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Brownfield layout planning for production of large-scale machinery

Master's thesis

to achieve the academic degree of

Diplom-Ingenieur

Master's degree program:

Production Science and Management

Graz University of Technology

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

Graz, January 2018

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.

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Acknowledgement

This thesis was drawn up in collaboration with an Austrian company and under the scientific supervision of the Institute of Innovation and Industrial Management at Graz University of Technology under the direction of Univ. -Prof. Dipl.-Ing. Dr. techn. Christian Ramsauer.

I would like to thank Univ.-Prof. Dipl.-Ing. Dr. techn. Christian Ramsauer and my supervisor from the University Dipl. -Ing. Hugo Karre for their advice and scientific supervision throughout this project.

Also cordial thanks to my supervisors at the company, the Production Manager and the Lean-Expert who supported me through their professional knowledge and ideas and have always been open for questions.

Thanks also to my friends and colleagues who have always encouraged and motivated me.

Finally, my biggest acknowledgment goes to my parents, who have supported me throughout my studies and my whole life.

Abstract

This Master´s thesis was drawn up within the scope of a cooperation between an Austrian company and the Institute of Innovation and Industrial Management. The company is a leading international supplier of machinery and systems for the mechanical and mechanical-biological treatment of solid waste, and for the treatment of biomass as a renewable energy source. This company planned a relocation of the work carried out in their plant in Austria to the existing plant in Slovenia.

The aim of this Master`s thesis was to create a new, optimized and value-oriented plant layout for the plant in Slovenia, which includes the assembly contents of both plants. The layout of the new planned layout should be designed to meet the demand of machinery for the next 5 years.

Firstly, the existing situation was planned to be examined in the course of a material flow analysis within the production network of the company. Due to the insufficient quality of the data, a material flow analysis could not be performed. Instead of the material flow analysis, recommendations for an improved data structure were developed. The second step was to plan the new layout of the plant in Slovenia. Optimization potentials as well as optimization measures were derived from the analysis of the current situation. Based on the resulting data and findings, several rough layout variations were created. Three layout variants have been carried over to the fine layout phase.

By analyzing the target times and restructuring the current assembly process, it was possible to increase annual output by 24% whilst reducing the space needed for the assembly process by almost a third. It therefore became possible to meet the forecasted demands for the next 5 years whilst shifting production from two plants into one.

Kurzfassung

Diese Masterarbeit wurde im Rahmen einer Kooperation zwischen einem österreichischen Unternehmen und dem Institut für Innovation und Industrie Management erstellt. Das Unternehmen ist ein international führender Anbieter von Maschinen und Anlagen für die mechanische und mechanisch-biologische Behandlung von festen Abfällen sowie für die Aufbereitung von Biomasse als erneuerbare Energiequelle. Dieses Unternehmen plant eine Verlagerung der Montageinhalte, die bisher im Werk in Österreich durchgeführten werden, in das bereits bestehende Werk in Slowenien.

Ziel dieser Masterarbeit war es, ein neues, optimiertes und wertorientiertes Anlagenlayout für das Werk in Slowenien zu erstellen, das die Montageinhalte beider Anlagen beinhaltet und den Bedarf an Maschinen für die nächsten 5 Jahre decken kann.

Im Rahmen einer Materialflussanalyse wurde als erstes die bestehende Situation bezüglich des Materialflusses im Produktionsnetzwerk des Unternehmens untersucht. Aufgrund der unzureichenden Qualität der Daten konnte jedoch eine Materialflussanalyse nicht durchgeführt werden. Anstatt der Materialflussanalyse wurden Empfehlungen für eine verbesserte Datenstruktur für das Unternehmen entwickelt. Der zweite Schritt beinhaltete die Planung des neuen Layouts für das Werk in Slowenien. Durch die Analyse der aktuellen Situation in beiden Werken wurden Optimierungspotenziale erarbeitet sowie Optimierungsmaßnahmen abgeleitet. Basierend auf den daraus resultierenden Daten und Erkenntnissen wurden einige Grob-Layout Varianten erstellt. Anschließend wurden drei Layout-Varianten in die Fein-Layout Planung übernommen.

Durch die Analyse der Vorgabezeiten und die Neustrukturierung des laufenden Montageprozesses konnte die Jahresproduktion um 24% gesteigert und gleichzeitig der Platzbedarf für den Montageprozess um fast ein Drittel reduziert werden. Somit kann der prognostizierte Bedarf an Maschinen für die nächsten 5 Jahre durch die Verlagerung der Produktion von zwei Werken in ein Gemeinsames erfüllt werden.

Table of Content

1 Introduction

The following describes the problem underlying this Master's thesis, the objective, and the procedure.

1.1 Task and Objective

The company with whom this master’s thesis was conducted is a producer of machines for the treatment of mechanical and biological waste. It has over 560 employees and a revenue of over 100 million euros per year. The current production network is shown in figure 1. The company has four production sites in Germany, Austria and Slovenia.

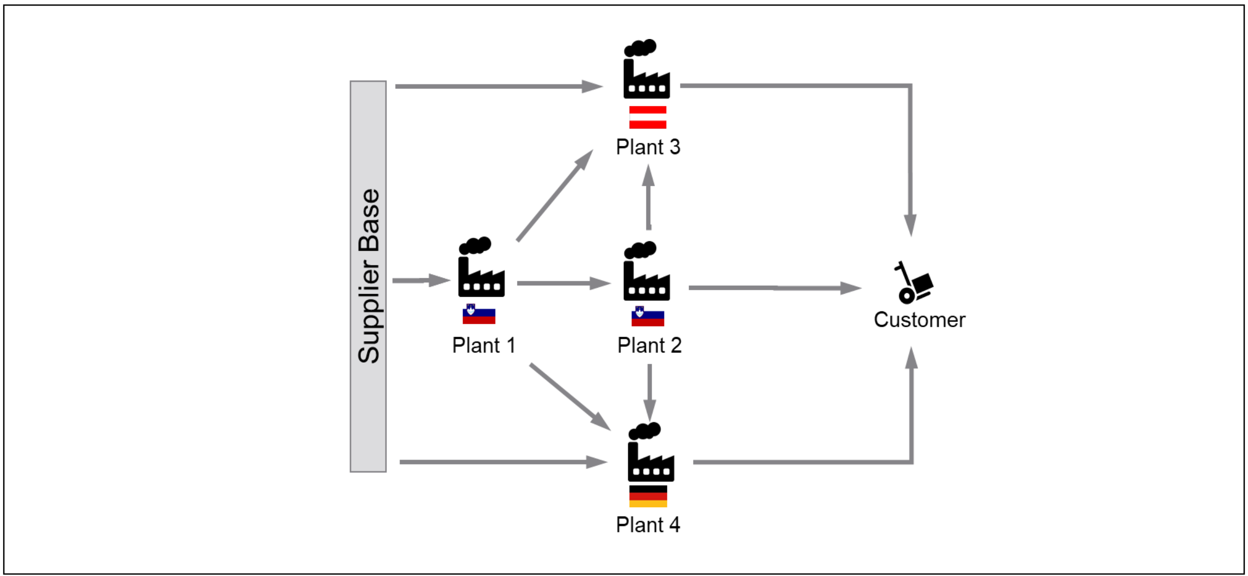


Figure 1: Current Production network

The initial situation for this master’s thesis is a planned relocation of the environmental products which are currently assembled in plant 3 to plant 2 in Slovenia (see figure 2). Due to this situation an analysis of the current material flow between the production sites should be carried out. Based on this, the future material flow should be planned. As a second step, the layout for assembling environmental technology products in plant 2 should be planned. The goal is to make a statement about the capacity utilization of the environmental technology assembly in plant 2, taking future development into account.

