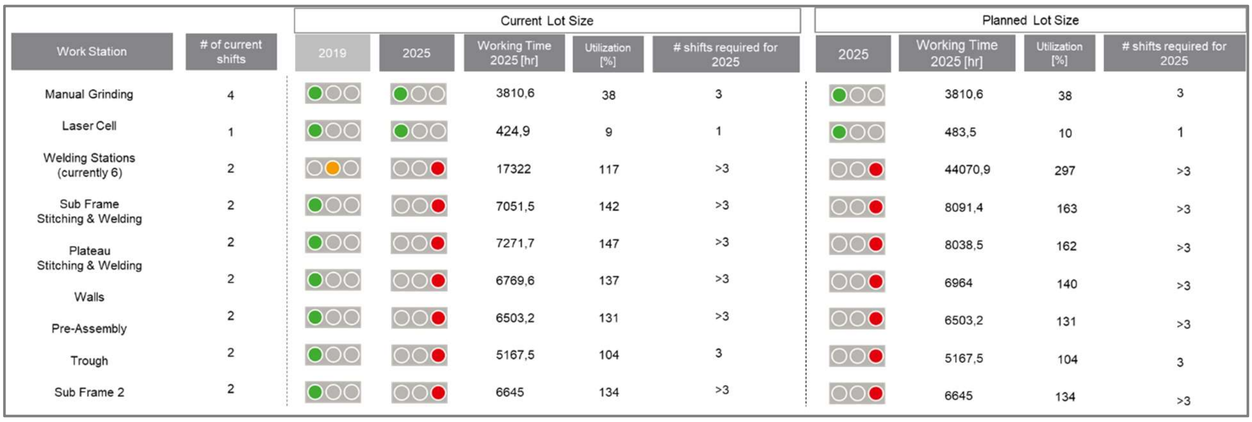
a.) Utilization of the machines

		Current Lot Size					Planned Lot Size			
Machine	# of current shifts	2019	2025	Working Time 2025 [hr]	Utilization [%]	# shifts required for 2025	2025	Working Time 2025 [hr]	Utilization [%]	# shifts required for 2025
Eccentric Press	1	●○○	●○○	1005	20	1	●○○	1947	39	2
Hydraulic Press	1	●○○	●○○	2063	42	2	●○○	3364,8	68	2
Press Brake small	3	●○○	○○●	5196,7	105	>3	○○●	6797,4	137	> 3
Press Brake big	3	●○○	●○○	2642,3	53	2	●○○	3540,1	72	3
Bandsaw small	1	●○○	●○○	2040,5	41	2	●○○	2646,9	54	2
Bandsaw big	3	●○○	●○○	2587,1	52	2	●○○	2929,1	59	2
Manual Plasma	1	●○○	●○○	1423,8	14	1	●○○	1704,5	17	2
Plasma	2	●○○	●○○	2239,3	45	2	●○○	2239,3	45	2
Laser	3	●○○	●○○	3398,1	69	2	●○○	3398,1	69	2
Pillar Drilling Machine 1	1	●○○	●○○	832,7	17	1	●○○	1065,4	22	1
Conventional lathe	3	●○○	●○○	2155,3	44	2	●○○	2504,7	50	2
Conventional Milling	1	●○○	●○○	526,9	11	1	●○○	806,5	16	1
CNC big	1	●○○	●○○	153,9	3	1	●○○	153,9	3	1
Pillar Drilling Machine 2	1	●○○	●○○	813,9	16	1	●○○	978,3	20	1
Radial Drilling Machine 1	2	●○○	●○○	1116,7	23	1	●○○	1400,4	28	1
Radial Drilling Machine 2	2	●○○	●○○	534,2	11	1	●○○	730	15	1

Figure 34: Utilization of the machines

It can be seen that among all the machines only the small press brake is a critical one. This means that steps must be taken to meet the requirements of increasing quantities and reduced lot sizes. How these steps may look like will be described in chapter 3.2.6, which is about the greenfield layout planning and the simulation.

b.) Utilization of the manual work stations



Work Station	# of current shifts	Current Lot Size: 2019	2025	Working Time 2025 [hr]	Utilization [%]	# shifts required for 2025	Planned Lot Size: 2025	Working Time 2025 [hr]	Utilization [%]	# shifts required for 2025
Manual Grinding	4			3810,6	38	3		3810,6	38	3
Laser Cell	1			424,9	9	1		483,5	10	1
Welding Stations (currently 6)	2			17322	117	>3		44070,9	297	>3
Sub Frame Stitching & Welding	2			7051,5	142	>3		8091,4	163	>3
Plateau Stitching & Welding	2			7271,7	147	>3		8038,5	162	>3
Walls	2			6769,6	137	>3		6964	140	>3
Pre-Assembly	2			6503,2	131	>3		6503,2	131	>3
Trough	2			5167,5	104	3		5167,5	104	3
Sub Frame 2	2			6645	134	>3		6645	134	>3

Figure 35: Utilization of the work stations

It can be seen that nearly all manual work stations are critical. Especially the welding stations have a very high utilization. Currently six of them are used for the production of both environmental and agricultural products. To calculate the shifts and the utilization it has been assumed that only three are used for the agricultural products. Also for the manual workstations the steps needed to meet the different requirements are described in chapter 3.2.6.

3.1.7 Catalogue of Requirements

After finishing the current state analysis of the flow of materials, processes, and the capacities, it was possible to create a catalogue of requirements. Based on observations, surveys, and the results or problems encountered during the situational analysis, different criteria have been identified, which have to be taken into account when planning the new plant. In the following, the effects of the occurring problems are described and possible solutions are explained.

a.) Material Supply

One problem regarding the material supply is that some workspaces do not have clearly defined delivery areas yet. This fact leads to barred paths and restrictions on the movement of the employees. To solve this problem, it should be ensured that the workspaces in the new plant have a sufficient space for provision and delivery of parts and that the transport containers are adapted to the new situation.

Another issue is that the current amount of gantry cranes is not enough. This leads to waiting times by interrupting the ongoing processes. To avoid this, additional resources should be provided in the new plant.

The narrow paths in the welding line currently represent a challenge. By providing wider routes in the new hall, the waiting times for fork lifts should be reduced.

b.) Required Space

Due to the high lot sizes, many single components of the finished parts are located on the welding workstations. For this reason, high requirements of space in the welding line exist. This problem can be solved by adjusting the lot sizes of individual products.

c.) Internal Logistic

The analysis of the flow of materials showed that several different components are partly stored in a single transportation container. This results in an unmanageable number of transport boxes and an increased logistical effort, especially during the picking process. This problem may be avoided by unifying the transportation containers.

d.) Flow of Materials

The problem with the materials flow is that a significant number of components display high transport distances throughout the entire facility. The resulting high transport times should be reduced by the proper arrangement of the workstations in the new building.

3.1.8 Technology selection for the new facility

The final part of the situational analysis was a vote on the new plant's necessary machines. The production program as well as the results of both the material flow and the capacity analysis were taken into account to find all needed machines and work stations for the new facility. One of the main criteria for the decision whether to invest in a new machine or to take over the already existing ones into the new plant had been the current set-up times as well as the current processing times of each machine. In order to obtain a good overview of all required data, a catalogue has been compiled, in which all important information for each machine and workstation was summarized, taking into account not only the quantities for 2019 and 2025 but also the change in lot size. In addition to that, the most important statements (for example regarding the lean conformity) have been provided for every work place. To make the decision-making that was achieved during a workshop as structured as possible, checklists were created. Different questions were asked to get all information needed for the following work phases. One of the major ones was the question about whether to buy a new machine or not. If yes, then several sub-questions raised. Due to the fact that the use of a new technology may cause a change in set-up and processing time, this information has also been collected. Also the number of possible shifts was queried individually for each workstation. Finally, estimates regarding the investment costs have been made. This information is especially important for the third work phase, as it contains an estimation of the production costs for the agricultural products after the greenfield layout planning. An example of such a catalogue and the checklist for a machine can be seen in the following Figure 36.

Press Brake

Machine Data

	2019	2025 (LS_plan.)	2025 (LS_cur.)
Utilization [hr]	2218,5	6206,9	4495,3
Set-Up [hr]	705,4	3067,7	1320,1
Proportion Set-Up [%]	32	49	29
# current Shifts	3		
Proportion EP / AP [%]*	55 / **45**		
# Employees	1		

Checklist

1) Take over of the existing machine? Yes ☐ No ☐
2) Buying a new machine? Yes ☐ No ☐
   2.1) Change in processing-time: + / - ___ %
   2.2) Division Set-Up / Processing [%]: Set-Up: ___ Processing: ___ Same ☐
3) Number of shifts: max.1 ☐ max. 2 ☐ 3 possible ☐
4) Estimation of investment costs: ~ __________ €

Catalogue of Requirements

Criterion	Problem	Effects	Possible Solution
Material-Supply	Existing derlivery areas are sometimes insufficient	Partially blocked transport routes	Providing enough space for delivery in the new facility

General Information

- This machine can be considered as critical since three shifts are not enough to meet the requirements for 2025
- This station is needed for all nine products and has already been revised by the Lean-Management

LS…Lot Size
EP…Environmental Line
AP…Agricultural Line
*…100% = 4950hr

Figure 36: Example of catalogue and checklist

3.1.9 Relevant decisions for the greenfield layout planning

Due to the fact that the decisions that have been made after the situational analysis have an impact on the greenfield layout planning, is seems to be necessary to describe and explain them before the chapter of the layout planning begins.

a.) Hydraulic Press & Eccentric Press

Both machines have been analysed with respect to the components that are processed on them. By outsourcing the production of selected level three components the capacity utilization of both machines should be reduced. In addition, enough space has to be provided in the new plant for at least one hydraulic press. The reason for this is a necessary straightening of the board walls, which represent one of the main sub-assemblies. The calculation of the utilization in the previous chapter does not include the times needed for this operation because the needed information has been provided after the analysis of the current situation has already been finished.

b.) Press Brake “small”

An investment in a new machine should reduce the set-up time from over 3.000 hours to 2.000 hours for the year 2025. As already mentioned, a reduction of the lot sizes to five for each product contributes to the fact that this machine represents a bottleneck. Therefore, those parts that can’t be processed here shall be processed on the bigger press brake in the future.

c.) Band saw and drilling machines

Currently, two band saws, two radial drilling machines, and two pillar drilling machines are used for the manufacturing for the agricultural products. However, the analysis has shown that one of each would also be enough. Therefore, the area calculation of the new plant, which is shown in the next chapter, only considers the required space for one of each.

d.) Welding stations

Due to the high capacity utilization, which can be justified by the high processing times, the number of the welding stations has to be adopted. The required space per workplace has been specified by the company.

e.) Welding line

After all components that are needed to assemble the final product arrive at the welding line, the first operation, the stitching, can start. Afterwards the welding occurs manually. This is true for all subassemblies, the lower frame, board walls, and the plateau. The use of robots in the new plant for both the frame and the plateau shall reduce the processing time by 40%. The same is true for the two bigger products of those which had been analysed, product six and nine. It follows, of course, that the sizes of the areas for these work station have to be adjusted, too. The supply areas of the frame and the plateau should be taken from the current state.

f.) Storage

The current situation is that both the raw material and the board walls are stored outside the production facility. The aim is to place the storage locations within the new hall. Therefore, 90% of the current area used for storing the raw materials should be considered during the layout planning. The needed area for the board walls has to be calculated. Additionally, the possibility of an optimized storage should be considered as well, meaning that, for example, an increase of the area (if required) should be possible.

3.2 Greenfield Layout Planning

After the situational analysis had been completed, the layout planning phase commenced. The purpose of this work section is to develop a layout for the production of the agricultural products.

In addition to the necessary databases, which were already mentioned in the previous chapter, it was particularly important to incorporate the derived optimization potentials and decisions made at the end of the first phase. These relate in the first instance to the material flow to be optimized and the selection of the technologies to be used.

In the first step, the required space for work area, supply, and storage was determined. An ideal layout has then been developed using the Schmigalla method, which has been presented in chapter 2.4. After the structuring, which took the required areas and manufacturing forms into account, various layout variants were worked out. After the evaluation of these variants and the selection of those three that showed the greatest overall optimum, the selected one was has been detailed further. At the end of this phase, a simulation model has been created to analyse both the impact of the different lot sizes and the production program of the year 2025 in general. The procedure within this phase is also shown in the following Figure 37.

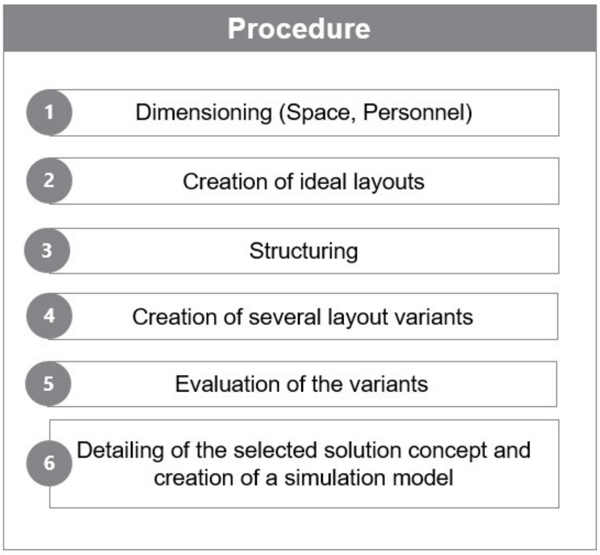


Figure 37: Procedure during the greenfield layout planning

3.2.1 Dimensioning

As already addressed, the first step during layout planning was the dimensioning of both the required space and capacity. Thereby a distinction was made between machine workstations, manual workstations and various storage areas, which can be justified by the fact that the different workplaces necessitate different calculation methods for the areas.

The required data for this sub-phase were taken on the one hand from the provided CAD layouts and on the other hand obtained by measuring the sizes of the machines on site. This was followed by the determination of the required areas per workplace, taking into account the decisions made at the end of the situational analysis. These led to the fact that an exact calculation, based on the procedures presented in the methodology part, was not necessary for all workplaces, but the empirical values of the company for the required spaces were used. The total area required for the new factory building could then be computed.

3.2.1.1 Area for machine workstations

Figure 38 shows the required area for each machine workstation. Based on Nestler (1968), each area shown consists of the following sub-areas:

- Production area A_F
- Area for the interim stock A_{ZL}
- Area for transport and traffic A_T
- Additional area A_Z

As additional information, the required amount of machines was also indicated, which is either required for the production of the products with a lot size of five, or which is available at maximum due to different reasons, such as investment costs.

Workstation	# of Workstations	Required Area [m²]
Eccentric Press	1	36
Hydraulic Press	1	36
Press Brake small	1	30
Press Brake big	1	54
Bandsaw	1	50
Plasma	1	200
Laser	1	120
Conventional Lathe	1	20
CNC	1	30
Pillar Drilling Machine	1	12
Radial Drilling Machine	1	12
Welding Robot Frame	1	208
Welding Robot Plateau	1	208
Welding Robot big products	1	105
Sum Maschines	-	1.121

Figure 38: Area for machine workstations

A total area of 1.121 m² is required for the machines. The two welding robots for the frame and plateau account for the largest share. The space required for these machines was determined by the company itself, and is based on the already existing welding robot placed in plant 1.

3.2.1.2 Area for manual workstations

One of the biggest differences between mechanical and manual workstations is the number of workstations. Figure 39 shows that this number differs from one, especially for welding workstations. The indicated area therefore does not indicate the area per workstation, but that which is required for the entire work area. Furthermore, the welding workplaces were subdivided. This is due to the fact that the company wanted to provide one of these workplaces with a larger area to ensure that even large components can be welded.

In addition, supply areas had to be provided for the various welding lines, which could not be determined using any of the methods presented in Chapter 2. These are not discussed in more detail in the following, since the sizes of these surfaces were taken from the current CAD layouts.

Workstation	# of Workstations	Required Area [m²]
Manual Plasma	1	60
Manual Grinding	1	15
Laser Cell	1	10
Welding Station	4	120
Welding Station	1	56
Stitching Frame	1	70
Stitching Plateau	1	70
Walls	2	140
Pre-Assembly	2	140
Stitching big products	2	210
Sum Manual Workstations	-	891

Figure 39: Are for manual workstations

As already mentioned in chapter 3.1.9, one of the targets of the company is the storage of raw materials within the factory hall in the future. For this reason, the required area for the warehouses had to be determined too.

3.2.1.3 Area for the warehouses

No calculation methods were available for these areas either. Therefore, it was necessary to work with assumptions provided by the company.

At this point it should be noted that the final area design of the interim storage took place at a later point with the help of the simulation model. This means that the areas given here served as the basis for a preliminary design.

Assumptions made and the results of the required areas for the tubes, metal sheets, walls and the inner bearing are shown in Figure 40.

Metal Sheets	► An area of 90% of the current state is to be provided for the sheets ► Currently used area: 177 m² →160 m² storage area for the sheets
Pipes	► An area of 90% of the current state is to be provided for the pipes ► Currently used area: 164 m² →145 m² storage area for the pipes
Walls	► Currently a shelving system of 25 m length and 1.5 m cantilever = 37.5m² ► Increasing the amount to 8 shelves →300 m² storage area for the walls
Interim Stock	► An area of 50% of the current state is to be provided for the interim stock ► Currently used area: 400 m² →200 m² storage area for the intermediate storage system

Figure 40: Area for the warehouses

3.2.1.4 Total space requirement

At the end of the dimensioning, the total area required was determined. It can be seen that a total area of 3.100 m² is required for the new building. It should be noted that this information only refers to the machines, the material supply and any additional areas. Required transport routes between different work areas and thus the increase in the total requirement have not been taken into account yet.

Total		Required Area [m²]
	Machines	1.121
	Manual Workstations	891
	Storage	805
	Material Supply	283
	Sum	3.100

Figure 41: Required area for the new factory

3.2.2 Creation of an ideal layout

An ideal layout was created with the aid of the modified triangular method according to Schmigalla.

The following Figure 42 shows the ideal layout considering the storage and the separated welding lines. The central position of the storage is clearly visible. This is due to the fact, that components are delivered to the storage from almost every workstation. This situation also corresponds to the results of the material flow analysis, which is presented visually in Chapter 3.1.4. Since all parts are placed accordingly in different welding lines after the intermediate storage, relations also arise here. However, it can also be seen that high transportation intensities, represented by the thickness of the lines, exist between the laser, press brake and the welding stations.

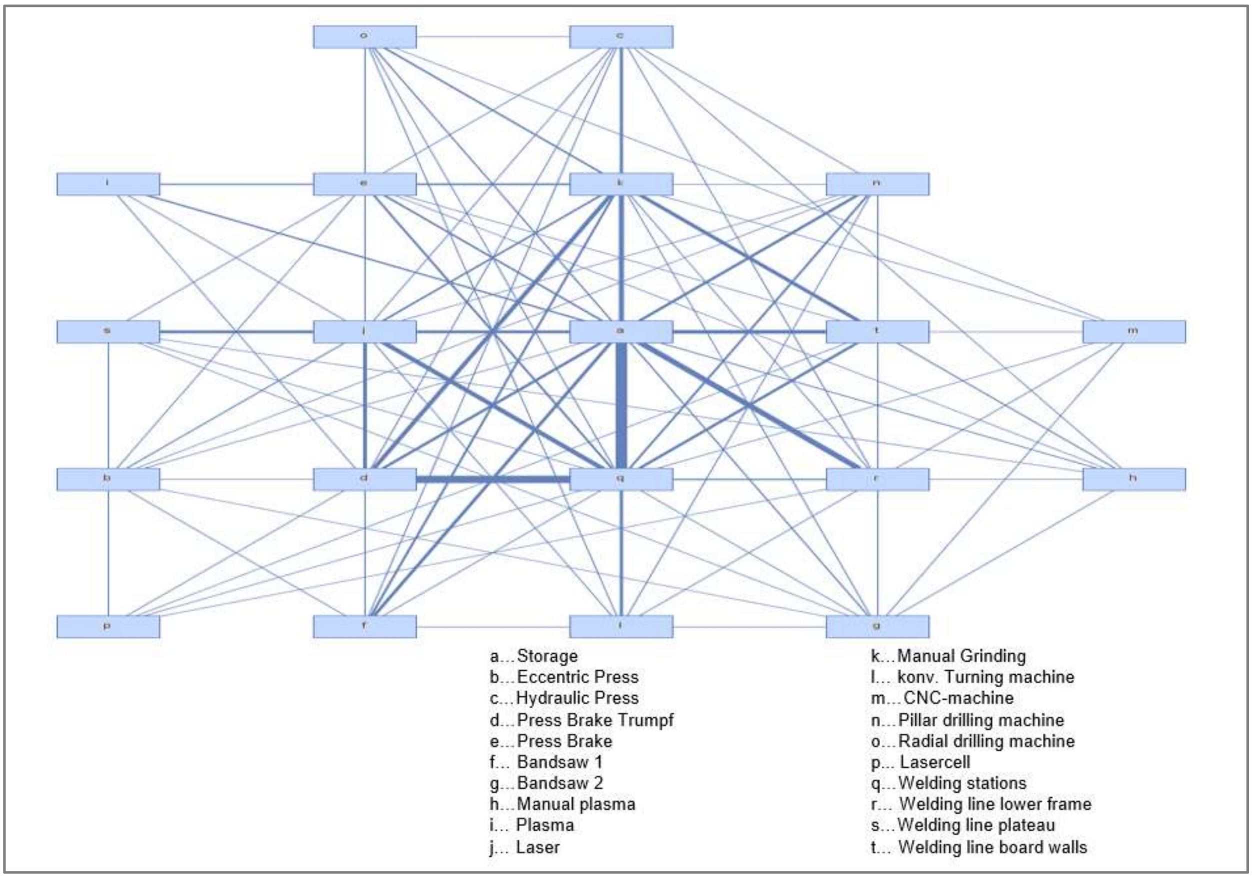


Figure 42: Ideal layout

The ideal layout shown served as the basis for the next phase, in which different real layout variants were developed. Before that, however, a structuring in the broader sense was carried out.

3.2.3 Structuring

This step within the planning of different real layout variants will not be discussed in too much detail in the following, as the most important points will be dealt with separately in the following sub chapter. The material flow and the manufacturing forms have been considered once again with the goal of an efficient layout planning process.

Material flow

Although the Schmigalla method used to create an ideal layout takes into account the material flow within the factory, the external material flow has not been given any consideration up to now, despite the fact that this also plays an important role within the factory planning process. For this reason, the following criteria are paid attention to during the design of the different variants:

- Since the final products have to be painted before they are delivered to the customer, the route between the factory building and the paint shop, which is located in a different building, needs to be considered.
- The delivery of the bulk material and the raw material, which then have to be distributed among the different storages, is also taken into account during the planning of the real layout. For this reason, care was taken to ensure that the new hall was properly integrated into the company premises.

Manufacturing forms

The ideal layout identified with the method according to Schmigalla, shows the arrangement of the workplaces optimised for the material flow, but does not takes into account the different manufacturing forms. Considering the process steps of the individual products, the capacity utilization of each workplace and the required area of the workplaces, the individual stations had been rearranged during the project, resulting in several real layout variants. In addition to that, special attention was paid to the different types of assembly, as described in chapter 2.4. The reason for this is the necessary, constant differentiation between small and big products during this project. Attention was also paid to the placement of the inner warehouse, as this separates the machinery from the assembly area in terms of process engineering.

In the next step, the different variants have been created, giving attention to all the aspects discussed so far.