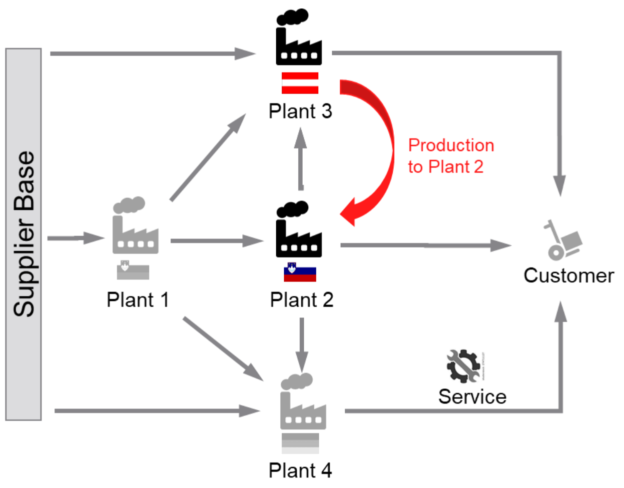


Figure 2: Planned relocation

Aims:

a) Material flow planning between the planned production sites

b) Analysis of the existing environmental technology assembly in Plant 2 and 3

c) Derivation of optimization potential, considering current challenges under the given boundary conditions of the existing business premises

d) Different layout variants for environmental technology assembly in Plant 2

e) Examination of the capacity utilization of the environmental technology assembly in Plant 2

1.2 Structure of the Thesis

To ensure a structured project process, the project was divided into two work packages.

Work package I

The first work package includes the collection, analysis and processing of existing data for the analysis of the current material flow within the company’s production network. The results of this evaluation serve the subsequent material flow planning to show the effects of the restructuring within the company production network.

Work package II

Work package II is divided into three phases:

Phase I – Analysis of Current State

In the first step, an operational analysis of plant 2 and plant 3 is carried out. The database for the analysis forms the data provided by the company. That includes the REFA time measurement, forecast data and the bill of material of the different products. The result of the first phase is the demonstration of optimization potential and the derivation of a catalog of requirements which serves as the planning basis.

Phase II – Rough Layout Planning

Based on the findings of the current state analysis, several rough layout variants are developed. The layout variants respect already existing restrictions. Furthermore, one variant was created together with the responsible persons of the company in layout workshops. For the evaluation of the layout variants, specific evaluation criteria are chosen.

Phase III – Fine Layout Planning

In the fine layout phase, the three layout variants selected in the rough layout phase are developed further. The aim of the fine layout phase is to create ready-to-implement versions of the selected variants.

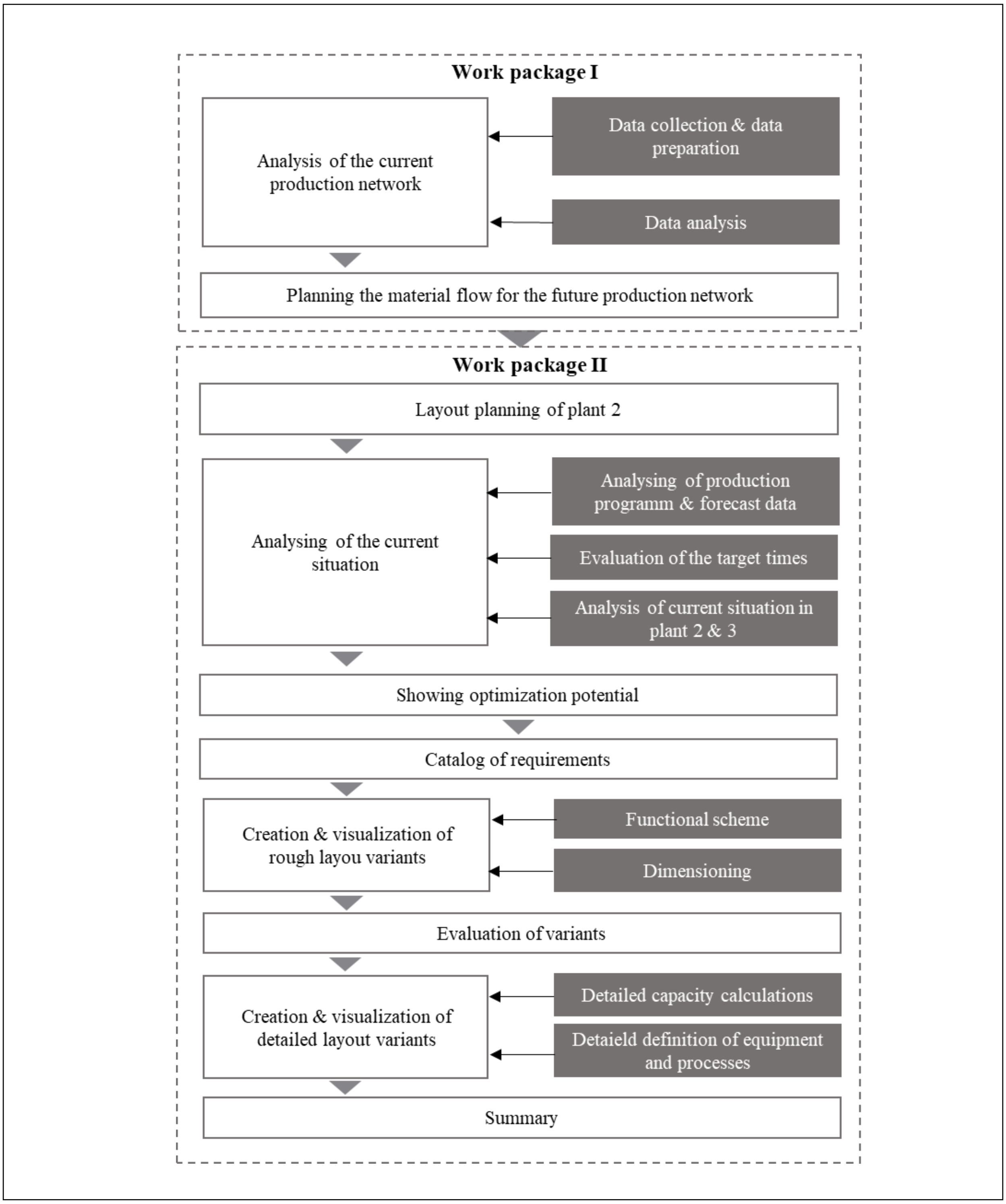


Figure 3: Structure of approach

2 Theoretical Input

In this chapter, the theoretical foundations for the practical considerations are described. Because layout planning is a subset of factory planning, an overview of factory planning is given in the first chapter. The layout planning will be explained in more detail in the following chapter.