3.2.4 Creation of real layouts

As already mentioned, the following subchapter deals with the elaboration of layouts which reflect the real conditions. These variants were developed by using data that has been collected in workshops with company employees. Within this workshop, also a selection of layouts occurred, which had to be detailed further. For this purpose, the already mentioned value-benefit analysis was used.

3.2.4.1 Workshops

Two workshops were carried out to find and analyse various layout variants. The procedure during these workshops is shown and explained in the following Figure 43.

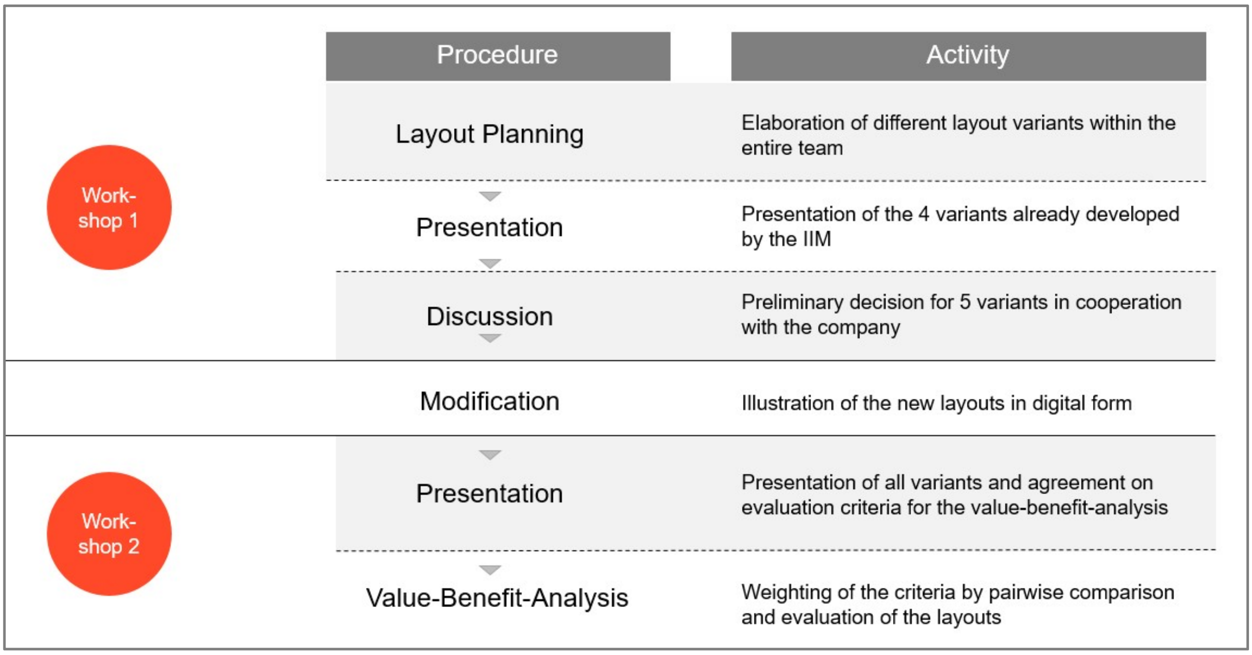


Figure 43: Procedure and explanation of the workshops

A total of nine rough layout variants were worked out. Five of them were selected during the first workshop and had to be detailed further. As shown, at the end of the second workshop, the value-benefit analysis was carried out, to find those variants that show the greatest overall optimum.

3.2.4.2 Selection of variants

In the first step, evaluation criteria had to be determined, that serve as a basis for the value-benefit analysis.

Definition of Evaluation Criteria

- Transport Intensity
  Transport Intensities are to be reduced by suitable placement of the workstations. The aim is to reduce transport times and thus transport costs.

- Expandability

  When assessing this criterion, particular attention is paid to machines with a high capacity utilisation. If productivity is increased in the coming years, it should remain possible to expand the machines and the space required for them.

- Required space

  The different variants partly have different (estimated) areas. Since costs increase with increasing area, the area requirement should also be taken into account when selecting a variant.
- Warehousing Solution

  The positioning of the different warehouses near the goods receipt and to the respective machines (laser, plasma, band saw) is important. The arrangement of the inner bearing (buffer) is also taken into account due to the high transport intensities.

Determination of weightings for the criteria

In order to be able to determine weightings for the criteria, the mentioned pairwise comparison method was carried out. All criteria were initially written into the columns and rows of a matrix (see Table 5). Subsequently, all participants voted on whether they considered the respective column-criterion as more important than the row-criteria. If this question was answered with yes, the entry one was assigned in the appropriate cell, otherwise zero. After all criteria have been worked through, for each criterion the row sum has been calculated, which is shown in the penultimate column in the table below. The weighting was then done by a simple fractional calculation, in which each row-sum has been divided by the total sum.

Row criterion more important than column criterion? (YES=1 / NO=0)		Warehousing Solution	Expandability	Transport Intensity	Required Space	Sum	Weighting
Number	Criterion	1	2	3	4		
1	**Warehousing Solution**		0	0	1	1	**8,33%**
2	**Expandability**	1		0	1	2	**33,34%**
3	**Transport Intensity**	1	1		0	2	**50,00%**
4	**Required Space**	0	0	1		1	**8,33%**

Table 5: Pairwise comparison

As can be seen from the table above, the transport intensity is given the highest importance with a percentage of 50%. The lowest weighting, and thus the lowest influence in determining the value-benefit, is found in the warehousing solution and in the required space.

Determination of the partial value benefit

In this step, all variants have been evaluated by awarding points, with a comparison of variants being carried out for each criterion. All participants were able to assign points between one and five, whereby the latter can be equated with an excellent result.

Determination of the total value benefit

In the present case, the total value-benefit of a variant is obtained by summing up the results of the multiplication of the weightings with the partial value-benefits, which were determined in the previous step. The following Table 6 shows the result.

Criterion	Weighting [%]	Layout A	Layout B	Layout C	Layout D	Layout E
Transport Intensity	50	4	4	5	3	5
Expandability	33,34	2,9	2,8	4,5	3,6	4,5
Warehousing Solution	8,33	3,5	3,4	2,8	3,2	4,9
Required Space	8,33	5	4	3	5	4
Value-Benefit	-	3,7	3,5	4,4	3,5	4,7

Table 6: Results of the value-benefit-analysis

Layout "E" was rated highest with 4.7 out of 5 points, followed by layout "C". The variants with the lowest points are the variant "B" and "D", both receiving 3.5 points.

Evaluation of the Advantageousness

The variant with the highest value-benefit shows the highest total optimum. In the following, the variant with the highest value is shown and described. The remaining ones can be seen in Appendix D.

3.2.4.3 Real layout

The following describes the storage solutions and possibilities for expansion. Also the material flows within the chosen layout will be discussed in more detail, after general information has been provided.

General information

Figure 44 shows the selected Layout “E” which represents the real layout variant with the highest overall optimum.

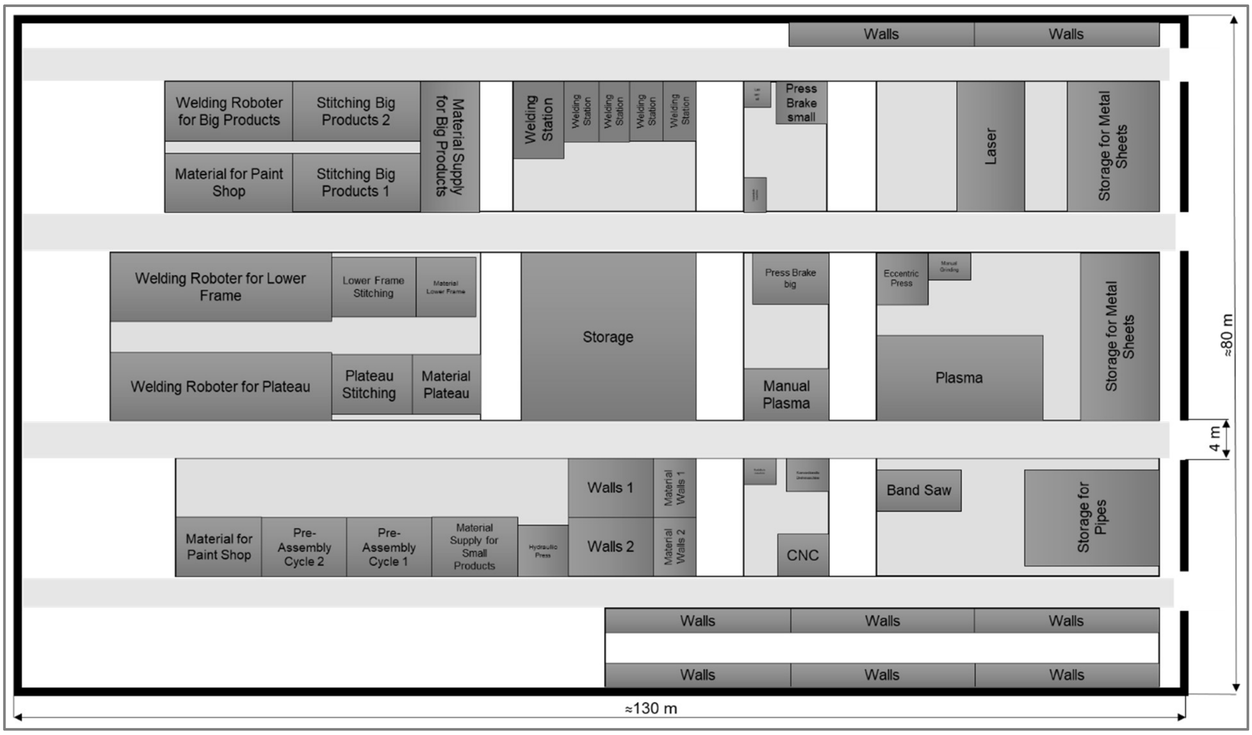


Figure 44: Real layout

The variant developed has a space requirement of around 10.400 m². A width of all transport routes of 4 m was taken into account, which was requested by the company for keeping sufficient space for transporting the large components (e.g. the pipes for the lower frame). The bars at the edge of the layout that are declared as "walls", are the aforementioned shelving systems and not to be mixed up with the workstations.

Material flow of the small products

Those work areas and storage systems that are required for the production of the small products are highlighted with a frame in Figure 45, shown in the following. The entire material flow, represented by the black lines and arrows, starts with the bearings for the pipes and metal sheets. With the laser, plasma or band saw, the work processes of the level 3 components begin. After all work steps have been completed, the parts are stored in the inner warehouse, named as storage. The components are then transported to the respective welding lines. The storage area for the walls was divided into small and large products. For this reason, a material flow is created only from the lower shelf system to the workstations walls 1 and 2. In this case, two goods departures are also shown with the grey arrows. Since the lower frame is no longer required in the pre-assembly stage, the finished frames can be sent straight to the paint shop. The plateau and the walls are adjusted in the pre-assembly cycles and do not leave the new plant until they are finished there. An additional area in which the finished products can be temporarily stored has been provided and is called "Material for Paint Shop".

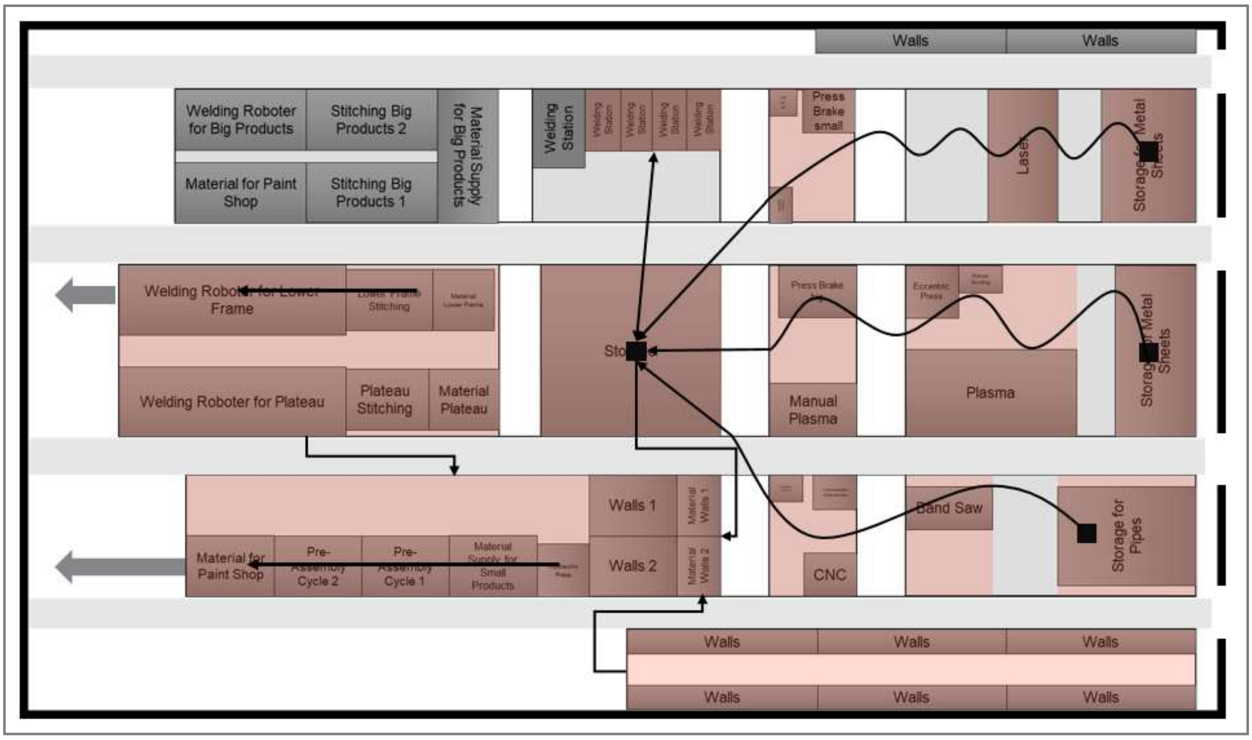


Figure 45: Material flow of the small products

<u>Material flow of the big products</u>

The material flow for the larger products (see Figure 46 below), which is in this case represented by blue lines and arrows, differs only slightly from that for small products. Two shelving systems were provided for the walls of the large products, which are located at the upper end of the layout. Here, too, a buffer place was provided where the products can be temporarily stored after the welding process until they are transported to the paint shop. This area is provided immediately below the planned welding robot for the large products and is thus located at the upper left end of the layout.

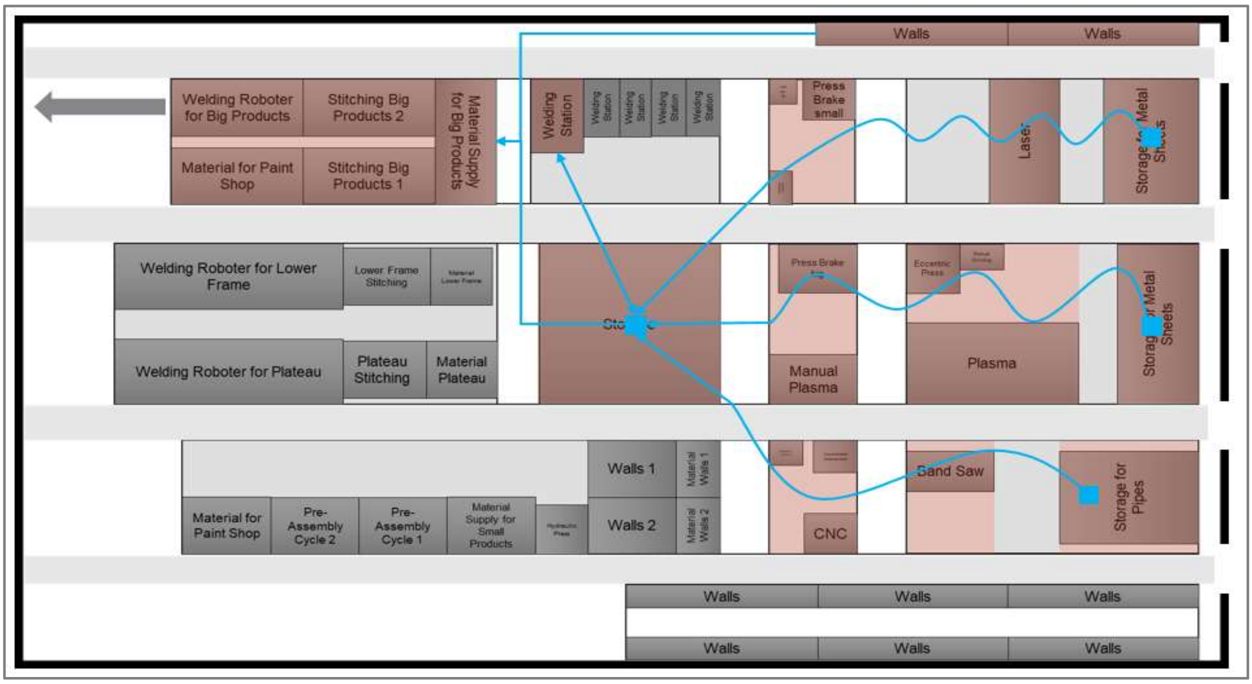


Figure 46: Material flow of the big products

Expandability

As mentioned above, this criterion took particular account of workstations classified as critical during the analysis of the current situation. This applies primarily to the small press brake. However, since the number of band saws has been reduced from two to one, this machine can also be classified as critical for a planned lot size of five. For this reason, care was taken to ensure that both workstations had sufficient space for the possible installation of an additional machine. The welding workstations of the walls are ranked third among the critical workstations. This is due to the fact that in the future the hinges will no longer be welded in the pre-assembly stage but at the workstations for the walls. Figure 47 shows not only the planned additional areas, but also the capacity utilization of all the workstations just mentioned, based on the results of the as-is analysis.

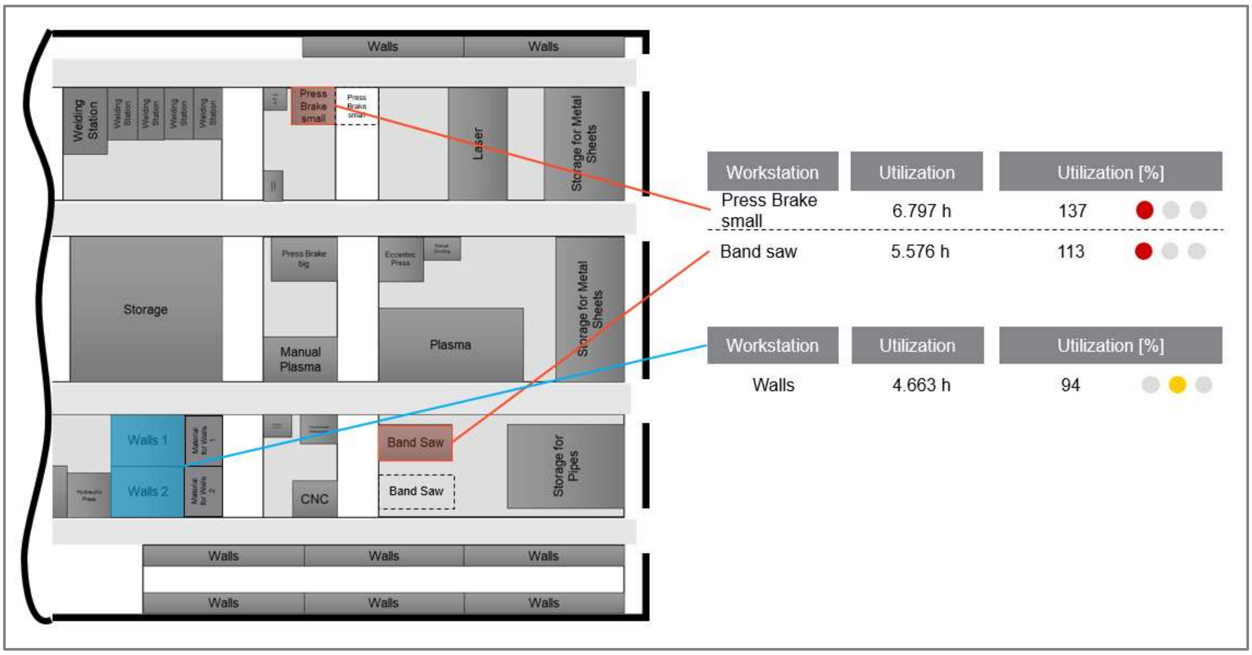


Figure 47: Expandability of the real layout

Summary of the real layout

The special aspects of the rough layout can be summarized as follows:

- Compliance with the flow principle
- Centrally located intermediate storage
- Separate storage of the walls for the small and the big products
- All welding stations are in line
- Extension areas are available for critical workstations
- Separation of small and large products assembly

In addition, the change in transport intensity should be explained. During the current state analysis, an intensity, the unit of which can be represented by "Number of Transports Times Meters", of 966.189 was determined for the year 2019 in the current layout. Due to the shorter distances and the changed arrangement of workplaces in the new plant, this number was reduced to 386.277 [#*m]. This will mean a reduction of 60% in transport intensity in the new plant.

3.2.5 Detailed layout

The next step was to create the detailed layout. A CAD model is created for this purpose in order to represent the designed layout true to scale. Figure 48 shows the final layout. Since some work areas are much smaller than others, they are specially marked and annotated with the legend on the right side.

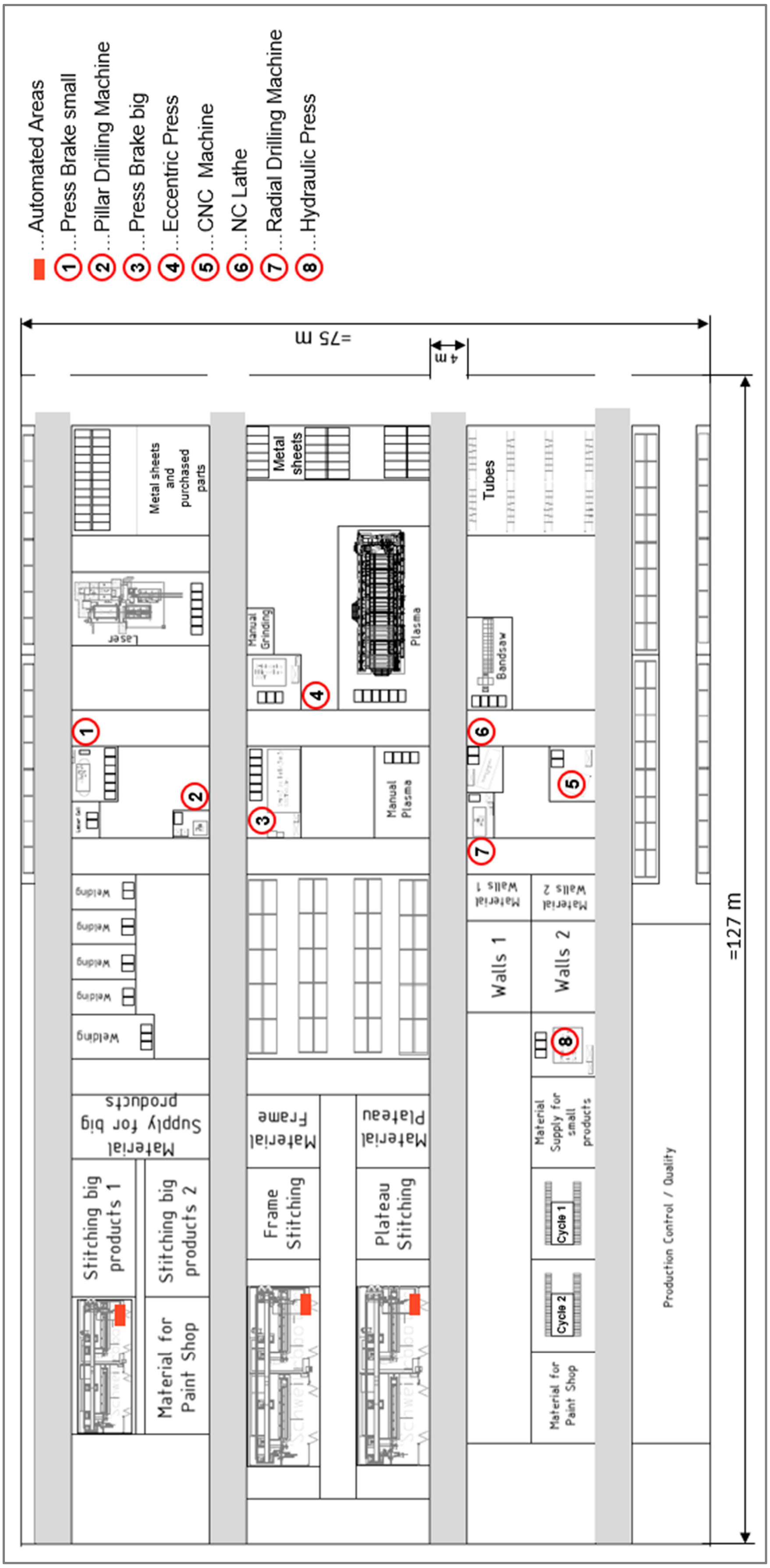


Figure 48: Detailed layout

The most important points such as material flow, expandability and warehouse solution have already been described in detail in the rough layout. Nevertheless, there is a clear difference between the rough and fine layout. While in the rough layout all areas are only displayed as blocks, in the fine layout not only all machines, but also the corresponding shelves for tools and staging areas are displayed. The latter are represented by the small, empty rectangles, which represent parking spaces for the pallets. Additionally, the computer-aided presentation of the layout led to the fact that final adjustments had to be made. These are briefly described below.

- In order to avoid returning the items, the shelves for the walls of the small products had to be adapted. These can be seen at the lower right end of the layout. Two shelving systems each were combined, which doubled the width of the shelves, but saved so much length that the shelving systems were aligned with the material provision area for the walls.
- The true-to-scale representation showed that the intended area for the metal sheets was too large. For this reason, part of this area was provided as a storage area for the purchased components.
- The final dimensions of the hall are 75 x 127 meters. Compared to the rough layout (shown in Figure 44), this means a reduction of the total required area by 875 m².

3.2.6 Simulation

In order to be able to make statements about the effects of the changed lot sizes and to carry out a feasibility analysis, a simulation model was created. In addition to that, the simulation serves also as a basis to identify and analyze both buffers and machines that represent bottlenecks.

A production program for the year 2025, based on the forecast data shown in chapter 3.1.3, served as the basis for the simulation. Based on this, data sheets were created for all products, containing all components of the products and associated work sequences. Subsequently, several different simulation experiments were carried out to identify bottlenecks and derive preventive strategies to avoid these bottlenecks. Based on the results a final design of the required area for the intermediate storage was carried out.

Assumptions

- Buffer

A buffer was inserted on each work station, which works according to the “first-in-first-out” principle. This means that those components that are first encountered at the machine are processed first and sent to the next work station according to the work sequences.

- Intermediate storage

A storage block was inserted, which reflects the real warehouse of the factory. All components are stored after the work process until all articles of a final product are finished. The components are then removed from storage and distributed to the various welding lines.

- Shift schedule

The shift calendar was adapted to the real conditions. Three shifts (à 8 hours), each with a half hour break, were set. In addition, the public holidays in both Slovenia and Austria were inserted as work-free days.

- Order control

In this simulation model, there is no intelligent order control, meaning that no products are prioritized, but the production program is processed line by line.

3.2.6.1 Design and constraints

The entire simulation is based on the delivery list for the year 2025, in which the products are imported as lots. For each product all components are stored in a table, whereby attention was paid to a separation into the respective subassemblies. Each individual component is then stored in a sub-table, in which the work processes are read in. These were each supplemented by the step "intermediate storage" and subsequent removal from storage in the corresponding welding line. All set-up and processing times are then processed using so-called methods depending on the corresponding lot sizes. After completion of the work processes within the machine park, the intermediate storage of level 3 components takes place. For this purpose, a subprogram was written so that the components are stored until all parts for a complete lot have been produced. The parts are then transferred to the welding lines. The first pre-assembly cycle does not begin until a plateau and the associated walls have been completely welded. This structure can also be seen in the following illustration.

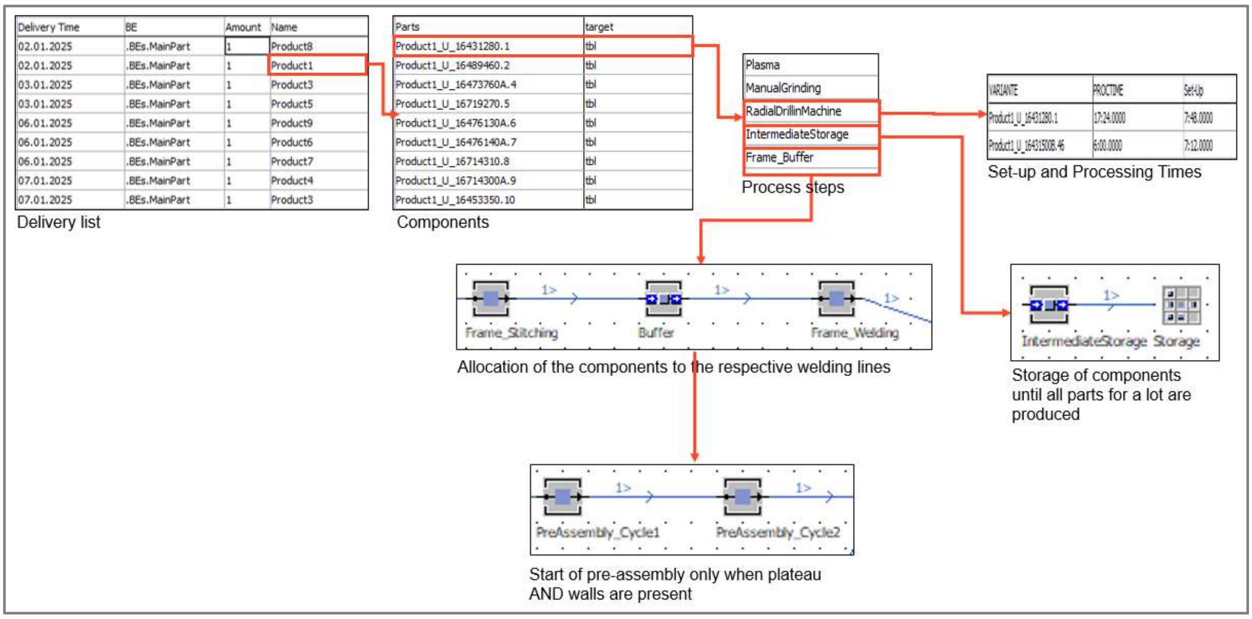


Figure 49: Structure of the simulation model

Subsequently, various simulation rounds were carried out, taking into account the findings and results of the respective preliminary rounds. These rounds are explained below.

3.2.6.2 First simulation experiment

In the first stage, the simulation was carried out by using the technology the company had planned to use in the new factory. Thus, the planned welding robots were taken into account and no machine was duplicated. Additionally, the first experiment was carried out twice, once for the planned and once for the actual lot sizes.

Throughput analysis – first round

The results are shown in the following Figure 50, with a subdivision into small and large products. The target given refers to the number of lots that must be produced from each product to achieve the planned throughput. The column next to it shows the number of lots actually created, based on the simulation. For each product, the traffic lights indicate whether the goal was achieved, with red indicating a deviation from the plan. Since the current lot sizes are different for each product, these are indicated in the round brackets. It can be seen that the company achieves its target with current lot sizes, whereas the planned lot size of five for each product results in a deviation of 107 lots in total (shown in the last line of the figure).

Category	Product	Actual Lot Size: Target [# Lots]	Actual Lot Size: Simulation Results [# Lots]	Lot Size 5: Target [# Lots]	Lot Size 5: Simulation Results [# Lots]
Small	Product 1	11 (26#)	11	57	47
	Product 2	15 (27#)	15	80	62
	Product 3	14 (26#)	14	72	58
	Product 4	10 (36#)	10	71	64
	Product 5	24 (21#)	24	100	74
	Product 6	8 (38#)	8	63	53
	Product 7	10 (19#)	10	37	28
Large	Product 8	55 (3#)	55	33	26
	Product 9	45 (3#)	45	27	21
Total	-	191	191	540	433

Figure 50: Throughput analysis – first round

In order to be able to make a better comparison between the different lot sizes and the resulting different setup times, the analysis of the capacity utilization for current lot sizes takes place at a later point in this work. In the following, the focus is on the planned lot size of five and the analysis of those workstations that lead to the deviation from the planned throughput.

Analysis of the critical work stations – first round

During the analysis of the critical machines, not only the capacity utilization but also the buffer load was examined more closely. The first of these will be discussed below.

Figure 51 shows the capacity utilization of both machines that were identified as bottlenecks in the first work phase, spread over the entire year 2025. While the horizontal axis displays the work centers, the vertical axis displays the percentage of time. This means, that a utilization of 100% equals to 365 days per year with 24 hours per day. The dark blue bars, making up about 30%, are those days in which no work is planned (Saturdays, Sundays and public holidays). These are followed by the grey ones, showing the waiting times of these two machines. The light blue bars show the mentioned 30 minutes' brakes within each shift, making up in total about 4% of the entire year. In order to illustrate reality as accurately as possible, a disturbance has also been set for each machine, which amounts to 10% of the working time and is represented by the red bars. The pure working time and the total set-up time of the two machines is represented by the green and brown bars respectively. In addition, the respective end times of the individual shifts are also drawn in with black lines, meaning that about 23% of the total time are available for one shift.

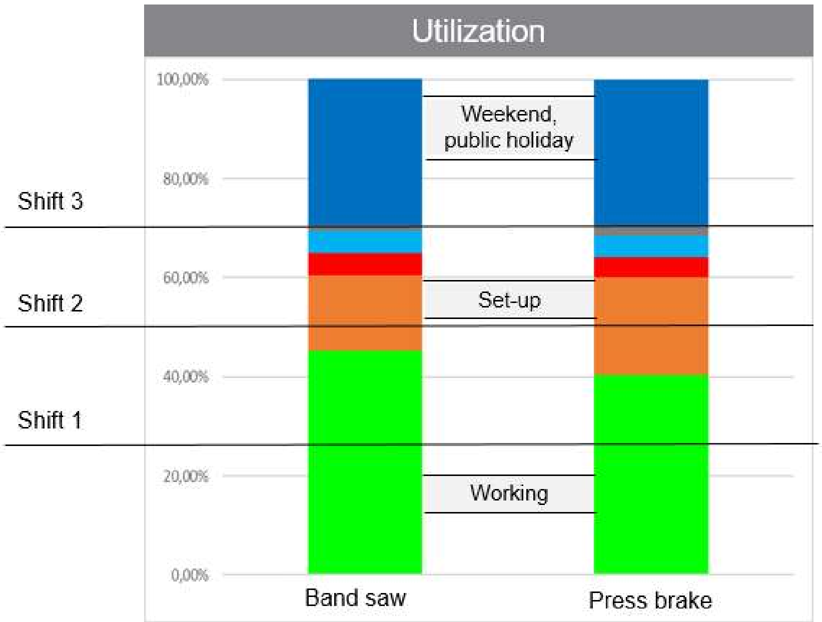


Figure 51: Utilization of the critical machines – first round

Although both machines are almost fully utilized, the planned throughput for the year 2025 cannot be achieved with the reduced lot sizes. This means that an available capacity of over 100% is required for both machines, which would be an ideal state, not allowing for reality. In a planning way, these machines can be identified as bottlenecks.

In order to be able to carry out an estimation of the required material supply areas, the respective buffers were also analyzed. Table 7 shows the maximum number of pallets waiting at the same time for the two machines shown above.

Buffer Load	
Work Station	**# Pallets**
Press Brake	32
Band Saw	61

Table 7: Buffer loads – first round

A number of pallets of 32 or 61 would mean a staging area that far exceeds the determined ones used for the layout planning. In addition, the waiting times and thus the total throughput times of the products would increase. For this reason, action is required to achieve the planned throughput. Possible measures to solve this problem are listed below.

Possible Actions

- Adding a second press brake
- Adding a second band saw
- Production of some components in the already existing plant
- Purchasing specific components
- Increasing the lot sizes of selected products
- Reduction of both the processing and the set-up times by the usage of new technologies

In order to achieve throughput with the planned lot size, a second band saw and a second press brake were added to the model in the second simulation round and a new analysis was carried out.

3.2.6.3 Second simulation experiment

Analysis of the critical work stations – second round

The same work stations as in the first round were checked again for capacity utilization and buffer load.

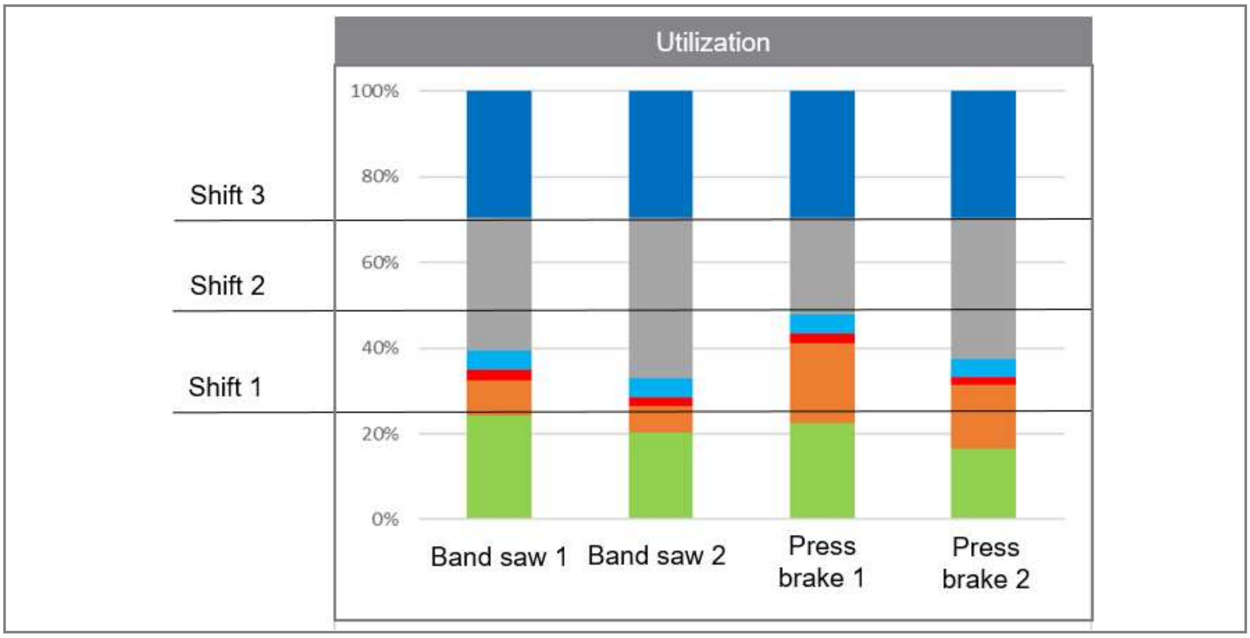


Figure 52: Utilization of the critical machines – second round

It can be seen that all four machines work two shifts per machine. Converted to one machine each, this means that four shifts would have to be worked per workstation in 2025. However, the measure taken also increases waiting times for all machines, which is represented by the grey proportion.

The buffers were also analyzed in the second round and compared with the results of the first simulation run. This comparison is shown in Table 8.

Buffer Load		
Work Station	# Pallets first round	# Pallets second round
Press Brake	32	9
Band Saw	61	17

Table 8: Buffer loads – second round

A high reduction in the number of pallets waiting at the same time on the processing machines could be achieved by the measure taken. This fact has a positive effect not only on throughput times, but also on the required supply areas.

A feasibility study was again carried out to check whether the planned throughput could be achieved with a lot size of five. Figure 53 shows that all planned products can be produced within 2025. In comparison with Figure 50, it can thus be seen that there is no deviation from the plan and that the desired number of products can be manufactured.

Category	Product	Lot Size 5 Target [# Lots]	Lot Size 5 Simulation Results [# Lots]
Small	Product 1	57	57
	Product 2	80	80
	Product 3	72	72
	Product 4	71	71
	Product 5	100	100
	Product 6	63	63
	Product 7	37	37
Large	Product 8	33	33
	Product 9	27	27
Total	-	540	540

Figure 53: Throughput analysis – second round

Since the goal was reached in this round, the intermediate storage, which represents a part of the production process, was also examined more closely. This analysis is described below.

Analysis of the intermediate storage – second round

In order to be able to analyse the warehouse, a storage module was added to the simulation model, as previously mentioned. Each individual storage and retrieval order were plotted for the year 2025 using a diagram. In order to be able to make realistic statements, however, some assumptions had to be made. These can be listed as follows:

- The components are transported on pallets, whereby each component is stored on its own pallet for an entire lot
- After completion of the entire work order, each component is stored until all components for a product and lot are ready
- Each component is then transferred to the respective welding lines, whereby each component is again transported on its own pallet

As already mentioned in chapter 3.1.4, during the analysis of the material flow the problem arose that the company had no record of the transport containers. The assumptions made during the simulation solved this problem as the transport of each pallet was mapped over the year 2025. The result of the simulation of the inner bearing is shown in Figure 54.

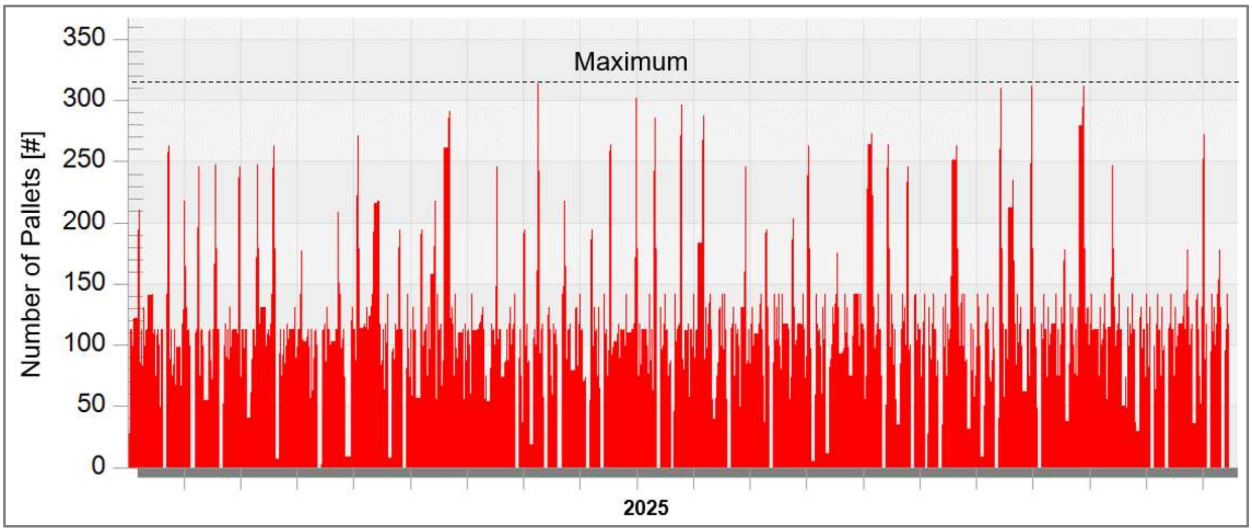


Figure 54: Simulation of the storage

A maximum value of 312 pallets, which have to be stored at the same time, is visible. This is triggered by a specific product mix that occurs several times a year and is highly dependent on the simulated production program. Nevertheless, a solution has to be found for the high number of pallets, as a storage area for 312 pallets is not provided in the layout yet. For this reason, all the components of a specific product were analysed in more detail, and it was found that a large proportion of the components could also be transported on so-called small component wagons. The company has therefore offered to transport the components on suitable transport containers (pallets, boxes, ...).

Commissioning after storage to the respective welding lines can then take place on small part wagons. The result would not only be a saving in the space required for the warehouse, but also smaller provisioning areas in the welding lines.

After the second simulation round, the results achieved were presented to the company. This meeting also served as a workshop in which final simulation parameters were defined in order to be able to represent reality even more accurately. The following decisions were made:

- The rest period should be increased from 30 to 45 minutes in order to also take coffee break times into account
- There are machines that can work without the employee being present. There are no break times to consider for these machines. This concerns the laser, the plasma cutter as well as all welding robots
- An investment in a second press brake or band saw is out of the question for the company due to the costs and the long downtimes of the machine as shown above. Instead, it will be investigated whether the use of a new, improved technology can reduce processing and set-up times to such an extent that the planned throughput can be achieved.

In addition, all possible strategies which could contribute to the fulfilment of the plan throughput were discussed again and all possible positive and negative effects of the individual options were addressed. The results of this workshop are shown in the following Figure 55.

Strategy \ Effect	Production costs	Utilization	Separation of the product lines	System effort	Cycle time	Dependency on the supplier
Purchase of additional machines	↑	↓	↑	↓	↓	↓
Usage of the existing plant	↓	↑	↓	↑	↑	↓
Purchase of components	↑	—	↑	↑	↓	↑
Adjustment of process times	↓	↑	↑	↓	↓	↓

Figure 55: Effects of the strategies

Since no additional machines have to be invested in and thus no additional personnel requirement arises, the production costs decrease. At the same time, the capacity utilization of the critical machines increases because there are no such long waiting times, compared to the second simulation round. In addition, this measure makes it possible to strictly separate the company's different product lines, which in turn reduces the total system effort. Another positive effect concerns the throughput times. Due to the reduced process and set-up times, these can be reduced as well. Finally, it should be noted that there are no additional dependencies on suppliers, as the measure taken means that all components can be produced in-house. For these reasons, the strategy marked in Figure 55 was selected for the final simulation round.

3.2.6.4 Third simulation experiment

The first task was to find out by what percentage the times of the small press brake and the band saw had to be reduced. For this purpose, it was necessary to find out how high the total set-up and processing times of both machines are for a lot size of five. Therefore, an additional simulation round was carried out in which the adjusted break times were already taken into account. The demand surplus is shown in the following Table 9. Since the ratio between setup time and machining time should remain the same, the percentage distribution of these two times is also shown in the table.

Work Station	Demand Surplus [%]	Share of Setup time [%]	Share of Processing time [%]
Press Brake	27 (= 1.802h)	49	51
Band Saw	10 (= 846h)	30	70

Table 9: Demand surplus of the critical work stations

For easier understanding, the example of the band saw will be explained in more detail. A 10% reduction in the total machining time, which consists of set-up and processing time, is required to achieve throughput. After deducting the percentage, the new total time was again divided into setup time and machining time according to the shares shown in the table above.

For the results of the feasibility study, see Figure 53: Throughput analysis – second round. Reducing the times of the two critical machines results in the fact that the company is able to achieve the planned throughput at a lot size of 5. In the following, the analysis of the workplaces and their buffers will be dealt with.

Analysis of the critical machines – final round

Once again, the small press brake and the band saw were examined with regard to capacity utilization. Figure 56 shows that both workstations must be operated in three-shift production. The disadvantage of long waiting times, which occur in the second simulation round due to the adding of redundant machines, could be avoided by reducing processing times. A further advantage of this approach is that the required number of employees could be reduced from eight to six.