2.1 Factory Planning

The Verein Deutscher Ingenieure (VDI) defines factory planning as a systematic and goal-oriented process, from the first idea to the construction and the ramp-up of production. This process is structured in successive phases and is carried out with the help of methods and tools.[1]

The overall goal in factory planning is to create the place for designing innovative, efficient and value-added industrial goods.[2] The factory planning process represents an investment process, which means that the core contents are the development of economic solutions of factory or production processes and their rational implementation.[3] The primary challenge for all manufacturing and service companies is to design a versatile, resource-efficient, and energy-efficient factory which includes all relevant processes and objects inside and outside the company.[4]

Factory planning links corporate planning with company operations across all planning levels. The effective system (product, technology, organisation, plant, personnel and finance) with its dependencies and its effective direction in terms of total organisation planning are also taken into consideration.[5]

The object and methodology of factory planning are subject to changing influences and conversions. Reasons of the resulting constant adjustment and change pressures are the following developments:[6]

- Globalisation of markets and locations
- Rising customer dominance
- Decentralization of added value
- Dominance and differentiation of cost structure
- Short cyclic and innovative conversion of products and equipment
- Declining lifetime of products and processes

[1] Cf. VDI (2009), p. 3
[2] Cf. Schenk et al. (2014), p. 7
[3] Cf. Grundig (2013), p. 11
[4] Cf. Schenck et al. (2014), p. 17
[5] Cf. Pawellek (2014), p. 15
[6] Cf. Grundig (2013), p. 14

Because of the change from a seller’s market to a buyer´s market in recent years, production companies must focus on market oriented strategies. New strategies are targeted at low costs, shortest lead times and absolute controllability of the technology. The factory of the future must be material flow oriented, product and customer order related, continuous, minimally collaborative and oriented to a batch-size of one.[7] Table 1 shows typical changes in trends for production companies.

Previously **Seller´s market**	Today **Buyer´s market**
• Long product life cycles • High capacities • Long lead times • Large inventories • Low flexibility • Large batch sizes	• Short product life cycles • High readiness for delivery • Flexibility • Short lead times • Small inventories • Small batch sizes • Low cost utilization

Table 1: Trend change for production companies[8]

2.2 Base Cases for Planning

Generally in literature there are four or rather five base cases, which can be differentiated by level of difficulty, size and character of the task.[9] VDI structures the base cases in new planning, re-planning, dismantling and revitalization. These four base cases are related to the plant life cycle (development, design, ramp up, operation and dismantling).[10] Planning is the creation of a plant which previously did not exist. Because this is carried out in a previously unused area it is also known as greenfield-planning. In contrast to greenfield-planning, brownfield-planning is the re-planning of an existing plant. Within brownfield-planning, the plant is adapted to new requirements.[11]

Grundig (2015) divides the base cases for planning into two major parts. On the one side is the structure replacement/restructuring (brownfield-planning) and on the other side the creation of a new plant (greenfield-planning).[12] He also subdivides the basic case of restructuring into the expansion of industrial companies. Figure 4 gives an overview of the planning principles.

[7] Cf. Pawellek (2014), p. 5
[8] Cf. Based on Pawellek (2014), p.5
[9] Cf. VDI (2009), p.3 and Schenk et al. (2014), p.146f.
[10] Ibidem
[11] Cf. Hopf (2016), p. 20
[12] Cf. Grundig (2015), p. 18 f. and REFA (1985), p. 149

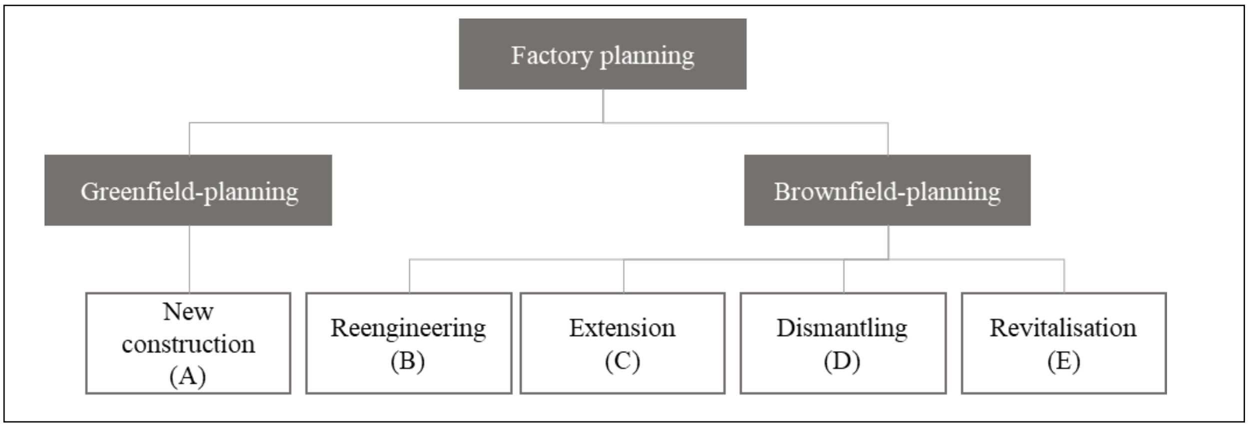


Figure 4: Planning base cases by Grundig[13]

- **Base case A: New construction of the plant**

Base case A contains a new construction of an industrial plant. It is defined as the ideal classical basic case of factory planning. In literature, this case is also known as greenfield-planning because the factory is built up on an as yet undeveloped area. A new construction is characterized by high temporal and content-related planning cycles, as well as a high degree of decision-making independence. Additionally, this basic case contains the determination of an optimal location and a general development plan.[14]

- **Base case B: Reengineering**

Because of permanent changes in the production program, factories must be continually adapted to new requirements. The base case B represents this operational permanent task (rolling factory). Aims of basic case B are often rationalizations and modernizations.[15]

- **Base case C: Extension of existing plants**

Base case C mostly comes into effect when an extension of capacity is necessary, which can be for example caused by revenue and order growth. An increase in capacity normally requires an extension of the existing facility. In some cases, this increase in capacity can cast doubt on the suitability of the current location for the increase in capacity, and therefore lead to outsourcing of the manufacturing site.[16]

[13] Cf. own figure based on Grundig (2015), p.18f.
[14] Cf. Grundig (2015), p. 18 and Pawellek (2008), p. 118
[15] CF. Grundig (2015) p 19f.
[16] Cf. Grundig (2015), p. 19

- **Base case D: Dismantling of plants**

Decline in sales, reduction of production depth or outsourcing of production steps can cause a dismantling of plants. Fundamentally, this case leads to a readjustment of capacities and structures of both the production areas and the corresponding secondary areas such as maintenance.[17]

- **Basic case E: Revitalization of plants**

The base case revitalization of plants defines a restructuring process. Within this process, decommissioned facilities are being put to new industrial use.[18]

2.3 Planning Principles

In order to solve complex factory planning tasks and for the fulfillment of given objectives, it is essential to comply with the following general planning principles:[19]

- Integrated planning
- Gradual approach (Iteration)
- Principle of variants
- Efficiency
- Profit oriented
- Flexibility and versatility
- Standardization and reduction of complexity

Schmigalla (1995) gives another description of factory planning, and defines it as a design process. The designer is therefore the person in charge of creativity. For this design process, shown in table 2 can be applied:[20]

[17] ibidem
[18] Cf. Pawellek (2008), p. 118
[19] Cf Grundig (2015), p. 25 ff. and Kettner et al. (1984) p. 4ff.
[20] Cf. Schmigalla (1995), p. 89 ff.