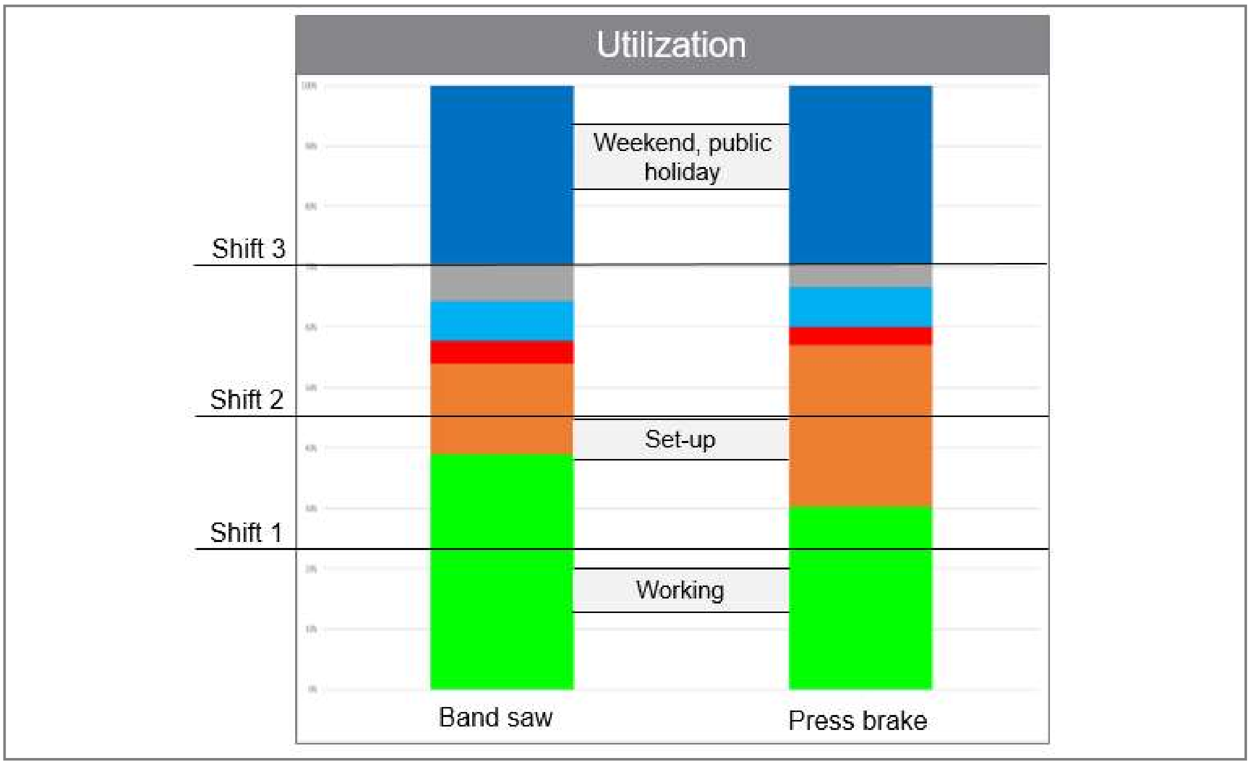


Figure 56: Utilization of the critical machines – final round

The band saw, the laser and the plasma cutter are the first steps in the production of the components. Since the buffer loads of these machines can be easily controlled by the company, the analysis of the buffers of these workplaces was not necessary. All other workstations were examined more closely. The two workplaces with a very high number of pallets are discussed below.

Analysis of the buffer loads – final round

Figure 57 shows the number of pallets in front of the small press brake and the manual workstation where grinding is performed. For example, a number of 20 pallets means that 20 different components are waiting at the same time in front of each workstation for further processing.

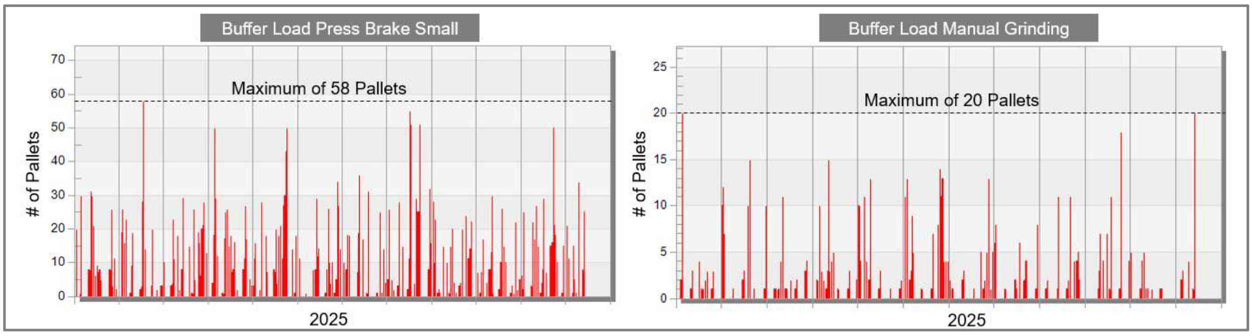


Figure 57: Maximum buffer loads – final round

Once again, the press brake shows an occupancy of 58 pallets. This number is also higher than the result of the first simulation round. The load on the grinding station is considerably lower. A maximum of 20 pallets can be seen here. It is also worth mentioning that exactly these two workplaces show the maxima among all workplaces. These are the workplaces that come after the laser or plasma machine, which, as mentioned before, represent the first workplaces of the processes. For both machines, the pause time was set to zero. This means, that these machines are able to work all the time and are therefore able to process the components faster.

The high difference between the two buffer fills can also be easily explained. While a very high proportion of the processing time on the press brake consists of set-up operations, there is no set-up process for grinding. Due to this fact, the grinding process of the components can not only be started faster, but also completed faster. This is also due to the longer processing times required by the press brake.

Nevertheless, the problem of the high number of pallets must be solved for both workstations, since the planned areas in the layout would not be sufficient. Since the company is planning to buy a new plasma cutter that includes an automatic grinding device that would reduce the number of components in manual grinding, the focus is again on the press brake. The already mentioned strategy of suitable transport boxes, of which several can be placed on a pallet, is recommended here again. It should be noted that this action reduces the number of pallets at each workstation and also in the warehouse.

At the end of the final simulation round, the capacity utilizations of all workstations were analyzed. At the same time, a comparison was made between the current and planned lot sizes.

Analysis of the capacity utilization – final round

As already mentioned at the beginning of this work, the effects of the changed lot sizes had a special role throughout the project. For this reason, the following shows the capacity utilization of all machines for both current and planned lot sizes. The comparison will follow afterwards.

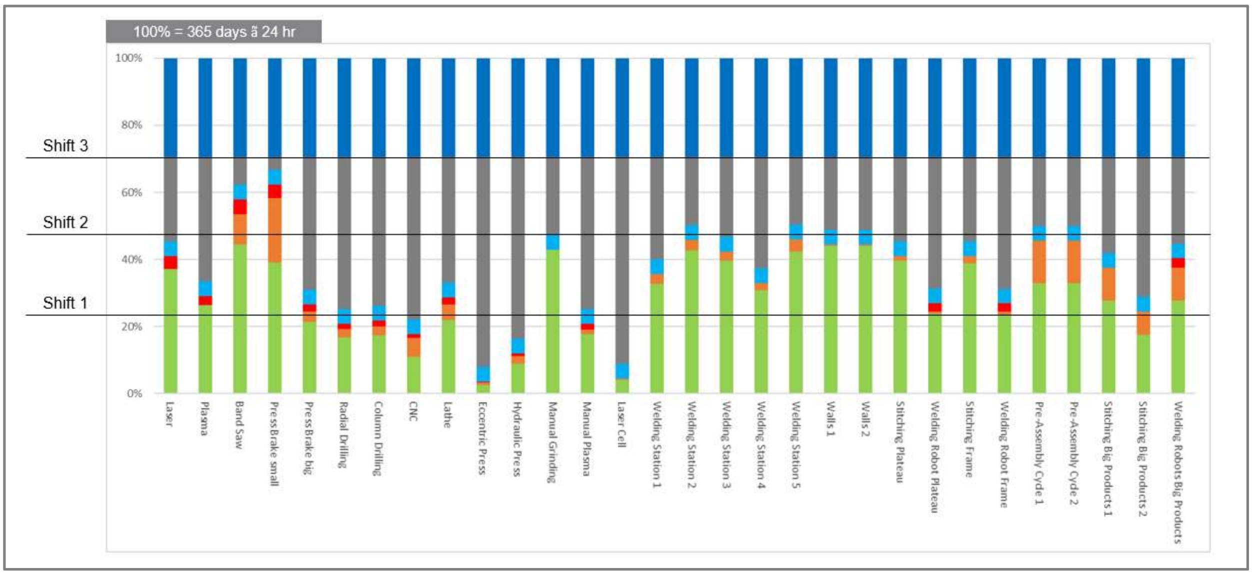


Figure 58: Capacity utilization – current lot size

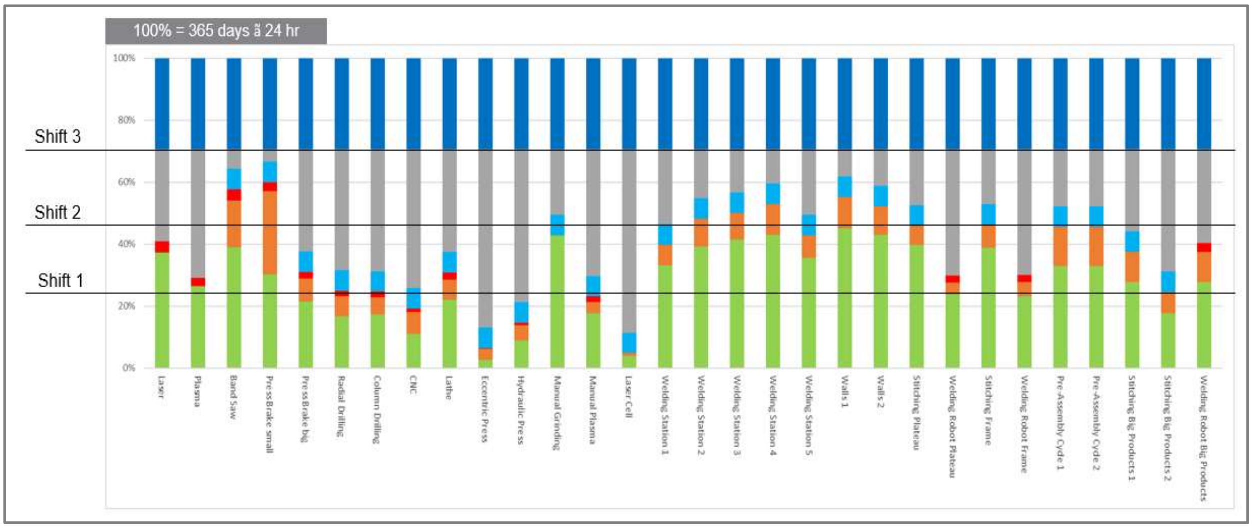


Figure 59: Capacity utilization – planned lot size

Unplanned times

The unplanned times, represented by the dark blue bars at the top, are the same in both diagrams and amount to just under 30% of the total available time, which is 365 days at 24 hours. The fact that the unplanned times do not change is a consequence of the fact that the year 2025 was simulated in all simulation rounds. This means that neither the weekends nor the public holidays have changed.

Break times

These times are, as already mentioned, represented by the light blue bars. It can be seen that in Figure 59 the pause times are slightly higher than those shown for the current lot sizes. As required by the company, these times were increased from 30 to 45 minutes in the last simulation round. For this reason, there is a difference of about 2% within a year in which the machines are not operated and therefore no machining process is created.

Processing times and downtimes

The disturbance times shown in red amount to 10% of the processing time in both simulation rounds. The latter are indicated by the green bars. Since both times do not change despite the change in lot size, there is no change in either proportion.

Setup times

In both diagrams shown above, the brown bars represent the corresponding setup times of the workstations. At this point, it should be noted that there are also workstations that do not require retooling. For this reason, this proportion is zero, for example for the laser or plasma cutter. Due to the fact that a planned lot size of 5 is much smaller than the current lot sizes, the number of setup operations in 2025 will be much higher than it is today. For this reason, it can be seen that the share of setup in Figure 59 is higher than that in the previous diagram, which shows the workloads associated with the current lot size. This is particularly evident with the small press brake. Although both the set-up times and the machining times were shortened in the last simulation round, the Figure 59 nevertheless shows that the set-up percentage is considerably higher than the current one for the actual lot size.

As mentioned above, in the last round of simulations, all of the company's constraints were taken into account. Despite longer set-up times, caused by the reduced lot sizes, and longer break times, the simulation showed that the planned throughput could be achieved. For this reason, it was possible to complete the determination of the utilization figures.

At the end of the simulation chapter, the number of employees required was determined. This information is necessary to be able to calculate the cost of production for both lot sizes, since this depends on the direct labour costs.

3.2.6.5 Required number of employees

Based on the results of the last simulation round, the utilization of all workstations was determined and entered in the following two diagrams in the second column. As a reminder, it should be noted that a 100% utilization corresponds to 365 days with 24 hours each. The number of shifts required for each workstation was taken from Figure 59 and takes into account not only working and set-up times, but also disturbance and break times. The number of work stations was determined during layout planning and is entered here again, since the number of employees depends on it. The employees per work station are entered in the penultimate column, whereby this data is based on information provided by the company during the first work phase. Based on this information, it was possible to determine the total number of employees required, whereby a distinction is made between mechanical and manual workstations.

Number of employees for mechanical workstations

Machine	Utilization [h]	Utilization [%]	# of Shifts	# of Workstations	# of Employees per Workstation	# of required Employees for 2025
Eccentric Press	1.147	13	1	1	1	1
Hydraulic Press	1.876	21	1	1	1	1
Press Brake small	5.837	67	3	1	1	3
Press Brake big	3.292	38	2	1	1	2
Bandsaw	5.634	64	3	1	1	3
Plasma	2.548	29	2	1	1	2
Laser	3.587	41	2	1	1	2
Conventional Lathe	3.278	37	2	1	1	2
CNC	2.257	26	2	1	1	2
Pillar Drilling Machine	2.738	31	2	1	1	2
Radial Drilling Machine	2.759	32	2	1	1	2
Robot for Frame	2.632	30	2	1	1	2
Robot for Plateau	2.621	30	2	1	1	2
Robot for big products	3.531	40	2	1	1	2
Sum Machines	-	-	-	**14**	-	**28**

Figure 60: Number of employees for mechanical workstations

In the last line of Figure 60, it is highlighted that a total of 28 employees are needed for the 14 machine workstations in 2025. Here, too, the two critical workplaces, small press brake and band saw, are the most important. While only one or two employees are required for the other machines, three are required for each of these two, as they are almost fully utilized.

Number of employees for manual workstations

The total number of employees for the manual workstations is significantly higher than that for the mechanical workstations. This is not only due to the fact that the number of workstations is higher, but also to the fact that the number of employees per workstation is in most cases higher than one. Figure 61 shows on the one hand the number of employees for the manual work areas and on the other hand the total number of employees required for 2025 in the new factory building. The latter are highlighted with a frame.

Workplace	Utilization [h]	Utilization [%]	# of Shifts	# of Workstations	# of Employees per Workstation	# of required Employees for 2025
Manual Plasma	2.607	30	2	1	2	4
Manual Grinding	4.333	50	3	1	1	3
Laser Cell	1.002	11	1	1	1	1
Welding Station small	18.407	53	3	4	1	12
Welding Station big	4.970	57	3	1	2	6
Stitching Frame	4.627	53	3	1	2	6
Stitching Plateau	4.600	53	3	1	2	6
Walls	10.565	57	3	2	2	12
Pre-Assembly	9.142	52	3	2	2	12
Stitching big products	6.595	38	2	2	2	8
Sum Manual Workstations	-	-	-	**16**	-	**70**
+				+		+
Sum Machines	-	-	-	**14**	-	**28**
Total				**30**		**98**

Figure 61: Number of total required employees

In the new factory, 98 employees will be needed to manufacture the agricultural engineering products in order to achieve the planned throughput in 2025 with a lot size of five.

With the help of simulation, it was possible to determine to what extent set-up and processing times had to be reduced in order to achieve the planned quantity with reduced lot sizes. In addition, the final storage design was also based on the simulation model. Furthermore, the effects of a smaller lot size could be shown by making a comparison between the capacity utilization. Finally, the assignment of employees was determined, which was also required as information in the next work phase. Thus the chapter of the simulation could be completed.

3.3 Impact of the Restructuring

At the beginning of this work, it was already noted that the company currently produces both products for agricultural engineering and products for environmental engineering in its existing plant. In Chapter 3.2, a layout planning was carried out with the aim of manufacturing the agricultural engineering products in the new, separate hall in future. However, the separation of the two product families also has an impact on those products that remain in the existing facility. For this reason, the effects of layout planning, and consequently of restructuring, will be discussed in this chapter.

First of all, it was examined how high the area gain is if those workplaces which are only needed for the agricultural machinery products are taken out. During a workshop with the company, the material flows for the environmental technology products were discussed. Based on this, a simplified layout planning for the existing plant was carried out, in which new machines and product groups were considered. The free capacities of the work stations were then determined. The reason for this was to show the company how large the increase in productivity could be if the project was to be realized. Finally, the manufacturing costs for the agricultural machinery products were calculated taking into account the different lot sizes as well as every investment needed to be done for the new plant. The procedure during this work phase is shown in the following Figure 62.

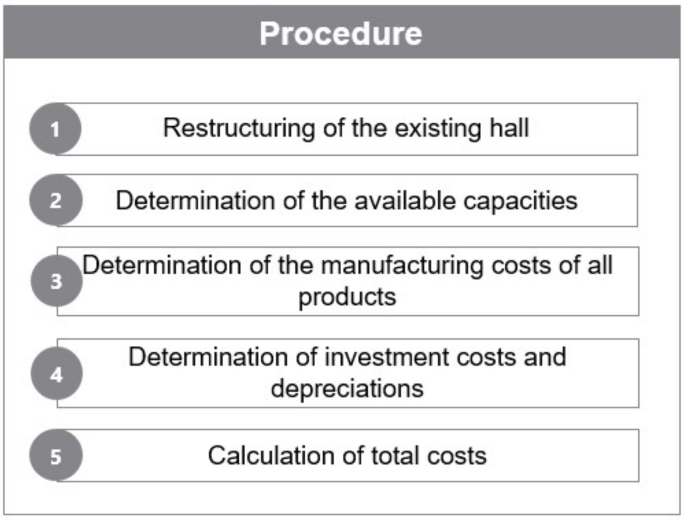


Figure 62: Procedure during the analysis of the impact of the restructuring

3.3.1 Restructuring of the Existing Plant

First, the current layout was examined in more detail. During the restructuring of the current layout, the fixed points had to be considered. These are the machines that cannot change their current position. In the following Figure 63, these areas are marked with red rectangles at the bottom. In addition, a distinction was made between those work areas that are only required for environmental technology products and those that are used for the production of both environmental technology products and agricultural technology products. The latter are highlighted with a blue frame (indicating machine workstations) or with blue rectangles. Manual work areas and welding workstations are highlighted in red. At the end those areas were marked with a grey frame and black rectangles which are only needed for the agricultural engineering products and consequently will no longer be needed in the existing production facility.

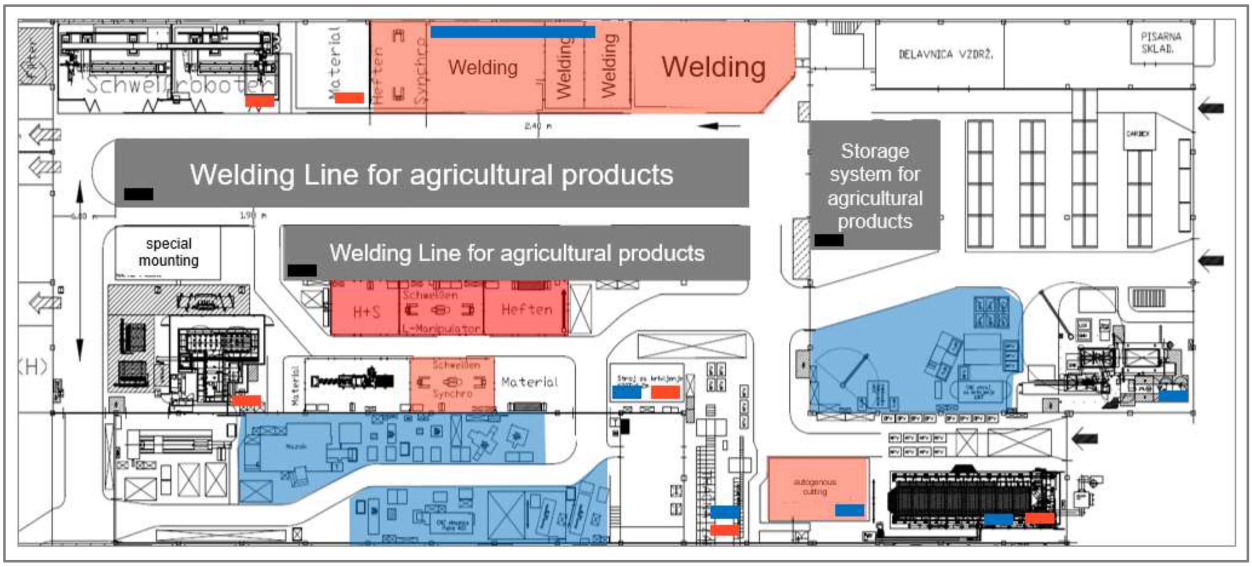


Figure 63: Current layout

The differentiation between the working areas shows that a large proportion of the total area is used only for agricultural machinery products. Due to the greenfield layout planning, this area will also be available for the company's environmental technology line in the future. Therefore, the next step was to determine the area gain.

As mentioned in previous chapters, the welding lines are working areas for plateau, frame and walls. Stitching, welding and material supply for all three work areas amount to a total of 569 m². At the beginning of the layout planning, the share of agricultural machinery products in the storage area was assumed to be 200 m². This means that additional 769 m² of space will be available in future for the production of environmental technology products.

Based on the conclusions of the aforementioned workshop, individual work areas were subsequently rearranged. The newly planned layout is shown in the following Figure 64. The entire inner storage area was moved a few metres downwards to allow an additional transport route into the building. In addition, a second laser was installed in the entrance area, which the company plans to purchase. Subsequently, the small welding workstations were moved to the centre of the hall in order to be able to provide a new, large welding workstation in which larger parts are to be welded in future. Areas have also been provided for the planned new machines, one press brake and one new robot. All new work areas are marked in the following illustration as a grey area. In the last step of the restructuring, the machinery workstations were rearranged. A large number of the machines highlighted in blue in Figure 63 were moved from the lower half of the layout to the area where the welding lines used to be. This also created a curve-free transport path in the lower part of the layout. The reason for this is explained afterwards.