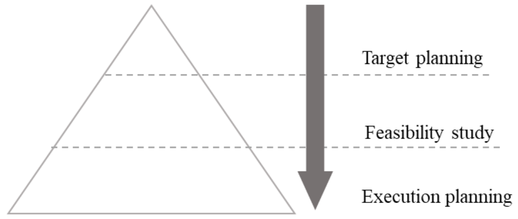
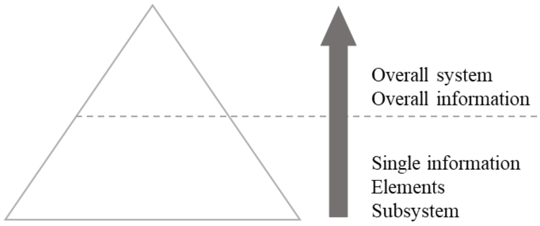
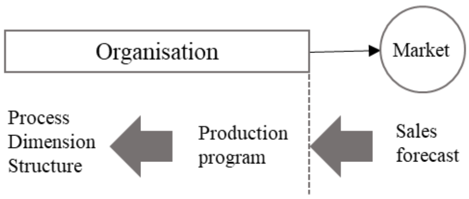
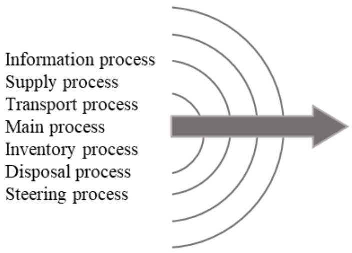
Principle	Sub-Aspects
Top-Down  	From general to individual From aggregated to detailed From global to concrete From typical to individual From rough to fine
Bottom-Up  	From element to the system From detail to overall concept From single value to the sum
From the outside to the inside  	From the environment to the system From system to sub-system From sub-system to element
From central to peripherin  	From manufacturing process to supply and disposal First set manufacturing process then management

Table 2: Planning principles[21]

Schmigalla (1995) defines furthermore the principle *from ideal to real* and *optimization and variation.* These six principles sometimes contradict eachother and must be used situationally.[22]

[21] Cf. own figure based on Schmigalla (1995), p.92
[22] Cf. Schmigalla (1995), p. 92

2.4 Phases in Factory Planning

In literature, the factory planning process is divided into different planning phases depending on the authors, whereby a generalized planning system can be derived. In most planning processes, the planning phases usually build on the results of the previous planning phase.[23]

Common factory planning approaches follow the principle „*top-down* “, meaning they make a statement about the planning object in such a way that the respective subsequent phase concretizes, details, clarifies, individualizes and refines the statements of the preceding phase.[24]

Figure 5 shows planning systematics of *Grudnig*, *Kettner*, *Wiendahl*, *Felix* and the *Verein Deutsch Ingenieure (VDI)*.

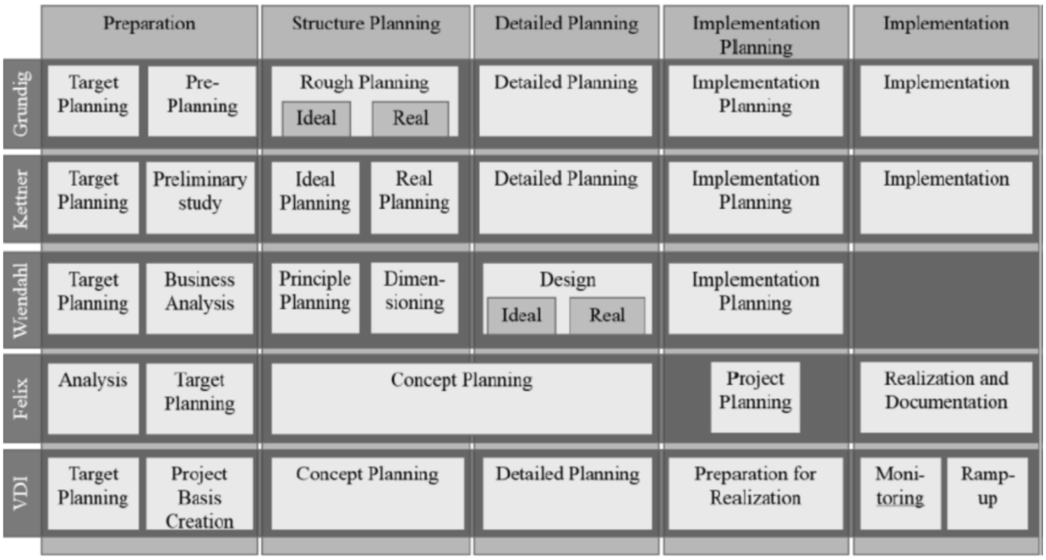


Figure 5: Overview of chosen planning systematics[25]

A very simplistic but graphic representation of the factory planning process is shown in the factory planning pyramid by *Aggteleky (1970)* (see figure 6). He divides the planning process into three phases:[26]

- **Target planning:** Creation of planning principles
- **Concept planning:** Development of concepts / project studies
- **Execution planning:** Detailed planning of the realization process and commissioning

[23] Cf. Grundig (2015), p. 37
[24] Cf. Schmigalla (1995), p. 93
[25] Cf. Brigitte Stellwag (2017), p.14
[26] Cf. Aggteleky (1970), p.4

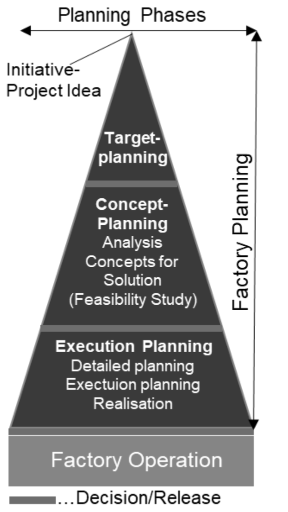


Figure 6: Planning pyramid by Aggteleky[27]

The target and concept planning concludes with one of the following options:[28]

- Termination of the planning phase
- Continuation to the next planning phase
- Continuation to the next stage, but with modifications made to the prepared planning status

Due to the possibility of continuing with modification of the planning status, an iterative-cyclical character of the planning process results and formal recourse to pervious work results is possible.[29]

A more detailed description of the system of factory planning represents the 6-phase model of factory planning according to *Kettner*. It is divided into four main phases:[30]

- **Planning basis:** target and preliminary planning
- **Factory structure planning:** ideal- and real planning
- **Detailed planning:** execution project
- **Execution:** implementation planning and implementation

The rough planning phase is the decisive planning phase in which solution concepts and variants are developed. Since this phase covers the actual design process, this phase can also be referred to as factory structure planning.[31]

[27] Cf. Own figure based on Aggteleky (1970), p.4
[28] Cf. Grundig (2015), p.39
[29] ibidem
[30] Cf. Grundig (2015), p.40
[31] Cf. Grundig (2015), p.48

Figure 7 shows in detail the rough planning phase.

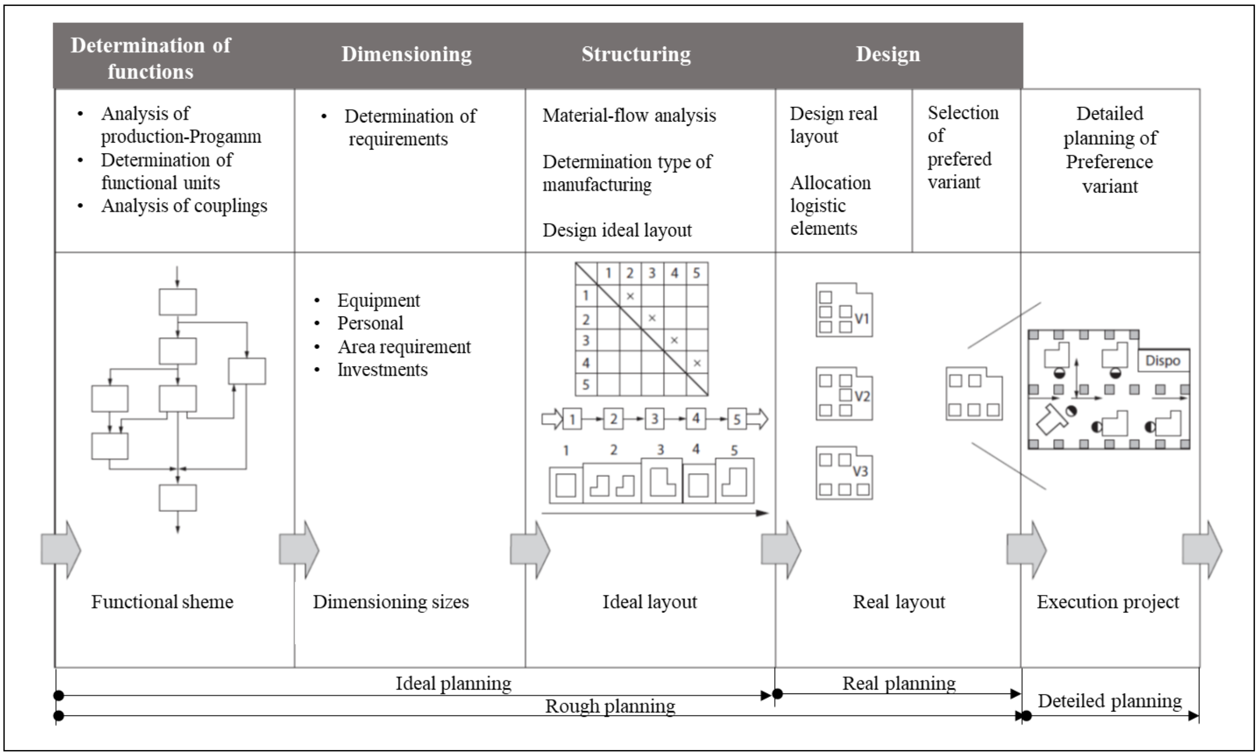


Figure 7: Core competences of factory structure planning[32]

The classic process models mentioned above are top-down oriented and are particularly well suited to integrated factory planning objects. However, employee experiences are not included from the beginning.[33] Today, companies have developed best practices based on company-specific features of existing resources, such as employees. These must be included in the formation of the factory concept.[34]

In a counter flow process, the analytical procedure of classical factory planning approaches is systematically combined with the synthetic perspective from practice. The analytical perspective pursues the designing of an "ideal factory" regardless of existing restrictions, based on product and market conditions in one classic "green field” approach.[35]

The “bottom-up” perspective therefore focuses on the strengths-weaknesses analysis. In the process, change needs are systematically derived from existing experiences in a targeted analysis. In addition, successful solution components will be developed to convert them into the future factory concept. The result of the bottom-up perspective is a target concept. The resulting planning process pursues these two perspectives, bottom-up and top-down in parallel. The two perspectives

[32] Cf. Based on Grundig (2015), p. 49
[33] Cf. Pawellek (2008), p.50
[34] Cf. Schuh (2013), p.23
[35] Cf. Schuh et al. (2007), p. 196

are not processed separately, rather they are consciously linked, meaning the analytical and synthetic steps are joined together. This approach allows the merging of knowledge from theory and practice and actively involves all participants in the planning process.[36] (see figure 8)

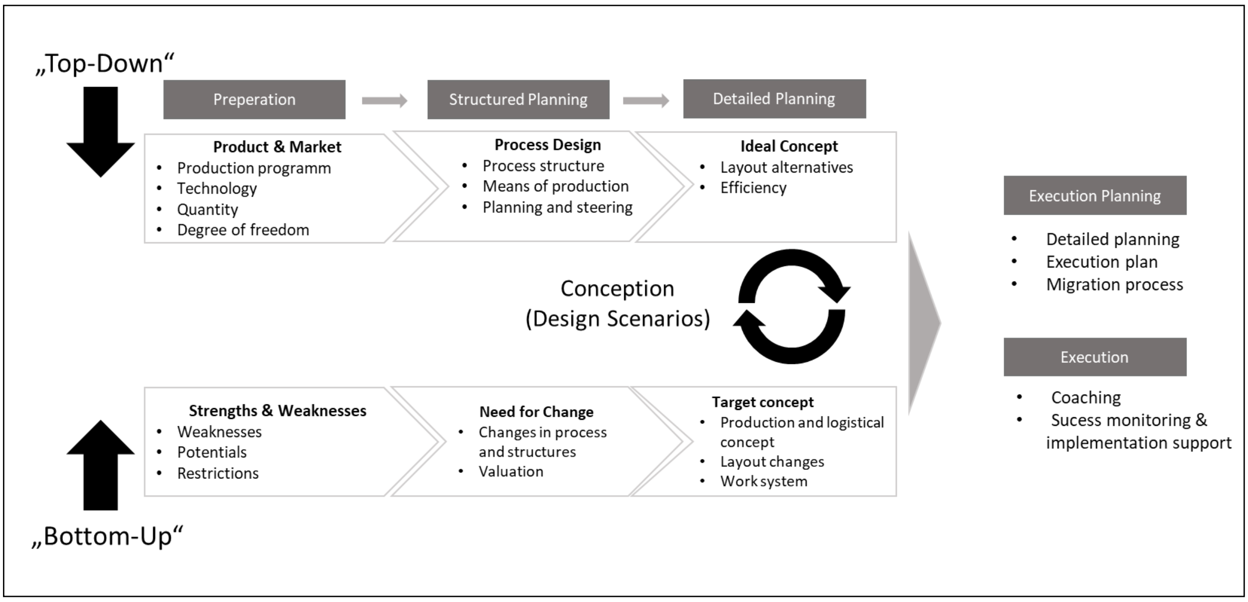


Figure 8: Counterflow planning process[37]

In the following chapters, the individual phases of the factory planning process are explained in detail.

2.5 Target Planning

In all common factory planning approaches, the starting point is the initiation of the management. The initiation can be based on very different initial situations and reasons.[38] In the summary of the planning systematic of *Schuh* (2007) the phases target planning and preliminary planning introduced by *Grundig* are grouped under the umbrella term preparation.[39]

Target planning is usually inspired by strategic considerations, new market requirements, or identified deficiencies.[40]

Pawellek set the strategy (target) planning as a first step in factory planning. He divides it into presence strategy and visionary strategy planning. The visionary strategy planning defines a target state and develops retrospective steps to reach it. In contrast, the presence strategy planning develops, originating from the current state towards the target states.[41]

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[36] ibidem
[37] Cf. Own figure based on Schuh (2013), p.13
[38] Cf. Kettner et al. (1984), p. 12
[39] Cf. Schuh et al. (2007), p. 196
[40] CF. Grundig (2015), p. 54 f.
[41] Cf. Pawellek (2008), p. 63

Figure 9 describes both models:

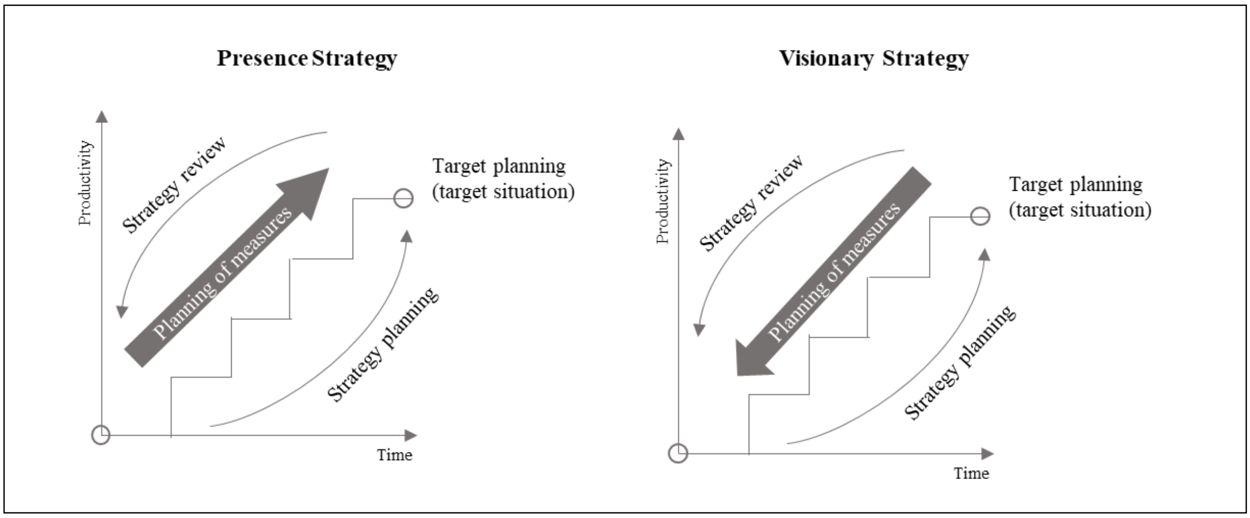

Figure 9: Basic forms of strategy planning[42]