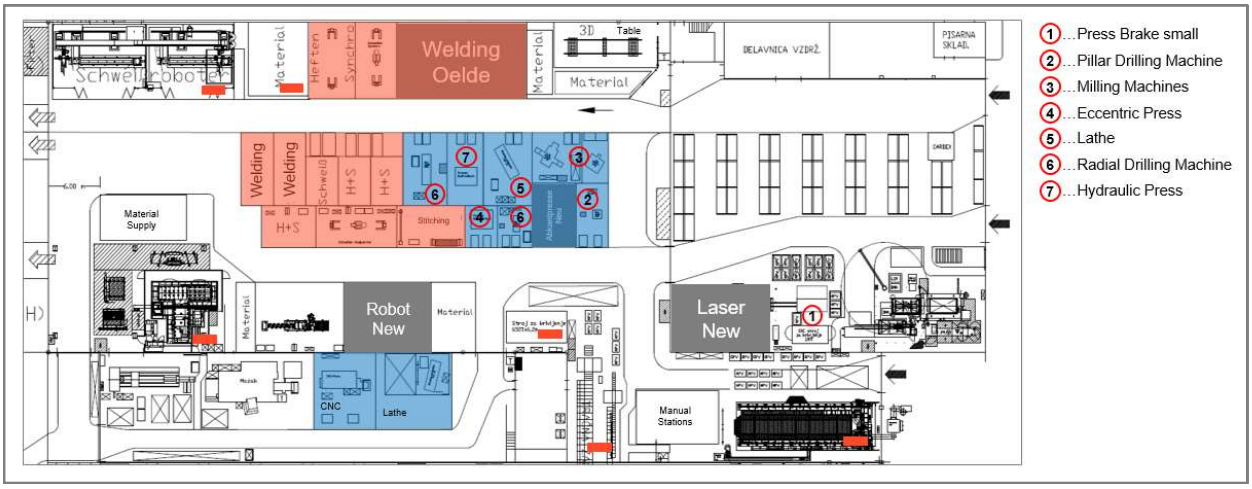


Figure 64: Rearranged existing layout

During the restructuring of the work areas, not only the new work areas and the fixed points were taken into account, but it was also ensured that, on the one hand, the existing transport routes gained in width and, on the other hand, the curved path at the lower end of the layout was more straightforward. The reason for the latter is the company's aim to keep all forklift traffic within the factory hall as low as possible. Instead, two tugger train systems are to be planned with the help of which the entire material transport, if possible, will take place. These two route systems are described below.

Figure 65 shows both tugger train systems, again distinguishing between manual and machine workstations. Since there are no welding workstations at the bottom of the layout, the tugger train for the manual workstations, shown here in black, is considerably shorter than the other. Both route trains begin and end at the inner warehouse. The advantage of these systems is on the one hand the adherence to the flow principle and on the other hand the possibility to transport several components at the same time.

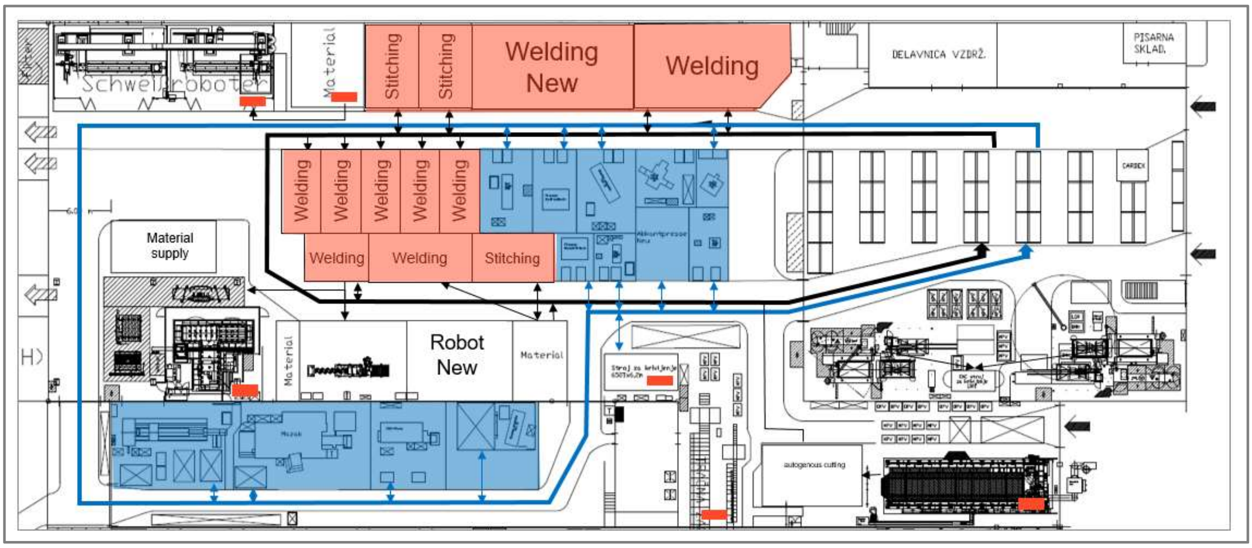


Figure 65: Tugger train systems

This allowed potentials for use to be shown to the company with regard to the available areas in the existing factory. Since capacities are also affected by greenfield-layout planning, they will be discussed in the next chapter.

3.3.2 Determination of Available Capacities

A large part of the workstations is used for the production of both agricultural engineering products and environmental engineering products. As these two product lines will be separated when the new facility goes into operation in 2025, capacity will be freed up in the existing plant. These capacities will be analysed in this chapter.

As mentioned above, this work package did not include an analysis of the production programme of environmental technology products. In order to assess the capacity that will be freed up, the capacity utilisation of all workplaces in 2018 was taken into account. With the help of the company's IT system, it was possible to divide these workloads between the two product lines. The shares were then calculated on the basis of 4.950 available hours per year (see chapter 3.1.3). From this number of hours, which corresponds to a single workstation in three-shift operation, the hours of agricultural engineering were subtracted in order to determine the total capacity that would be available purely for environmental engineering products. The following figures show these hours in the column on the right.

3.3.2.1 Free capacities of the machines

		Agricultural Products		Environmental Products		
Machine	# of Workstations	Working Time 2018 [h]	Utilization 2018 [%]	Working Time 2018 [h]	Utilization 2018 [%]	Available Capacity 2018 [h]
Eccentric Press	1	537	11	869	18	4.081
Hydraulic Press	1	1.068	22	1.806	36	3.143
Press Brake small	1	2.283	46	1.733	35	3.217
Press Brake big	1	1.493	30	2.867	58	2.083
Bandsaw small	1	1.265	26	1.209	24	3.741
Bandsaw big	1	1.486	30	1.827	37	3.123
Plasma	1	1.098	22	2.338	47	2.612
Laser	1	1.760	36	2.995	61	1.955
Lathe	2	1.302	13	2.636	27	7.264
CNC	1	570	12	3.306	67	1.644
CNC big	1	196	4	2.108	43	2.842
NC Lathe	1	22	0,4	3.851	78	1.099
Borer Mill	1	95	2	4.976	101	-26
Conventional Milling	2	388	4	2.357	24	7.543
Pillar Drilling Machine	2	1.016	10	1.602	16	8.298
Radial Drilling Machine	2	996	10	2.968	30	6.932
Welding Robot „Cloos“	1	0	8	1.666	34	3.284
Welding Robot „IGM“	1	0	0	5.555	112	-605

Figure 66: Free capacities of the machines

Two important statements can be made on the basis of Figure 66. On the one hand, it can be seen that the environmental technology line contributes to a higher utilization of the machines than the agricultural technology products. On the other hand, it is evident that almost no workplace is fully utilised, which would mean that considerably more environmental technology products could be manufactured in the future. Exceptions are the boring mill and the welding robot "IGM", where the free capacities are written in red. The negative values that occur here would theoretically mean that more hours were worked than are actually available. It is therefore a condition that is not possible in practice. This error can be traced back to the data recording of the company. The actual hours are continuously overwritten by the target hours. If the bills of materials are inaccurate at the same time, it can happen that more hours are displayed than were actually worked. This is a company problem that is currently being corrected. For this reason, it is not necessary to say any more about the machine workstations at this point.

3.3.2.2 Free capacities of the manual workstations

In the same way, the analysis of the manual workstations was undertaken. The results are shown in Figure 67.

		Agricultural Products		Environmental Products		
Workstation	# of Workstations	Working Time 2018 [h]	Utilization 2018 [%]	Working Time 2018 [h]	Utilization 2018 [%]	Available Capacity 2018 [h]
Manual Plasma	1	803	16	825	17	4.125
Manual Grinding	2	1.288	13	1.993	20	7.907
Laser Cell	1	147	3	185	4	4.765
Welding Stations	6	9.614	19	35.803	72	13.697
Tooling Station	1	0	0	486	10	4.464
Stitching for „Cloos“	1	0	0	1.694	34	3.256
Welding „Hard-Facing“	1	0	0	682	14	4.268
Welding Positioner	3	0	0	3.166	21	11.684
Welding 3D	1	13	0,13	1.752	18	3.198
Welding X / AX	1	1.048	21	2.471	50	2.479
Welding CR / TM	5	891	4	12.206	49	12.544
Welding New	1	4	0,01	3.235	65	1.715

Figure 67: Free capacities of the manual workstations

The same two statements as for the machine workstations also apply here. The only exception is the fact that there are no inconsistencies in the BOMs, and therefore the actual free capacities of all workstations could be determined.

After the company was shown on the one hand how to utilise the freed areas, and on the other hand the potential increase in productivity with regard to the environmental technology products was highlighted, the next step was to determine the production costs of the agricultural technology products.

3.3.3 Production Costs

The aim was to determine the production costs of the nine products depending on the different lot sizes. In the following it is also shown how the different costs arise and how high the influence of the individual cost types is.

3.3.3.1 Costing sheet

The calculation scheme currently used by the company was used to determine the production costs and is similar to the single-stage elective overhead calculation method described in chapter 2.3.2. This schema is shown in Figure 68. The production costs of the products are divided into material costs, manufacturing costs and the proportion of costs for small materials. The direct costs for the required materials are calculated by multiplying the number of units by an average price, the latter being different for all products. The indirect costs are calculated using percentage surcharges, which are dependent on the direct costs. As shown in the figure, the manufacturing costs can be calculated by multiplying the operating hours by the hourly rates. The company distinguishes not only between machine and personnel hours, but also between setup hours. Thus, this share is dependent on the different workstations. At the same time, it consequently follows that there are different costs for the current and planned lot sizes because the setup times differ. Any costs for small materials, such as screws and gaskets, are again taken into account by percentage surcharges, whereby a distinction is made between small and big products.

Cost Type	Apportionment	Calculation
Material costs	Direct material costs	Units x Average price
	Indirect material costs	7,48% of direct material costs
+ Manufacturing costs	Direct manufacturing costs	Operating hours x Rates
	Indirect manufacturing costs	17,45% of direct manufacturing costs
+ Costs for small materials	Big products	44,9% of direct manufacturing costs of the assembly stations
	Small products	27,68% of direct manufacturing costs of the assembly station
= Production Costs		

Figure 68: Costing sheet of the production costs

3.3.3.2 Results

Based on the company's method, the production costs of all products were calculated for the years 2019 and 2025 and are shown in Figure 69. Although nine products were mentioned from the beginning, ten products are shown here. This is due to the fact that an assembly of one of the two big products has a very high number of individual components, which is therefore represented as a separate cost unit in the internal controlling of the company.

It turns out that the production costs for small products with a lot size of five are higher than those for current lot sizes. As already mentioned, this is due to the fact that setup times are higher for small lot sizes, resulting in higher personnel and setup costs. However, this is not the case for the big products. As indicated in chapter 3.1, the lot sizes for these products were increased from three to five. This is exactly the reverse case of small products, which means that the production costs for large products with a lot size of five are slightly lower than those that would occur with current lot sizes. The percentage change in production costs between 2019 and 2025 is indicated in the round brackets. In order to make the comparison more transparent, the same hourly rates were used for the costs in 2025 as in 2019.

Category	Products	Current Lot Size [#]	Production costs 2019 (Current Lot Size)	Production Costs 2025 (Lot Size 5)
Small Products	Product 1	26	€ 4.296,71	€ 4.781,62 (+11%)
	Product 2	27	€ 5.659,02	€ 6.042,21 (+7%)
	Product 3	26	€ 7.670,11	€ 8.104,05 (+6%)
	Product 4	36	€ 5.951,22	€ 6.293,45 (+6%)
	Product 5	21	€ 9.116,17	€ 9.553,67 (+5%)
	Product 6	38	€ 6.922,84	€ 7.491,56 (+8%)
	Product 7	19	€ 10.470,62	€ 10.881,26 (+4%)
Big Products	Product 8	3	€ 15.878,63	€ 14.748,86 (-7%)
	Product 9	3	€ 12.999,08	€ 11.496,07 (-11%)
	Sub-assembly of product 9	3	€ 8.542,77	€ 8.274,76 (-3%)

Figure 69: Production costs

Product 8 has the highest production costs of any product. This is because, due to the large number of single components required for this products, the proportion of material costs is much higher than for the others. Product 1 has the lowest production costs with approximately 4.700 euros. At this point it should be noted that this is also the product with the lowest planned turnover.

After the differences in the cost of goods manufactured due to the changed lot sizes have been shown, the following section deals with the investments.

3.3.4 Investment Costs and Depreciations

In order to calculate the total costs, in addition to the production costs, the investment costs and the related depreciations were also calculated. Since the existing hall is to be used for the production of environmental technology products, some new machines have to be purchased for the new factory. Since machines and plants have different imputed useful economic lives, the investments were subdivided accordingly. The investment costs of the machines, which were already made available by the company after the first work phase, are shown in Figure 70 in the penultimate column. Those for the new construction of a hall were determined on the basis of the fine layout itself, whereby 1.200 euro per square metre was calculated. This amount was also a value given by the company and should take into account all costs incurred, including final installations. Additional assumptions had to be made to determine the straight-line depreciation. It was assumed that the investment date was 1 January 2025. This means that the total depreciation for the year 2025 must be taken into account. Based on this, the depreciation was calculated as follows:

$$Straigt - Line\ Depreciation = \frac{Investment\ Cost}{Imputed\ Useful\ Economic\ Live} \tag{12}$$

The following Figure 70 shows both the sum of the investment costs and the resulting depreciation, which are taken into account for the year 2025. Both values are highlighted in orange in the last row.

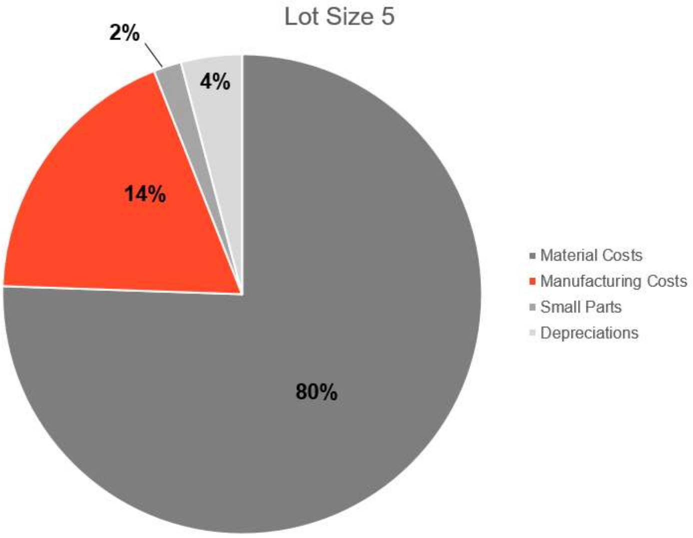
Category	Imputed Economic Useful Live	Naming	Investment Costs 2025	Straight-Line Depreciation 2025
Machines and Tools	8 Years	Press Brake	€ 400.000	€ 50.000
		Bandsaw	€ 100.000	€ 12.500
		Plasma	€ 300.000	€ 37.500
		Laser	€ 700.000	€ 87.500
		Grinding Machine	€ 300.000	€ 37.500
		CNC	€ 200.000	€ 25.000
		Pillar Drilling Machine	€ 20.000	€ 2.500
		Radial Drilling Machine	€ 50.000	€ 6.250
		Robot for Frame	€ 700.000	€ 87.500
		Robot for Plateau	€ 700.000	€ 87.500
		Robot for big Products	€ 700.000	€ 87.500
		Tools	€ 200.000	€ 25.000
Facility	33 Years	Hall	€ 11.520.000	€ 349.090,91
Sum	-	-	€ 15.890.000	€ 895.340,91

Figure 70: Investment costs and depreciations 2025

The investment costs for the new factory will be slightly less than 16 million euros, with the largest share being defined by the hall to be built. However, the total costs do not include the total investment costs, but the annual depreciation. These costs amount to around 900.000 euros.

3.3.5 Apportionment of the Costs

Due to the high number of 2.700 products that the company plans to manufacture in 2025, a large part of the costs incurred is made up by material costs. As a reminder, these are dependent on the quantity. 14% of the total costs are composed of the manufacturing costs. This means that machines and personnel cost more than 4 million euros to achieve the planned throughput. The smallest part of the costs, which results from the required small material, amounts to approximately 2% of the total costs. The situation in this paragraph is shown graphically in Figure 71.



Cost Type	Amount
Material Costs	€ 16.448.267,45
Manufacturing Costs	€ 4.022.607,06
Small Materials	€ 480.758,40
Depreciation	€ 895.340,91
Sum	**€ 21.774.973,82**

Figure 71: Apportionment of total costs for the year 2025

The last part of the project is a comparison between the contribution margin for the years 2019 and 2025, which is described below.

3.3.6 Effects on Contribution Margin

At the end of the project, a comparison between the current and future production costs was derived. The basis for determining the production costs was the number of units planned to be produced in 2019. Otherwise, the same procedure was followed as already explained in this chapter. In order to be able to make a good comparison, the impact of costs on the planned transaction volume was examined. For this purpose, the company provided the planned sales figures for the years 2019 and 2025, which can be used to determine the contribution margin. This is, as explained in chapter 2, the difference between the transaction volume and the variable costs, the latter being simplified by using the previously calculated production costs. The results of this analysis are shown in Table 10.

	2019 Current Lot Size	2025 Lot Size 5
Transaction Volume	€ 18.563.700,00	€ 39.123.000,00
-		
Variable Costs	€ 9.906.516,36	€ 20.879.632,91
=		
Contribution Margin	€ 8.657.183,64.	€ 18.243.367,09

Table 10: Comparison of the contribution margin

The contribution margin increases by 9.586.183,45 euro from 2019 to 2025, whereby only the planned lot size of 5 is considered. It should be noted again that no information on the fixed costs was provided by the company. Therefore, there is no calculation of profit. The calculation therefore only shows the increase in the contribution margin, and thus the amount that is theoretically available to cover the fixed costs. The results of this chapter are summarised in the following graph.

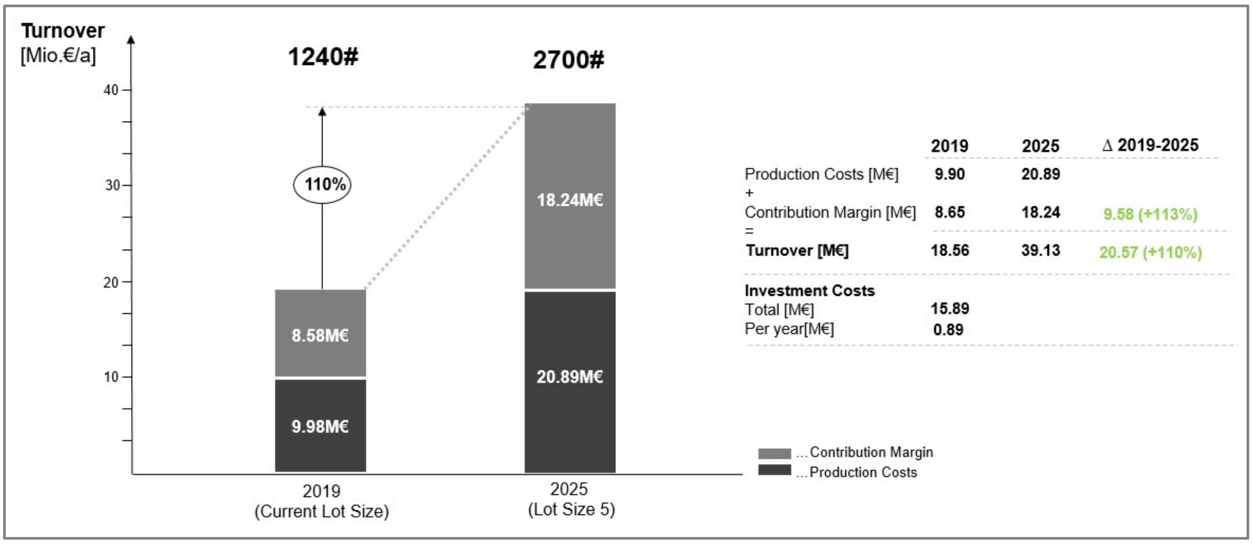


Figure 72: Impact of the layout planning

The identification of a potential increase in the contribution margin represents the final task of this phase. This means that the project is now considered completed. In the following chapter some encountered problems will be discussed and compared with the already existing cognitions from the corresponding literature.

4 Discussion

In this chapter, not only the individual outputs of some applied methods are addressed, but also the encountered problems during the phases of factory planning.

4.1 Situational Analysis

During this phase the current state has been analyzed. Material flow, production program, and the capacity utilization have been examined in detail, by always focusing on the different lot sizes.

Grundig (2012) describes in his work that the investigation period of the preparation phase of the factory planning is significantly influenced by the data situation.[182] This can be confirmed by the following fact:

The necessary data had not only to be collected, but also prepared for the purpose of the study. In particular, the analysis of the material flow posed major challenges. The required data about the transport containers, needed for the transportation matrix, were incomplete, if they existed at all. This fact led not only to the situation that the entire material flow analysis had to be revised shortly before the presentation of the interim results, but also that assumptions had to be made in cooperation with the company, which influenced the accuracy of the results. A delay of the entire project by a few weeks was the consequence.

In comparison, both the production program and the capacity utilization of each workplace could be carried out very quickly and precisely by means of computer support on the basis of the company's structured bill of materials.

4.2 Greenfield Layout Planning

One of the main tasks within the structure planning phase is the dimensioning of the subsystem, followed by the structuring.[183] In the first case, a distinction is made between static and dynamic methods.[184] The former mentioned have been applied within the framework of this project.

The required areas were determined on the basis of the dimensions of the machines and / or the assembly units. Supply areas, transport areas, and any additional areas were taken into account only by percentage surcharge factors. In the course of the greenfield

---

[182] Cf. Grundig (2012), p. 60
[183] Cf. Grundig (2012), p. 52
[184] Cf. Grundig (2012), p. 88 f.

planning, the calculated areas had to be corrected. Most of the spaces determined were too small for the intended use and had to be corrected in an upward direction. On the one hand, this is due to the fact that on some workstations very long parts have to be machined, whose size is not taken into account, especially when considering the areas for the machines.

In addition, it should be noted that the static methods are used to determine average values. Exact calculations are only possible with dynamic methods, which are based on, inter alia, simulation models.[185] This fact confirms the advantages of using simulation models already in the early phases of the factory planning procedure.[186]

Once the different layout variants have been created, they have to be evaluated afterwards. Since the results of the evaluation, and thus the selection, has to be objective and reproducible, the usage of quantitative methods is necessary.[187] For this purpose, a workshop lasting several hours had been performed during the project, in which not only layout variants had been created, but also evaluation criteria had been selected. This workshop was attended not only by Lean Management employees, but also by production managers from various departments. One reason for this was to cover all departments of the company and to not forget any areas. The cooperation between the institute and the company enabled a qualitative decision making with which the company, and thus the customer, is satisfied.