During the factory planning process, a constant reconciliation of the company's performance and deficits with set targets is required.[43]

One way to identify the trigger for a factory planning process, for example, is to subject the industry to a structural analysis. In doing so, the industry can be described using five decisive competitive forces, which create a starting point for the objective. The analysis starts with the determination of the number of competitors, and determines which intensity prevails in this industry. This rivalry can be determined, for example, by over capacities, brand identities and exit barriers. Subsequently, it is determined whether there are possible new providers and which barriers to entry exist in their own market. One complex concerns the bargaining power and price sensitivity of the customer base, which describes how easily the customer can change his/her supplier. Another complex deal with the danger of substitution products, which can push their own product out of the market. The last complex is the risk of supplier bargaining.[44]

These five forces determine industry profitability by influencing prices, expenses, investment needs, and thus the return on invested capital for the companies in the industry.[45]

A key problem of the target planning is the high uncertainty which characterizes the planning process. In order to make these uncertainties more predictable, *Pawellek* recommends the scenario technique shown in Figure 10. There are several scenarios for the same goal. During the planning process, further decisions are made after the various planning steps. These decisions narrow the

[42] Cf. Own figure based on Pawellek (2014), p.64
[43] Cf. Grundig (2015), p.54
[44] Cf. Wiendahl (2014), p. 54
[45] Cf. Porter (2015), p.25

planning scope for the next planning phase, leaving only one variant at the end of execution planning.[46]

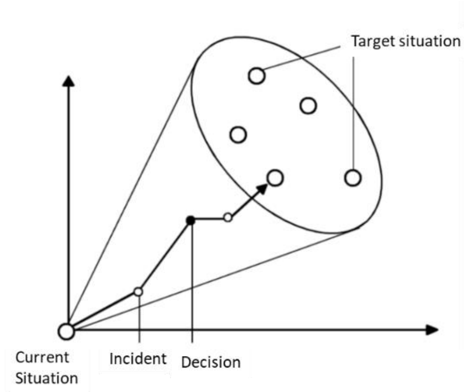

Figure 10: Adaption of the strategy to changes[47]

The results of the target planning provide a defined factory planning task with the following possible contents:[48]

- Description of problem (starting point)
- Setting of targets (short-, medium-, long-term)
- Budget and time frame
- Primary solutions (direction of solution)
- Project management and project organization

The results of the target planning are afterwards presented in a feasibility study.[49]

2.6 Preliminary Planning

The preliminary planning process serves as a basis for further phases. In literature, the phase of preliminary planning is described as one of the most important phases because the quality of the planning basis to be developed decisively determines the quality and accuracy of the solutions to be developed in the following planning phases.[50]

Basic planning contents of the preliminary planning in factory planning are:[51]

- Analysis of the factory and potentials
- Design of solution concepts

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[46] Cf. Pawellek (2014), p.68
[47] Based on Pawellek (2014), p.64
[48] Cf. Grundig (2015), p. 56 and Kettner et al. (1984), p. 12
[49] ibidem
[50] Cf. Grundig (2015), p. 57 and Kettner et al. (1984), p. 17
[51] Cf. Grundig (2015), p. 52 ff.

- Pre-feasibility study
- Assessment of needs and costs
- Concretized task

In most of cases, factory planning tasks have the character of conversion, extension or modernization. The processes to be changed are usually then described by a historically evolved starting position. In these cases, an analysis of the existing production potential must first be carried out. In literature this analysis is referred to as a situational analysis and has the purpose to show the difference between the actual state and the desired state.[52] For the execution of the current state analysis the principle as exactly as necessary – as rough as possible is valid.[53]

The current state analysis consists of the following phases:[54]

- Scrutiny of operational processes
- Analysis of production factors
- Analysis of secondary fields (space utilization, material flow)
- Investigation of tertiary fields (planning, management and steering)

The most important tools for the analysis of the organization are:[55]

- ABC-Analysis and PQ-Analysis for identification of the potential focus
- Workshops and interviews
- Work-sampling study/Time recording by REFA

Important contents for the current state analysis are data of the products, processes and the facility, which must be worked out and evaluated.[56] The next chapter shows the ways in which data can be collected and presented.

2.6.1 Data Collection

The data collection for the current state analysis can be carried out in two ways. Direct and indirect data surveys exist. When choosing a suitable recording method, besides the examination object and the target, the available staff (qualification, number of people) and time period must be taken into account.[57] Figure 11 shows the most common surveys for data collection.

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[52] Cf. Grundig (2015), p. 57
[53] Cf. Aggteleky (1982), p. 28
[54] ibidem
[55] Cf. Grundig (2015), p. 62ff. and Aggteleky (1982), p. 28
[56] Cf. Grundig (2015), p. 79
[57] Cf. Kettner et al. (1984), p.37

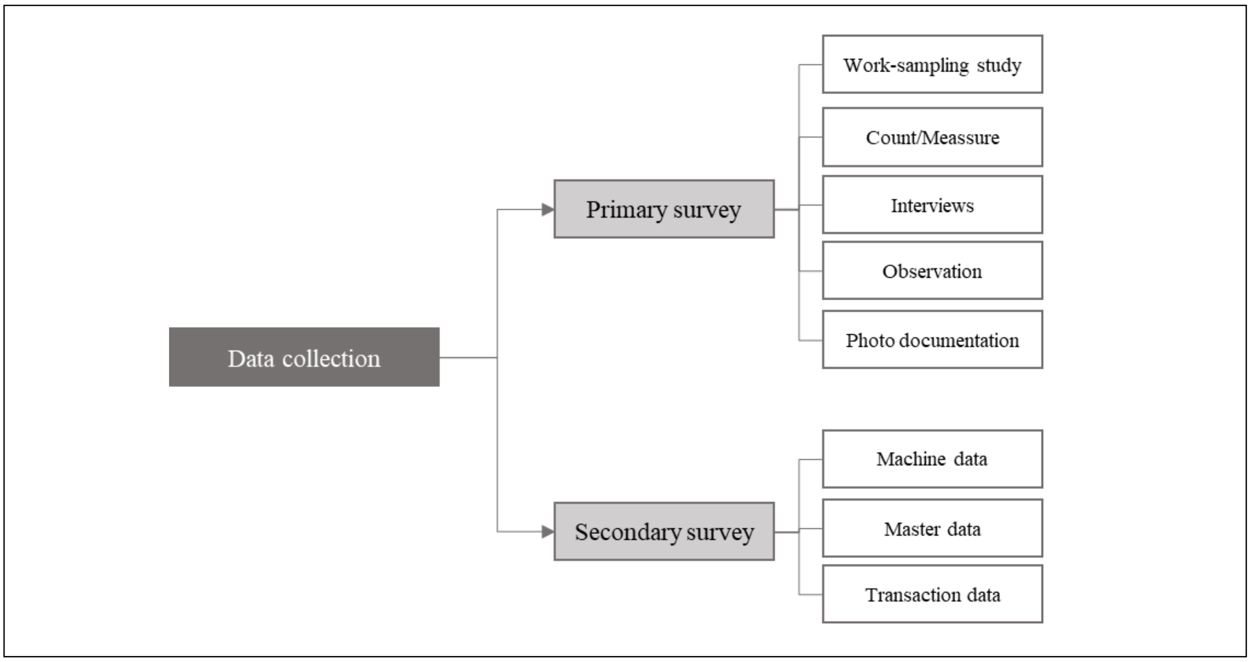

Figure 11: Possibilities for Data surveys[58]

Primary survey or direct data collection is necessary when the required data is not available or not available in the required quality.[59] Therefore the required data is gathered throughout the ongoing process. This type of data collection can often be very complicated.[60]

The secondary survey or indirect method is the use of existing data, which has been previously collected for other purposes. This means that no investigation for the conduct of the current state analysis is necessary and thus requires less effort than a primary survey.[61] Furthermore, indirect data collection does not disturb the production process. For an indirect data survey, it must be ensured that the data is up-to-date, complete, consistent and reproducible.[62] The following data can be considered indirect data:[63]

- Development and layout plans
- Machine data
- Production statistics
- Production program
- Bill of material
- Work and production plan
- Work sampling study

[58] Cf. Own figure based on Arnold/Furmans (2009), p.237
[59] Cf. Arnold/Furmans (2009), p. 237
[60] Cf. Grundig (2015), p.60 f.
[61] CF. Arnold/Furmans (2009), p. 237
[62] Cf. Kettner et al. (1984), p.39 and Arnold/Furmans (2009), p. 239
[63] Cf. Grundig (2015), p. 60 f.

In the practice of factory planning, the work sampling study, time recording, interviews and workshops are commonly used as a primary method for data collection.[64]

Interviews

Interviews can be carried out orally as well as in written form via questionnaires.[65]

The interviews must be clear, easy to understand and the questions should be objectively formulated. The significance of the survey can usually be increased by conducting parallel interviews with several knowledgeable individuals. Self-controlling allows the required information to be collected directly by the employee and recorded in a prepared form. An advantage of this method is the feasibility of collecting data from multiple people and workplaces simultaneously. A disadvantage of this method is that the quality of the output of self-controlling strongly depends on the performing employee.[66]

Workshops

Workshops are particularly well-suited for the development of ideas and proposals for solutions involving selected employees.[67]

The situation must be understood by all participants at the beginning of the workshop in order to be able to develop targeted measures and actions to change or improve the current situation. Concrete, goal-oriented actions are derived from the opinions of the employees.[68]

The choice of participants for the workshop strongly influences the quality of the result. The number of participants should be manageable, so that each participant has the opportunity to express their opinion and to contribute to the resolution process. If the group is too large, the creativity and willingness of employees may suffer.[69]

At the end of the workshop, a final report must be prepared in order to summarize the ideas and to document the most important interim results.[70]

REFA time recording

The time measurement by REFA defines an analysis of the current work process. Work processes are terms for the collaboration of human and operating material[71] Reasons for the examination of processes are the following:[72]

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[64] Cf. REFA (1978), p.81
[65] Kettner et al. (1984), p. 38
[66] Cf. Gonschorrek/Hoffmeister (2006), p. 152
[67] Cf. Hermann/Huber (2009), p. 130 ff.
[68] Cf. Borg (2013), p.323
[69] Cf. Herman/Huber (2009), p. 130ff.
[70] Herman/Huber (2009), p.133f.
[71] Cf. REFA (1992), p. 20
[72] ibidem

- The structure of processes according to process types offers the possibility of using the times for sections of certain process types in a variety of ways. (e.g. determination of quantities and default times)
- This structure is also the basis for the creation of key figures, which express how effective the interaction between human and resources is with the work object.

Figure 12 shows for the total process time T, the time per unit t_e and the three-time types of target time, the basic time, recovery time and distribution time. The execution consists of m repetitions of the same process. The setup time consists of the setup basic time, the setup recovery time and setup additional time. [73]

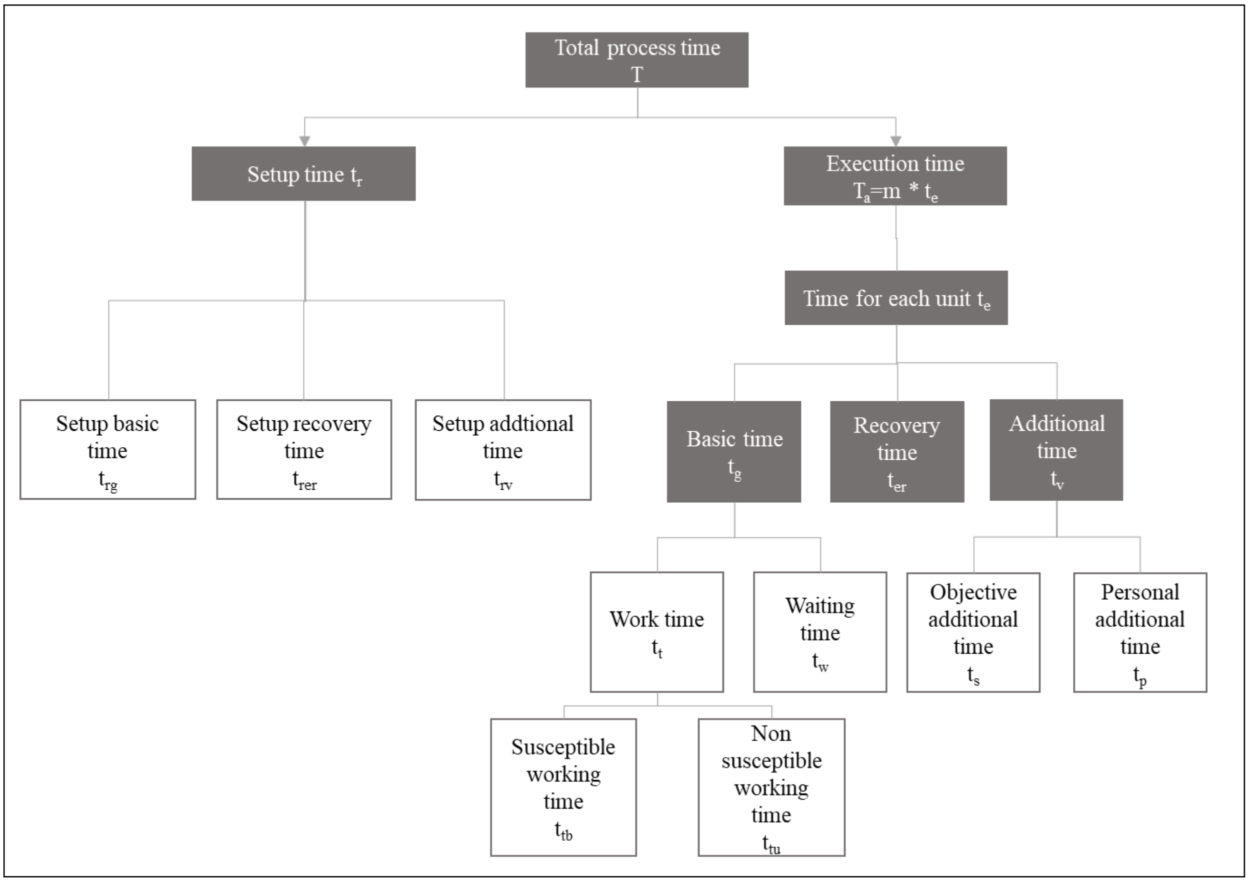

Figure 12: Total process time by REFA[74]

The total process time T is the target time for the execution of a task by a human. It is calculated as the sum of the execution time and the setup time, as in formula 1 shown.[75]

$$T = T_r + T_a \qquad \textbf{(1)}$$

[73] Cf. REFA (1992), p.42
[74] Own figure based on REFA (1992), p.42
[75] ibidem

The execution time is calculated using the sum of the basic time, recovery time and additional time. The factor m defines the quantity of one order. To sum up, the execution time is calculated using the following formula.[76]

$$t_a = m * (t_g + t_{er} + t_v) \quad \textbf{(2)}$$

The additional time is divided into two parts:[77]

- Objective additional time t_s: Contains the target times for additional activities and disruptions due to interruptions.
- Personal additional time t_p: Includes times for personal interruption of activities.