One of the requirements during layout planning was to always keep an eye on the changing lot sizes and the associated effects. The advantages of the smaller batch sizes are the reduced throughput times of the products as well as lower stock levels.[188] However, one of the basic prerequisites for economic efficiency is the existence of a high degree of setup flexibility. Put simply, this means short setup times.[189] Within the scope of this project, it was hardly possible to influence the setup times, as the current data had to be used. Therefore, assumptions were made to reduce setup times to the extent necessary to achieve the planned throughput. Due to the fact that the company had set a target lot size of five for each product, it was not examined whether this was also the optimum lot size. This leaves the question unanswered as to whether the layout that has been worked out also represents an optimum in terms of warehousing costs.

[185] Cf. Grundig (2012), p. 88 f.
[186] Cf. Grundig (2012), p. 241
[187] Cf. Grundig (2012), p. 200 f.
[188] Cf. Konold / Reger (1997), p. 1
[189] Cf. Konold et al. (1997), p. 43

4.3 Impact of the Restructuring

After completion of the layout planning, the company's existing plant was examined more closely. Among other things, an attempt was made in a workshop to find an optimal arrangement of the machines placed there. In addition, a possible increase in productivity, which is a consequence of the greenfield layout planning project, was also investigated.

As already mentioned in the introduction of this work, the analyses of this work phase were carried out by rough estimates based on data provided for the agricultural products. However, since it is exactly these products that will no longer be manufactured there in the future, it seems difficult to make any statements about the accuracy of the results achieved.

Nevertheless, it was possible to show the company possible usage potentials, since a very high space gain was achieved by excluding not only the welding lines for the agricultural products, but also nearly the half of the required storage system.

5 Conclusion and outlook

Due to the high demands of its products, one plant of an Austrian company increasingly represents a capacity bottleneck. For this reason, a greenfield layout planning for one of its product lines was carried out within the framework of this project.

First, the current situation was analyzed in detail. For this purpose, direct and indirect data acquisition methods were used to collect the information needed. These were then used to analyze the production program, the material flow, and the capacity utilization, with respect to the current and planned lot sizes and production quantities for the year 2025. Based on the results, weak points were identified, which were taken into account during the planning of the new facility.

The task of the second phase of this project was to create a detailed production layout. First of all, the required areas for the work places and storage system were dimensioned. Subsequently, different layout variants were created, whereby an ideal layout, based on the presented theoretical methods, served as the basis. The selection of the variant with the highest overall optimum was performed with a value-benefit analysis. A CAD program was then used to illustrate a fine layout, taking into account any, as far as possible, real world conditions. This layout was then mapped into a simulation model in which a plausibility analysis was executed, considering real preconditions of the company.

Finally, the effects of the layout planning on the existing plants were considered. After the production costs for the selected products had been estimated, a qualitative assessment of the usage potentials of the existing factory halls was undertaken. The information of only one product family served as a basis for this.

At this point it should be noted that no detailed analysis of the remaining product families has been carried out. For this reason, it is advisable to plan a new layout for the existing facilities as a follow-up project, which in this case would have to be carried out as a brownfield project. This new and detailed analysis would lead to an increased transparency of the results of the last work phase.

References

Adam, D. (1998). Produktionsmanagement. Wiesbaden: Gabler Verlag.

Anderson, D. M. (2014). *Design for Manufacturability- How to use concurrent engineering to rapidly develop low-cost, high-quality products for lean production.* Boca Raton: CRC Press Taylor & Francis Group.

Arnold, D., & Furmans, K. (2007). *Materialfluss in Logistiksystemen* (5th Ausg.). Karlsruhe: Springer Verlag.

Arnolds, H., Heege, F., & Tussing, W. (1996). *Materialwirtschaft und Einkauf-Praxisorientiertes Lehrbuch* (9. Ausg.). Wiesbaden: Springer-Verlag.

Blohm, H., Lüder, K., & Schaefer, C. (1995). *Investition-Schwachstellen im Investitionsbereich des Industriebetriebs und Wege zu ihrer Beseitigung* (8th Ausg.). München: Franz Vahlen.

Boysen, N., Fliedner, M., & Scholl, A. (2008). Assembly line balancing: Which model to use when? *International Journal of Production Economics*, S. 509-528.

Dellmann, K. (1980). *Betriebswirtschaftliche Produktions- und Kostentheorie* (Bd. 3 von Die Wirtschaftswissenschaften. Neue Reihe.). Kiel: Betriebswirtschaftlicher Verlag Gabler.

Dolezalek, C. M. (1973). *Planung von Fabrikanlagen.* Stuttgart: Springer-Verlag Berlin Heidelberg.

Domschke, W., Drexl, A., Klein, R., & Scholl, A. (2015). *Einführung in Operations Research* (9th Ausg.). Darmstadt / Kiel / Augsburg / Jena: Springer Gabler Verlag.

Erlach, K. (2010). *Wertstromdesign-Der Weg zur schlanken Fabrik* (2 Ausg.). Stuttgart: Springer Heidelberg Dordrecht London New York Verlag.

Fähnrich, K. P. (2006). Skriptum Softwaremanagement - 2. Planung. Universität Leipzig - Institut für Informatik, Anwendungsspezifische Informationssysteme.

Götze, U. (2006). *Investitionsrechnung-Modelle und Analysen zur Beurteilung von Investitionsvorhaben* (5th Ausg.). Chemnitz: Springer Verlag.

Grundig, C.-G. (2012). Fabrikplanung: Planungssytematik-Methoden-Anwendungen. Kleinmachnow: Carl Hanser Verlag München.

Gutenberg, E. (1983). *Grundlagen der Betriebswirtschaftslehre* (Bd. 1 Die Produktion). Köln: Springer Verlag Berlin Heidelberg.

Hartel, D. (2015). Projektmanagement in Logistik und Supply Chain Management-Praxisleitfaden mit Beispielen aus Industire, Handel und Dienstleistung. Baden-Württemberg: Springer Gabler Verlag.

Henn, G., & Kühnle, H. (1999). Strukturplanung. In G. Schuh, & W. Eversheim, *Produktion und Management 3 - Gestaltung von Produktionssystemen* (S. 9-57 - 9-92). Berlin: Springer Verlag, Redaktion Hütte.

Hömberg, K., Jodin, D., & Leppin, M. (2004). *Technical Report-Methoden der Informations- und Datenerhebung.* Sonderforschungsbericht, Dortmund.

Kettner, H., Schmidt, J., & Greim, H.-R. (1984). Leitfaden der systematischen Fabrikplanung. München, Wien: Carl Hanser Verlag.

Konold, P., & Reger, H. (1997). *Angewandte Montagetechnik- Produktgestaltung, Planung, Systeme und Komponenten.* Geislingen: Vieweg-Verlag.

Nestler, H. (1968). *Methoden zur Bestimmung der Raumgröße und Raumausnutzung von Fertigungswerkstätten.* Technische Hochschule Hannover.

Pack, L. (1964). *Optimale Bestellmenge und optimale Losgröße- Zu einigen Problemen ihrer Ermittlung.* Münster: Springer Verlag.

Pawellek, G. (2008). Ganzheitliche Fabrikplanung - Grundlagen, Vorgehensweise, EDV-Unterstützung. Hamburg: Springer-Verlag Berlin Heidelberg.

Poggensee, K. (2009). *Investitionsrechnung-Grundlagen-Aufgaben-Lösungen.* Kremperheide: Gabler Verlag.

Rockstroh, W. (1982). *Technologische Betriebsprojektierung* (Bd. 2). Berlin: Technik VEB.

Schenk, M., Wirth, S., & Müller, E. (2010). *Factory Planning Manual - Situation-Driven Production Facility Planning.* (M. Lorenz, Übers.) Berlin: Springer Verlag.

Schenk, M., Wirth, S., & Müller, E. (2014). *Fabrikplanung und Fabrikbetrieb-Methoden für die wandlungsfähige, vernetzte und ressourceneffiziente Fabrik* (2nd Ausg.). Magdeburg / Chemnitz: Springer Verlag.

Schmidt, M. (19. March 2008). The Sankey Diagram in Energy and Material Flow Management. *Journal of Industrial Ecology*, S. 1-13.

Schuh, G., Gottschalk, S., Lösch, F., & Wesch, C. (4 2007). Integrated parallel bottom-up and top-down approach for factory design. *wt-online*, S. 195-199.

Schulte, H. (1984). Die Strukturplanung von Fabriken. In K. H. Engel, *Handbuch der Techniken des Industrial Engineering* (S. 1201-1254). Landsberg.

Sule, D. R. (2009). Manufacturing Facilities - Location, Planning, and Design. Florida: Taylor & Francis Group.

Verein Deutscher Ingenieure. (1973). Material Flow Analysis. In *VDI 3300* (S. 2). Düsseldorf: Beuth Verlag .

Verein Deutscher Ingenieure. (1999). Methods for the layout of operational areas and resources in terms of optimum material flow. In *VDI 3595.* Berlin: Beuth Verlag.

Verein Deutscher Ingenieure. (2010). Analysis and planning of factory areas-Fundamentals, application and examples. In *VDI 3644.* Berlin: Beuth Verlag.

Verein Deutscher Ingenieure. (2011). Factory Planning - Planning procedures. In *VDI 5200* (S. Blatt 1). Düsseldorf: Beuth Verlag.

Wiendahl, H. P. (1999). Fabrikplanung. In G. Schuh, & W. Eversheim, *Produktion und Management 3 - Gestaltung von Produktiosnsystemen* (S. 9-1 - 9-13). Berlin: Springer-Verlag, Redaktion Hütte.

Wiendahl, H.-P., Reichardt, J., & Nyhuis, P. (2015). Handbook Factory Planning and Design. In R. Rossi (Hrsg.). Berlin Heidelberg: Springer Verlag.

Zunk, B. M., Grbenic, S., & Bauer, U. (2016). *Kostenrechnung-Einführung, Methodik, Anwendungsfälle.* Graz: LexisNexis-Verlag.

List of Figures

List of Tables

List of Equations

List of Abbreviations

ALBP	Assembly Line Balancing Problem
BOM	Bill of Materials
CAD	Computer Aided Design
EBIT	Earnings Before Interests and Taxes
EDP	Electronic Data Processing
e. g.	example given
FIFO	First In First Out
IIM	Institute for Innovation and Industrial Management
MFA	Material Flow Analysis
OEE	Overall Equipment Efficiency
ROI	Return On Investment
VDI	Verein Deutscher Ingenieure
WP	Work Phase

Appendix A: Transportation and Distance Matrix

Transportmatrix	Nach	Lager innen	Lager-Bordwände	Lager-Bleche	Lager-Rohre	Lager-Zelt	1305-Presse Exzentrisch	1312-Presse hydraulisch	1422-CNC Abkantpresse Trumpf	1425Abkantpresse 650T	2311-Bandsäge OK320	2313-Bandsäge OK410	2581-Hand Plasma	2593-Plasma	2595-Laser	2600-Schleifen manuell	3111-konv. Drehmaschine	4111-konv. Fräsmaschine	4300-CNC Werkzeugmaschine	61000-Säulen bohrmaschine	6105-Säulen Bohrmaschine	6501-Radial Bohrmaschine RB40	6502-Radial Bohrmaschine RB70	7205-Schweißen Laserzelle	7223-Schweißarbeitsplätze	7602-Schweißlinie U	7602-Schweißlinie P/W	7602-Schweißlinie B	Warenausgang
Von																													
Lager innen			0	0	0	0	36	66	42	20	0	0	0	0	0	134	58	0	0	63	13	0	17	0	609	811	680	407	445
Lager-Bordwände		0		0	0	0	0	0	0	0	0	0	0	0	0	103	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Bleche		0	0		0	0	0	0	54	101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Rohre		0	0	0		0	0	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Zelt		0	0	0	0		29	0	0	0	27	0	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1305-Presse Exzentrisch		112	0	0	0	0		0	38	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	88	0	0	0	36
1312-Hydraulische Presse		351	0	0	0	0	0		20	11	0	0	0	0	0	18	7	0	0	69	0	107	0	0	154	9	0	0	225
1422-CNC Abkantpresse Trumpf		1363	0	0	0	0	22	7		22	0	0	22	0	0	24	0	0	0	0	7	11	0	159	859	0	0	0	805
1425-Abkantpresse 650T		385	0	0	0	0	39	14	14		0	0	79	0	0	0	0	0	0	0	0	0	0	0	178	19	30	11	116
2311-Banksäge OK320		586	0	0	0	0	59	136	0	0		0	0	0	0	743	200	0	0	0	0	20	53	0	48	0	0	0	7
2313-Bandsäge OK410		113	0	0	0	0	20	0	0	0	0		59	0	0	79	130	20	0	28	0	24	13	0	41	11	5	0	49
2581-Hand Plasma		4	0	0	0	0	0	9	0	6	0	0		0	0	6	0	0	0	0	0	0	0	0	38	81	34	33	142
2593-Plasma		237	0	0	0	0	0	0	39	76	0	0	10		0	1144	0	0	0	0	0	0	0	0	4	0	0	0	0
2595-Laser		1409	0	0	0	0	35	217	1669	182	0	0	0	0		260	67	0	0	20	366	29	0	0	364	0	0	0	28
2600-Schleifen manuell		346	0	0	0	0	48	304	542	338	0	0	20	0	0		45	71	24	105	35	191	13	0	212	16	0	418	105
3111-konv. Drehmaschine		171	0	0	0	0	0	21	0	0	0	0	0	0	0	0		38	0	238	0	9	0	0	146	0	0	0	49
4111-konv. Fräsmaschine		34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	45	0	0	24	0	0	0	0
4300-CNC Werkzeugmaschine		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
6100-Säulen Bohrmaschine		222	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	134	0	0	9	126
6105-säulen bohrmaschine		341	0	0	0	0	0	26	160	0	0	0	0	0	0	44	0	0	0	0		0	0	0	40	0	0	0	34
6501-Radial Bohrmaschine RB40		238	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0		0	0	79	0	0	0	163
6502-Radial Bohrmaschine RB70		36	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0		0	31	0	0	0	24
7205-Schweißen Laserzelle		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		17	26	31	33	0
7223-Schweißarbeitsplätze		216	0	0	0	0	24	24	0	0	0	0	0	0	0	0	0	0	48	33	0	0	0	0		261	141	206	389
7602-Schweißlinie U		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
7602-Schweißlinie P		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
7602-Schweißlinie B		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Warenausgang		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		6374	0	0	0	0	308	504	2358	748	27	0	378	0	0	2959	527	129	72	528	461	434	96	159	3316	1234	506	1144	2752

Table 11: Transport matrix for the year 2019

Transportmatrix	Nach	Lager innen	Lager-Bordwände	Lager-Bleche	Lager-Rohre	Lager-Zelt	1305-Presse Exzentr	1312-Pressehydraul	1422-CNC Abkantpre	1425Abkantpresse	2311-Bandsäge OK3	2313-Bandsäge OK4	2581-Hand Plasma	2593-Plasma	2595-Laser	2600-Schleifen manu	3111-konv. Drehma	4111-konv. Fräsmas	4300-CNC Werkzeug	61000-Säulen bohr	6105-Säulen Bohrm	6501-Radial Bohrma	6502-Radial Bohrma	7205-Schweißen Las	7223-Schweißarbeits	7602-Schweißlinie U	7602-Schweißlinie P/	7602-Schweißlinie B	Warenausgang
Von																													
Lager innen			0	0	0	0	15,75	17	13,2	31,9	0	0	0	0	0	43,6	58,8	64,5	0	71,4	13	78,4	80	0	70,3	51,2	41,9	77,2	25
Lager-Bordwände		0		0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Bleche		0	0		0	0	0	0	51,3	73,9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Rohre		0	0	0		0	0	0	0	0	0	0	28,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lager-Zelt		0	0	0	0		133	0	0	0	43	0	43,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1305-Presse Exzentrisch		15,75	0	0	0	0		0	13,4	0	0	0	0	0	0	0	0	0	0	55,1	0	0	0	0	68,8	0	0	0	15,75
1312-Hydraulische Presse		17	0	0	0	0	0		10,1	32	0	0	0	0	0	37	51,5	0	0	63,1	0	66,5	0	0	68	46	0	0	17
1422-CNC Abkantpresse Trumpf		13,2	0	0	0	0	15,5	9,5		45,8	0	0	41,6	0	0	50,8	0	0	0	0	16,6	76,3	0	4,5	79,5	0	0	0	13,2
1425-Abkantpresse 650T		31,9	0	0	0	0	24,2	32	45,8		0	0	29,6	0	0	0	0	0	0	0	0	0	0	0	61,6	36	26,9	62,2	31,9
2311-Banksäge OK320		31,4	0	0	0	0	23,4	29	0	0		0	0	0	0	14,3	48,4	0	0	0	0	69,7	58,7	0	61,4	0	0	0	31,4
2313-Bandsäge OK410		33,4	0	0	0	0	17,3	0	0	0	0		13,1	0	0	16,3	50,4	60,8	0	66,1	0	63,3	65,8	0	63,4	38,6	29,5	0	33,4
2581-Hand Plasma		40,6	0	0	0	0	0	34	0	29,6	0	0		0	0	3	0	0	0	0	0	0	0	0	65,3	43,1	34	54	40,6
2593-Plasma		44	0	0	0	0	0	0	59,9	42,6	0	0	20		0	9,4	0	0	0	0	0	0	0	0	74	0	0	0	0
2595-Laser		14,4	0	0	0	0	26	22,7	14	53,7	0	0	0	0		56,5	65,8	0	0	81,5	5,2	87,1	0	0	84,7	0	0	0	15
2600-Schleifen manuell		43,6	0	0	0	0	28,2	37	50,8	32,6	0	0	3	0	0		50,3	55,1	76,8	61,2	56,8	67,5	69,3	0	68,3	46,1	0	72,3	43,6
3111-konv. Drehmaschine		58,8	0	0	0	0	0	51,5	0	0	0	0	0	0	0	0		10,4	0	19,3	0	24,9	0	0	79,7	0	0	0	58,8
4111-konv.Fräsmaschine		64,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	18,8	0	0	90,1	0	0	0	64,5
4300-CNC-Werkzeugmaschine		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	78,8
6100-Säulen Bohrmaschine		71,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	97,9	0	0	79,8	71,4
6105-säulen bohrmaschine		13	0	0	0	0	0	34,3	16,6	0	0	0	0	0	0	56,8	0	0	0	0		0	0	0	96,1	0	0	0	13
6501-Radial Bohrmaschine RB40		78,4	0	0	0	0	0	0	0	0	0	0	63,7	0	0	0	0	0	0	0	0		0	0	101,9	0	0	0	78,4
6502-Radial Bohrmaschine RB70		80	0	0	0	0	0	0	0	0	0	0	0	0	0	68,8	0	0	0	0	0	0		0	104	0	0	0	80
7205-Schweißen Laserzelle		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		75	52,9	43,8	79,1	8,7
7223-Schweißarbeitsplätze		70,3	0	0	0	0	68,8	68	0	0	0	0	0	0	0	0	0	0	112,9	99,3	0	0	0	0		57,7	48,6	83,9	70,3
7602-Schweißlinie U		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
7602-Schweißlinie P		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
7602-Schweißlinie B		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Warenausgang		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 12: Distance matrix

Appendix B: Visualization of the Material Flow

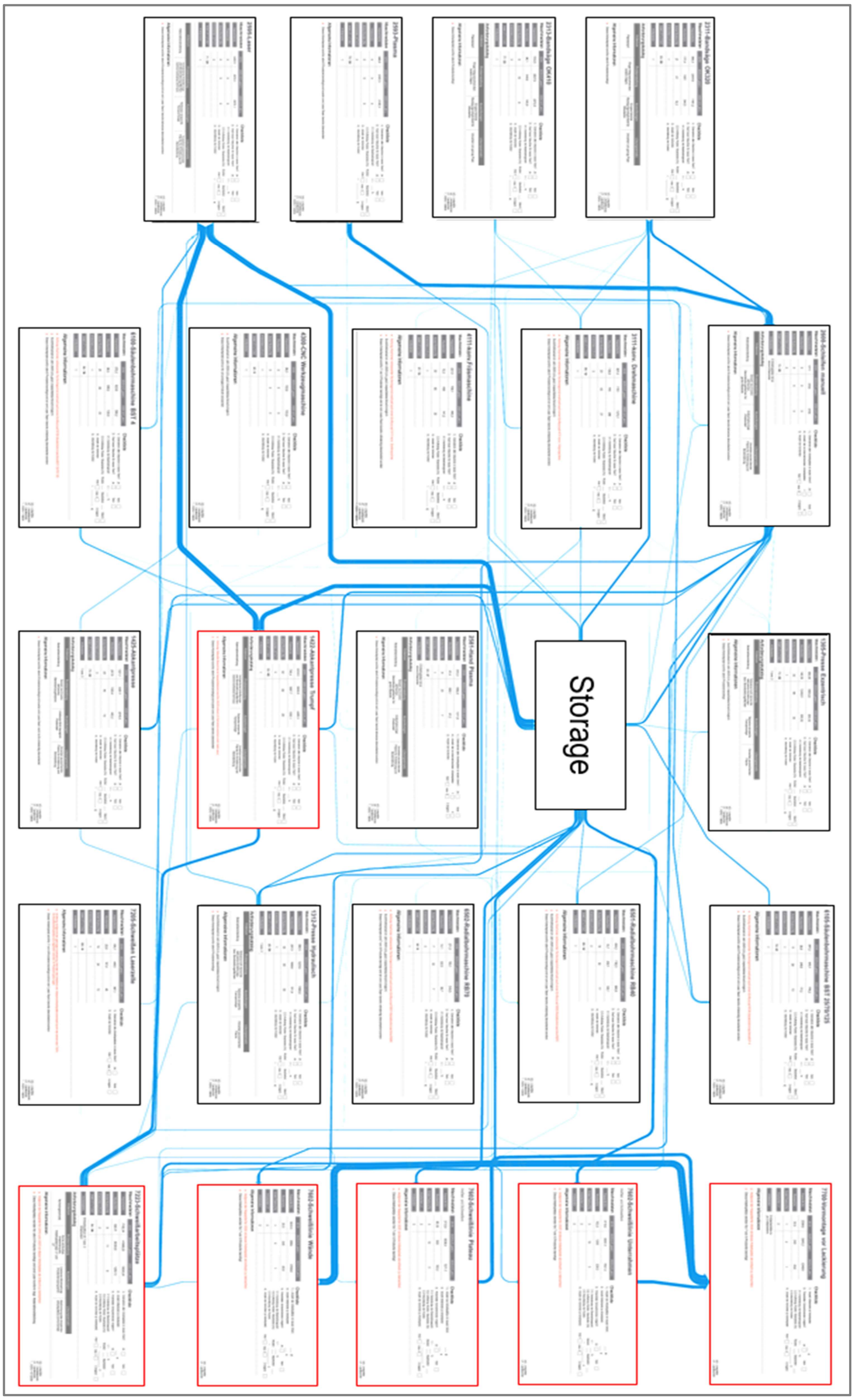


Figure 73: Sankey-Diagram

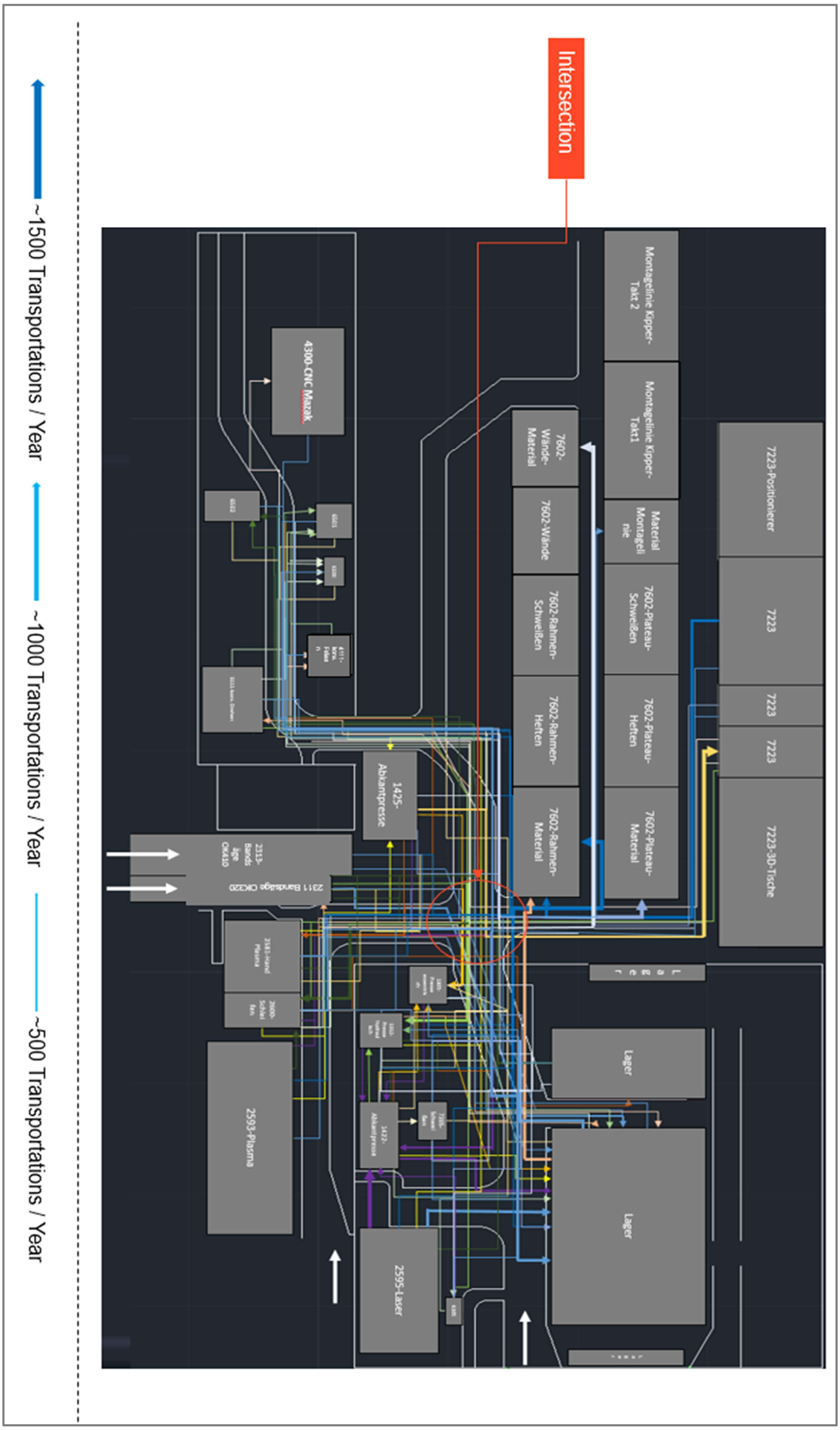


Figure 74: Oriented material flow scheme

Appendix C: Gantt Charts

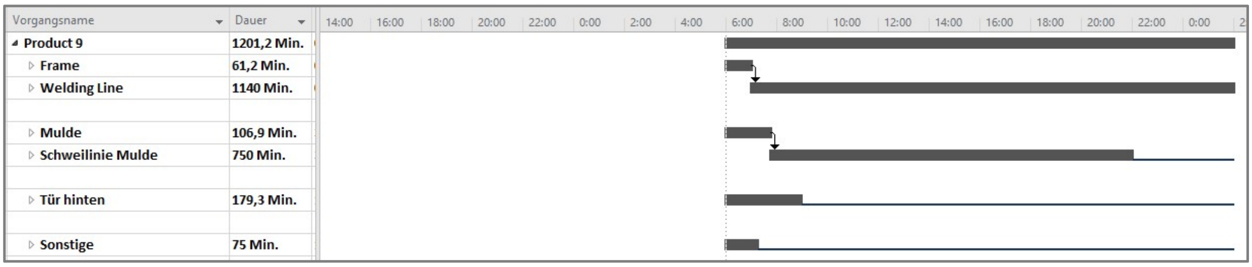


Figure 75: Gantt-Chart Product 9_Lot size 3

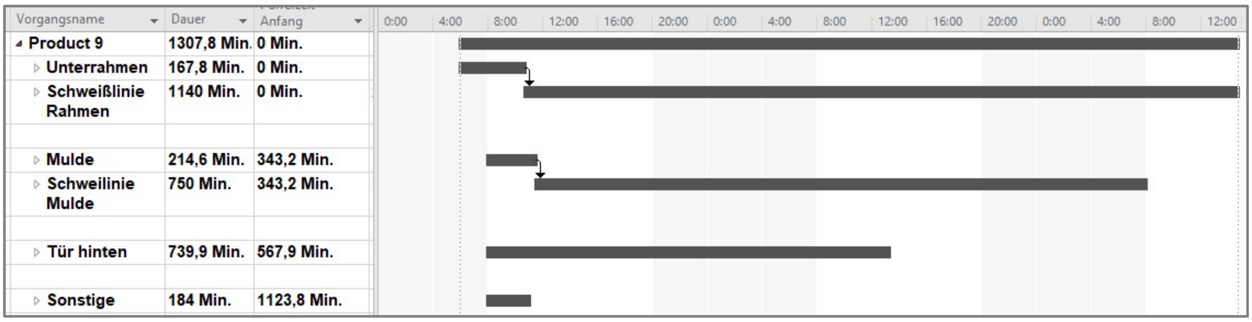


Figure 76: Gantt-Chart Product 9_Lot size 5

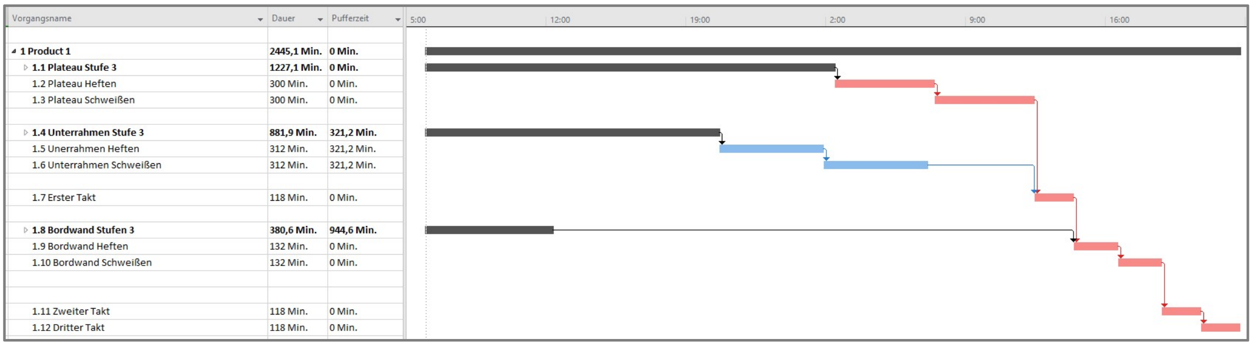


Figure 77: Gantt-Chart Product 1_Lot size 26

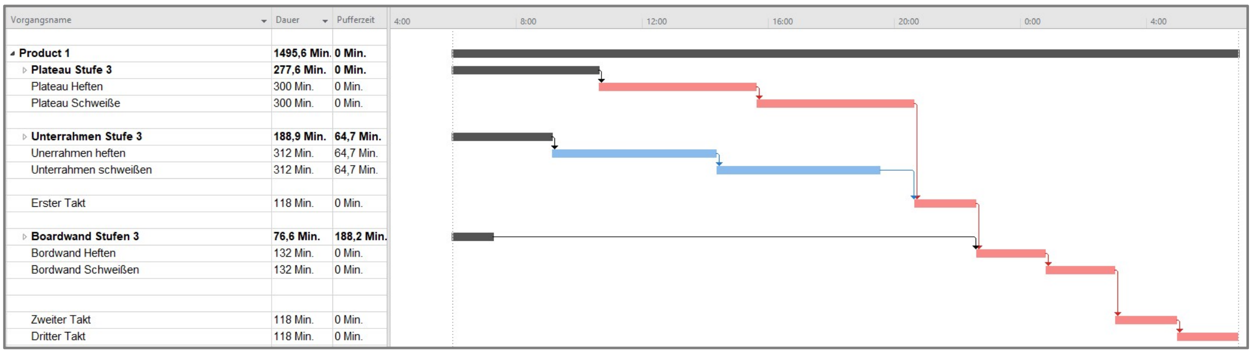


Figure 78: Gantt-Chart Product 1_Lot size 5

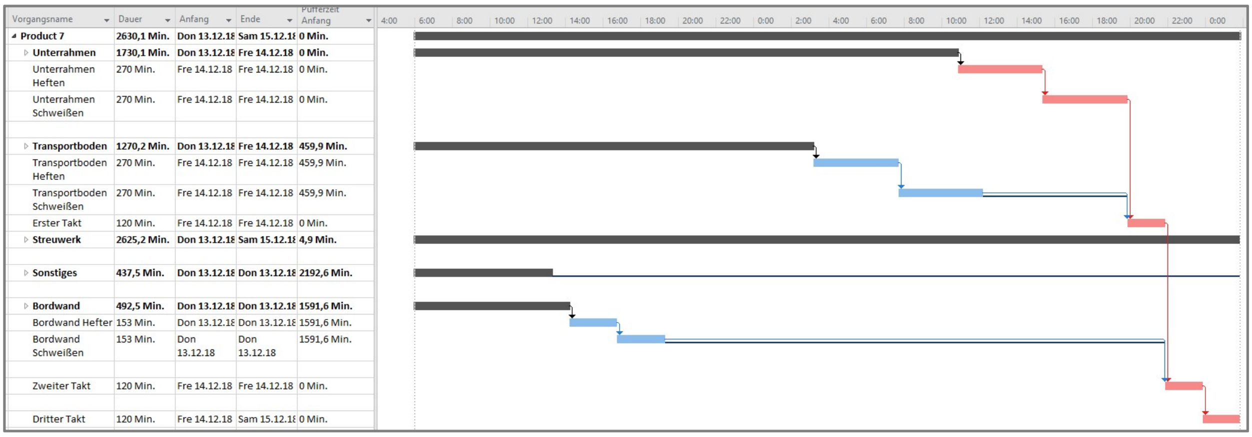


Figure 79: Gantt-Chart Product 7_Lot size 38

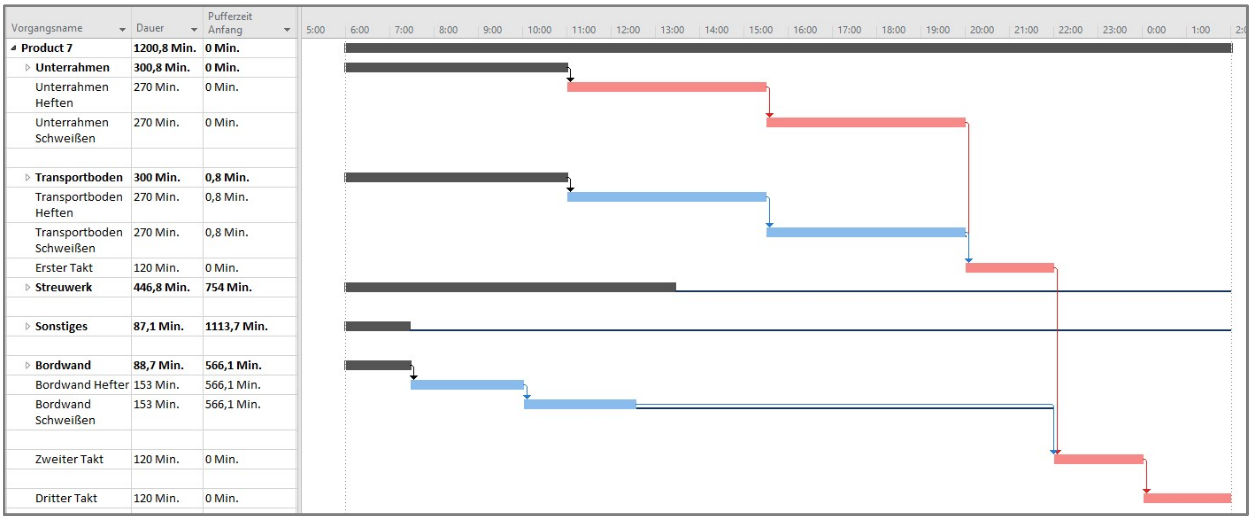


Figure 80: Gantt-Chart Product 7_Lot size 5

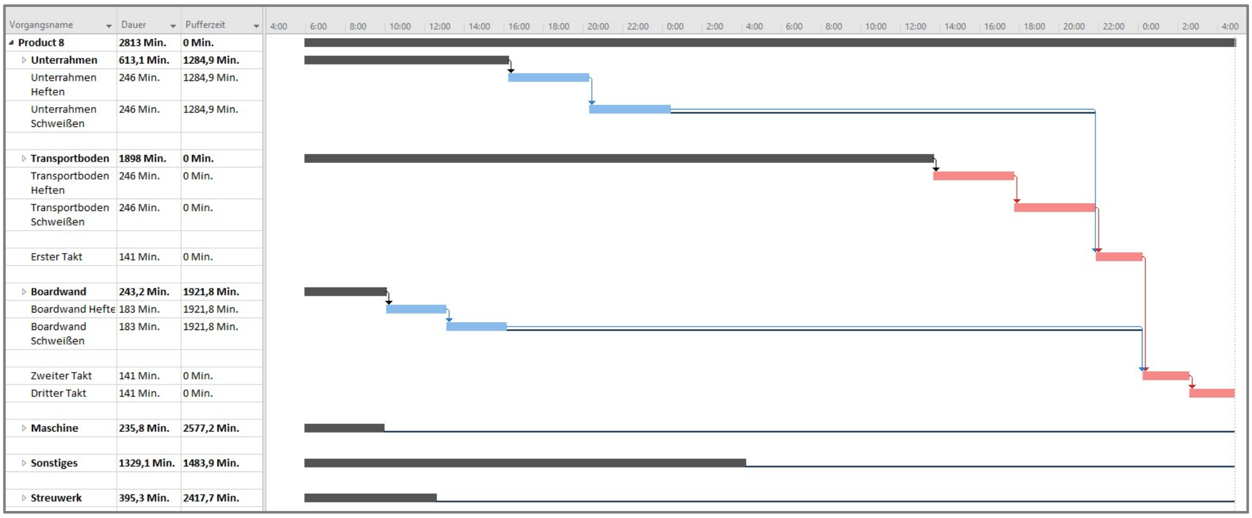


Figure 81: Gantt-Chart Product 8_Lot size 19

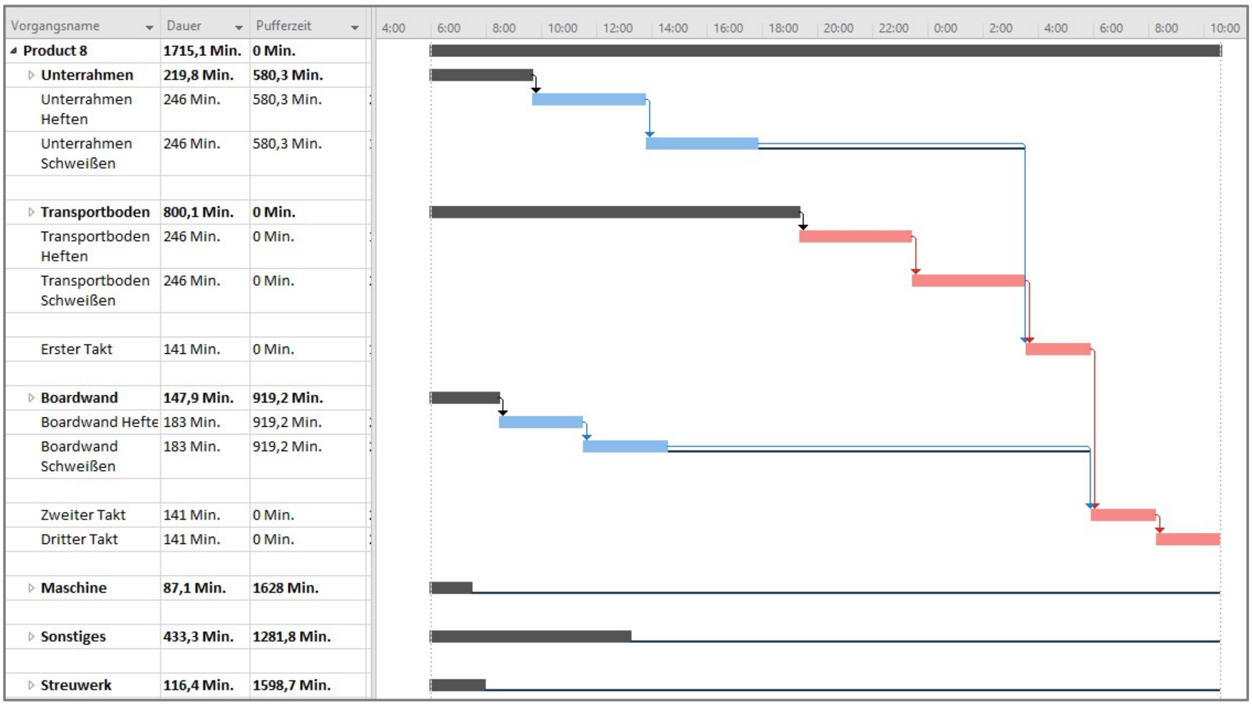


Figure 82: Gantt-Chart Product 8_Lot size 5

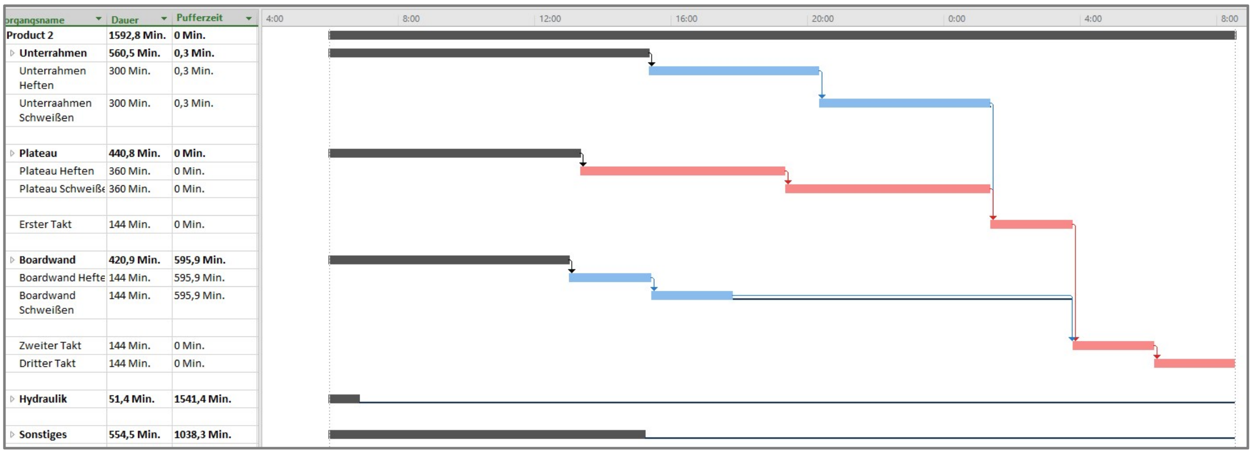


Figure 83: Gantt-Chart Product 2_Lot size 27

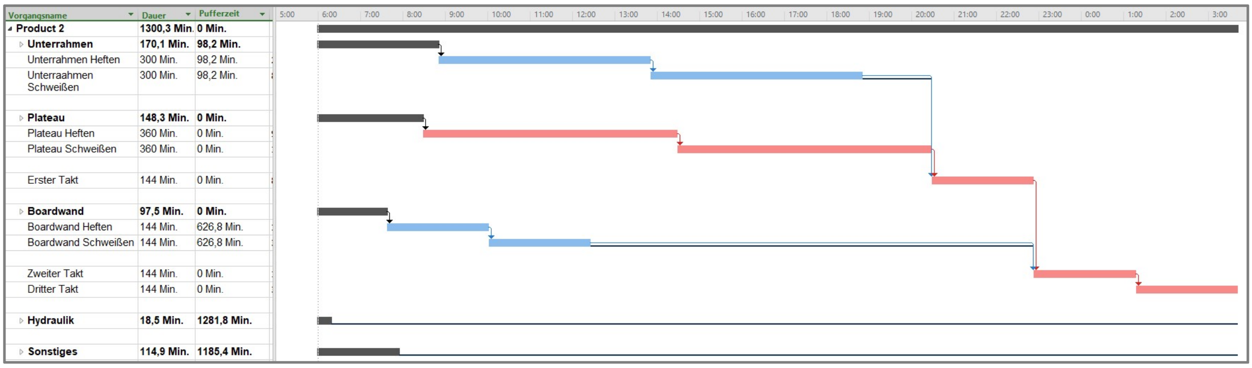
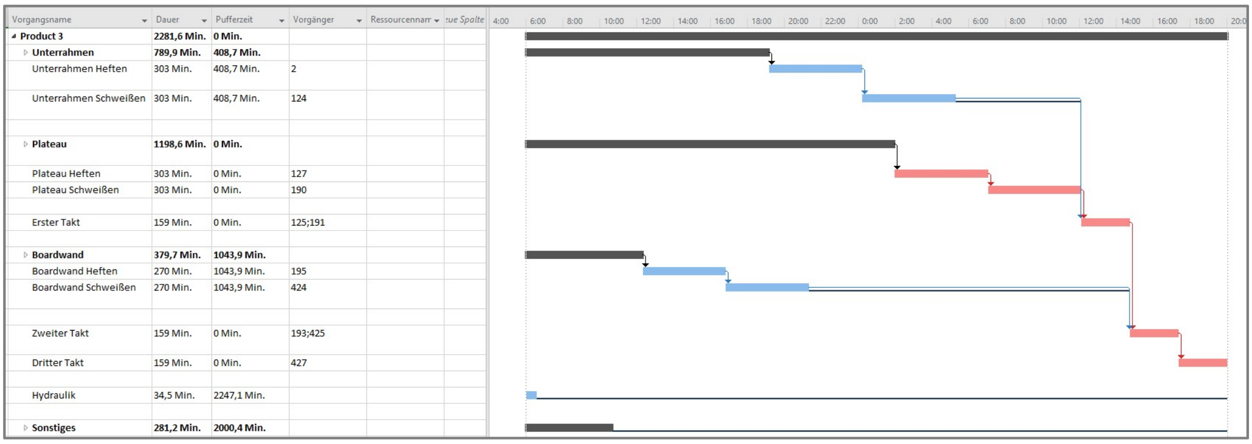
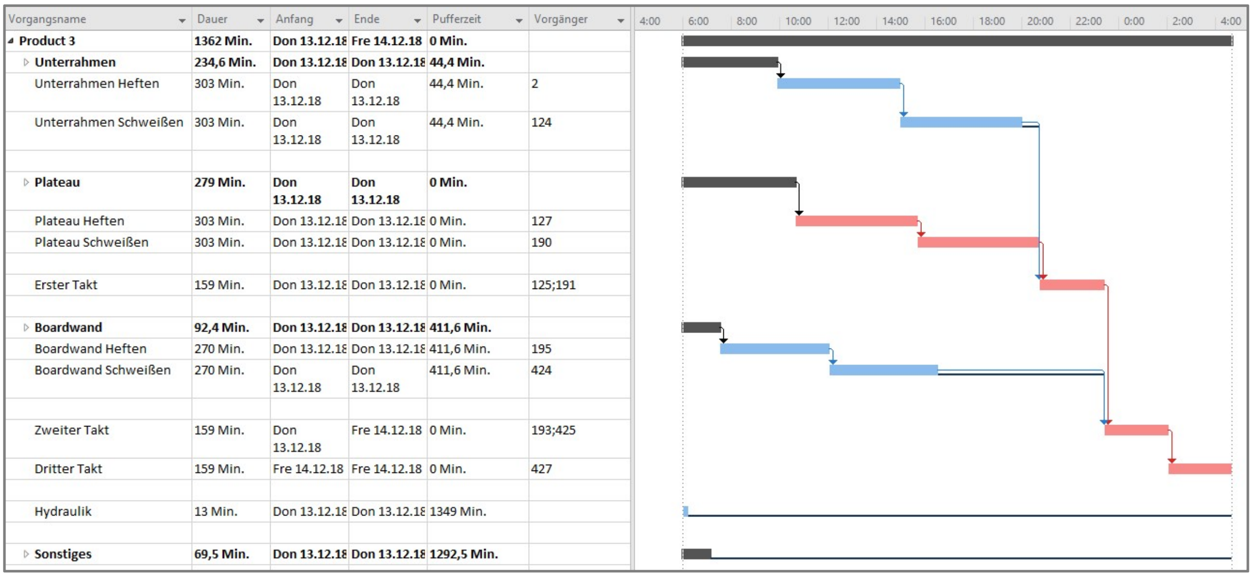


Figure 84: Gantt-Chart Product 2_Lot size 5



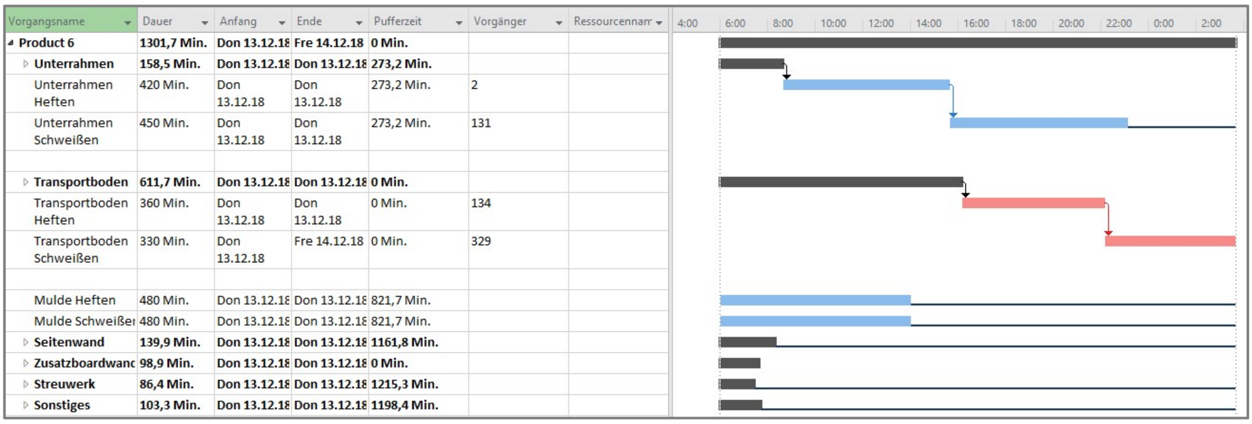
Vorgangsname	Dauer	Pufferzeit	Vorgänger	Ressourcennam	eue Spalte
Product 3	**2281,6 Min.**	**0 Min.**			
Unterrahmen	**789,9 Min.**	**408,7 Min.**			
Unterrahmen Heften	303 Min.	408,7 Min.	2		
Unterrahmen Schweißen	303 Min.	408,7 Min.	124		
Plateau	**1198,6 Min.**	**0 Min.**			
Plateau Heften	303 Min.	0 Min.	127		
Plateau Schweißen	303 Min.	0 Min.	190		
Erster Takt	159 Min.	0 Min.	125;191		
Boardwand	**379,7 Min.**	**1043,9 Min.**			
Boardwand Heften	270 Min.	1043,9 Min.	195		
Boardwand Schweißen	270 Min.	1043,9 Min.	424		
Zweiter Takt	159 Min.	0 Min.	193;425		
Dritter Takt	159 Min.	0 Min.	427		
Hydraulik	34,5 Min.	2247,1 Min.			
Sonstiges	**281,2 Min.**	**2000,4 Min.**			

Figure 85: Gantt-Chart Product 3_Lot size 26



Vorgangsname	Dauer	Anfang	Ende	Pufferzeit	Vorgänger
Product 3	**1362 Min.**	**Don 13.12.18**	**Fre 14.12.18**	**0 Min.**	
Unterrahmen	**234,6 Min.**	**Don 13.12.18**	**Don 13.12.18**	**44,4 Min.**	
Unterrahmen Heften	303 Min.	Don 13.12.18	Don 13.12.18	44,4 Min.	2
Unterrahmen Schweißen	303 Min.	Don 13.12.18	Don 13.12.18	44,4 Min.	124
Plateau	**279 Min.**	**Don 13.12.18**	**Don 13.12.18**	**0 Min.**	
Plateau Heften	303 Min.	Don 13.12.18	Don 13.12.18	0 Min.	127
Plateau Schweißen	303 Min.	Don 13.12.18	Don 13.12.18	0 Min.	190
Erster Takt	159 Min.	Don 13.12.18	Don 13.12.18	0 Min.	125;191
Boardwand	**92,4 Min.**	**Don 13.12.18**	**Don 13.12.18**	**411,6 Min.**	
Boardwand Heften	270 Min.	Don 13.12.18	Don 13.12.18	411,6 Min.	195
Boardwand Schweißen	270 Min.	Don 13.12.18	Don 13.12.18	411,6 Min.	424
Zweiter Takt	159 Min.	Don 13.12.18	Fre 14.12.18	0 Min.	193;425
Dritter Takt	159 Min.	Fre 14.12.18	Fre 14.12.18	0 Min.	427
Hydraulik	13 Min.	Don 13.12.18	Don 13.12.18	1349 Min.	
Sonstiges	**69,5 Min.**	**Don 13.12.18**	**Don 13.12.18**	**1292,5 Min.**	

Figure 86: Gantt-Chart Product 3_Lot size 5



Vorgangsname	Dauer	Anfang	Ende	Pufferzeit	Vorgänger	Ressourcennam
Product 6	**1301,7 Min.**	**Don 13.12.18**	**Fre 14.12.18**	**0 Min.**		
Unterrahmen	**158,5 Min.**	**Don 13.12.18**	**Don 13.12.18**	**273,2 Min.**		
Unterrahmen Heften	420 Min.	Don 13.12.18	Don 13.12.18	273,2 Min.	2	
Unterrahmen Schweißen	450 Min.	Don 13.12.18	Don 13.12.18	273,2 Min.	131	
Transportboden	**611,7 Min.**	**Don 13.12.18**	**Don 13.12.18**	**0 Min.**		
Transportboden Heften	360 Min.	Don 13.12.18	Don 13.12.18	0 Min.	134	
Transportboden Schweißen	330 Min.	Don 13.12.18	Fre 14.12.18	0 Min.	329	
Mulde Heften	480 Min.	Don 13.12.18	Don 13.12.18	821,7 Min.		
Mulde Schweißen	480 Min.	Don 13.12.18	Don 13.12.18	821,7 Min.		
Seitenwand	**139,9 Min.**	**Don 13.12.18**	**Don 13.12.18**	**1161,8 Min.**		
Zusatzboardwand	**98,9 Min.**	**Don 13.12.18**	**Don 13.12.18**	**0 Min.**		
Streuwerk	**86,4 Min.**	**Don 13.12.18**	**Don 13.12.18**	**1215,3 Min.**		
Sonstiges	**103,3 Min.**	**Don 13.12.18**	**Don 13.12.18**	**1198,4 Min.**		

Figure 87: Gantt-Chart Product 6_Lot size 3

Figure 88: Gantt-Chart Product 6_Lot size 5

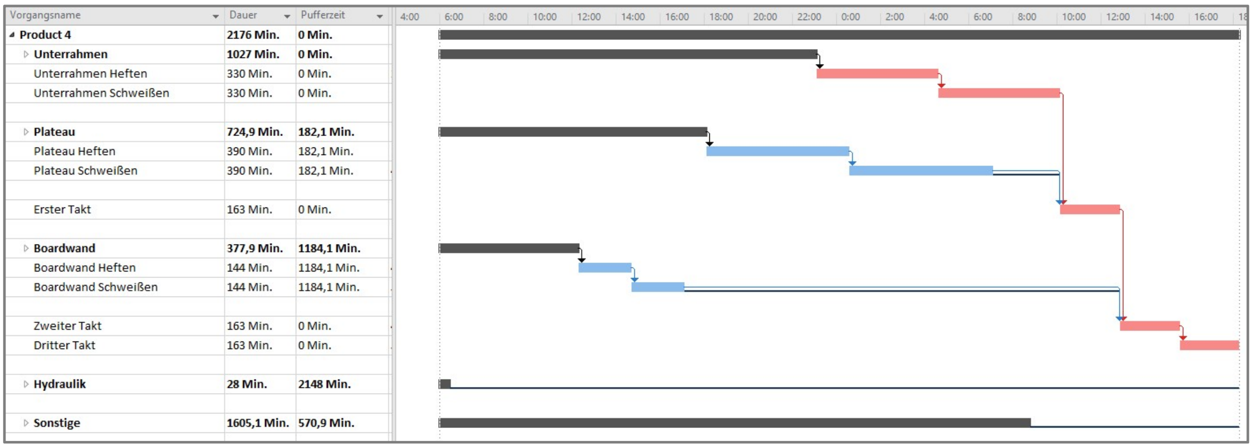


Figure 89: Gantt-Chart Product 4_Lot size 36

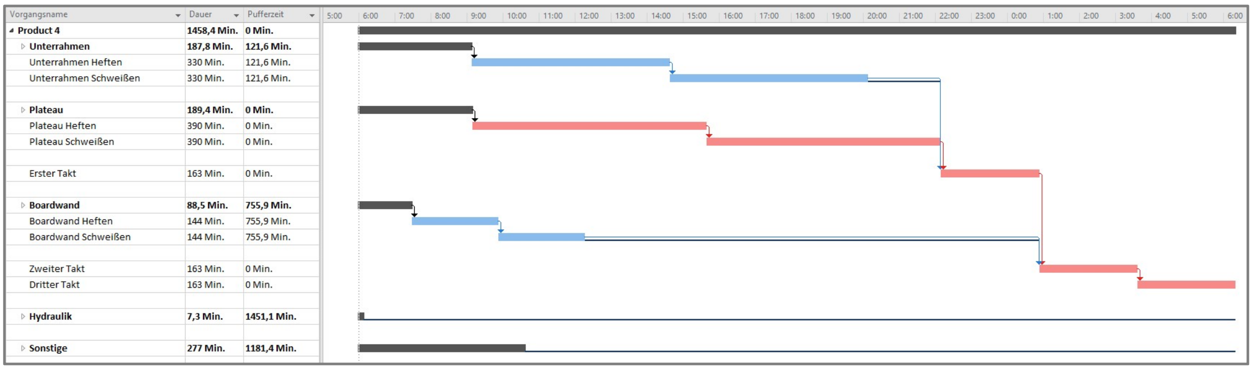


Figure 90: Gantt-Chart Product 4_Lot size 5

Figure 91: Gantt-Chart Product 5_Lot size 21

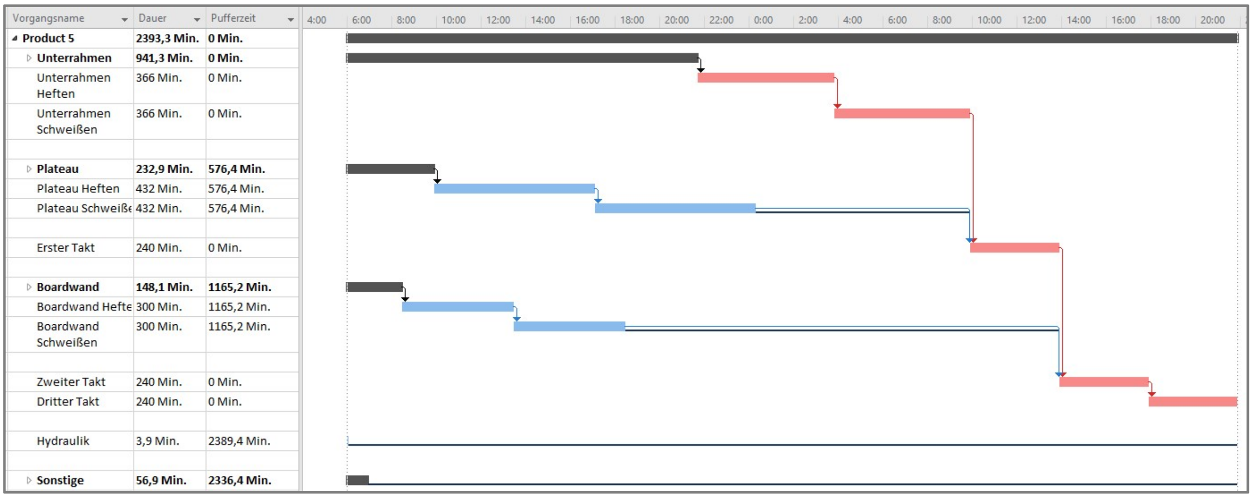


Figure 92: Gantt-Chart Product 5_Lot size 5

Appendix D: Layout Variants

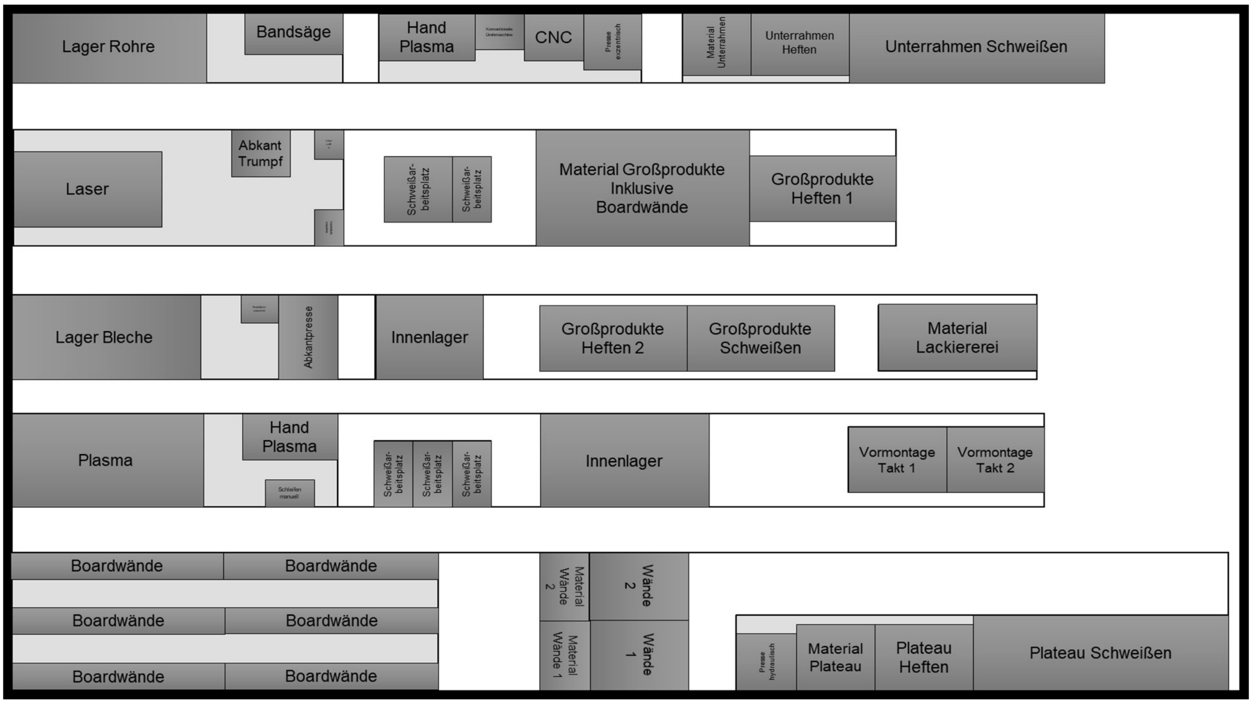


Figure 93: Layout C

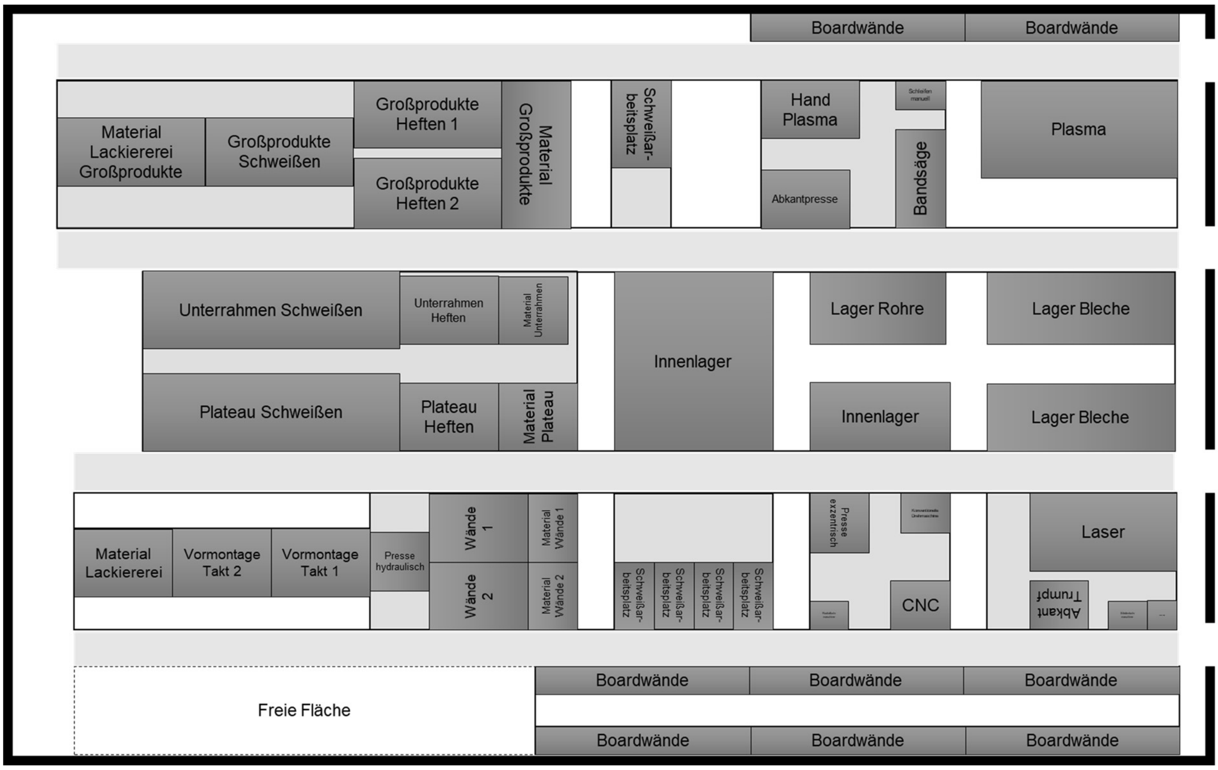


Figure 94: Layout A

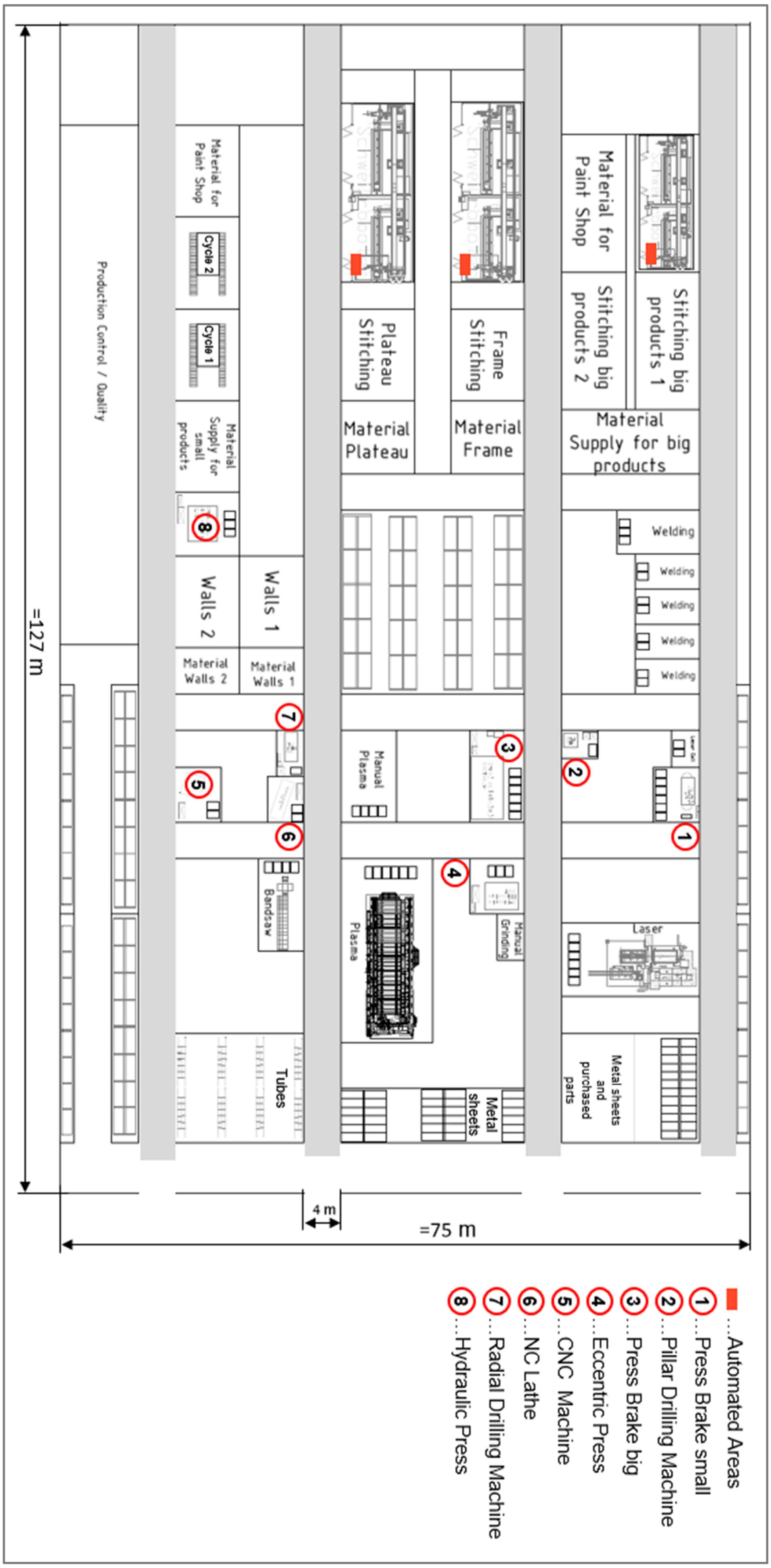


Figure 95: CAD- model