Part of the operational analysis is the production program, the operating material, the production processes and the material flows.[78]

The examination effort to be used is to be set in an economically justifiable relation with the task of the factory planning task. Excessive investigation effort can lead to unjustifiable expenses. Too little investigation effort can lead to superficialities and misguided projects.[79]

2.6.2 Production Program

The production program forms the basis for determining the scope of services of the planned production.[80]

The following points are considered:[81]

- Factual (product types, range of products)
- Quantity (amount, quantity per product type)
- Temporal (production period, costs)
- Value (price, costs)

The function, dimension and structure of the production system to be planned are derived from the production program. Therefore, it must be clarified which parts of the entire production program are relevant for the production system to be planned, and how much it should be purchased via cooperation.[82]

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[76] ibidem
[77] Cf. REFA (1992), p. 54
[78] Cf. VDI (2011), p. 13
[79] Cf. Grundig (2015), p.60
[80] Cf. Grundig (2013), p. 64
[81] Cf. Grundig (2013), p. 64
[82] Cf. Schenk/Wirth (2004), p. 297

The result of operational market and sales activities is usually specified by the corporate management product program. It is subject to constant reconciliation in the context of strategic business planning.[83] The goal is long-term sales planning. This is based on a long-term assessment of market development, own product policy and diversification projects.[84]

The type-delegate method is used to facilitate handling with large-scale production programs. The basis for this is the mathematical reduction of the product variety to product groups. Product groups which are technologically similar are formed, and for each group, a representative type is determined based on which the conversion of the parts or product quantity of each group takes place.[85]

There are different ways of looking at the choice of type representatives and determining the priority and meaning of the items to be examined. The most important points are the share of sales, profit share and contribution margin. The most commonly used analytical methods are ABC analysis or PQ analysis.[86]

With help of the ABC analysis, the essential can be distinguished from the non-essential. This allows a concentration and focus on the most important positions of an investigation.[87] The aim of the ABC analysis is the statistical classification of the frequency distribution of dominant characteristics. [88]

This happens in three categories:[89]

- A = High importance; relatively small number of elements with a high proportion of the overall result
- B = Normal importance; this group of elements contributes slightly in proportion to their number to the considered result.
- C = Low importance; a relatively large number of elements has only a small contribution to the overall result.

The division of the elements into classes is done arbitrarily. This arbitrariness is referred to in the literature as a disadvantage of ABC analysis.[90]

As part of the ABC-analysis on the product range, this analysis compares the proportions of the products in the total output volume and the sales shares of the respective products in the total sales. As a result, the revenue-generating products can be separated from the low-revenue products. This

[83] Cf. Grundig (2013), p. 65
[84] Aggteleky (1981), p. 233
[85] Cf. Schenk/Wirth (2004), p. 298
[86] Cf. Aggteleky (1982), p. 34f.
[87] Cf. Cordt (1982), p. 1f.
[88] Cf. Wiendahl et al. (2014), p. 451
[89] ibidem
[90] Cf. Wöhe (2008), p. 339

information is needed as part of the structure development and dimensioning to subdivide production into mass production and single-part segments.[91]

In direct or indirect data acquisition, processes can also be analyzed and visualized. The next chapter shows different visualization methods.

2.6.3 Process Analysis

The goal of the process analysis is the description of business processes and the flow of material, communication and value.[92]

Process visualization

For the representation of the processes, there are different methods and tools such as the system ARIS (architecture of integrated information systems), the process chain analysis and the Sankey diagram.[93]

One method of process visualization is process chain analysis. Therefore, the individual process steps and their connections are described with specific symbols for a product or product group. The so-called connectors cause either a multiple process element, each process element is described by four feature groups (process, steering, structure, resource). The goal of the process chain analysis is to make the processes transparent for all participants in a simple presentation as well as to uncover and eliminate possible weak points.[94] (see figure 13)

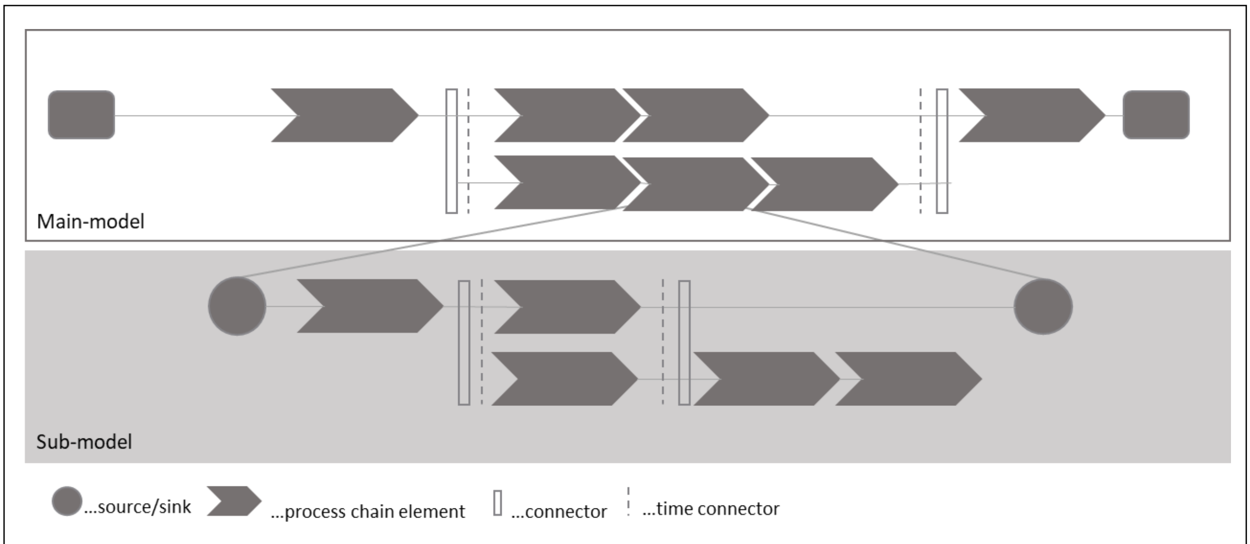

Figure 13: Process chain model by Kuhn[95]

[91] Cf. Wiendahl et al. (2014), p.451
[92] Cf. Wiendahl et al. (2014), p.452 f.
[93] Cf. Wiendahl et al. (2014), p.454
[94] Cf. ibidem
[95] Cf. Own figure based on Wiendahl et al. (2014), p. 452

Another tool for process visualization is the Gantt chart. This is a two-dimensional bar chart. Each process gets its own timeline. As a result, parallel or overlapping activities can also be shown. It is possible to show time reserves (buffers), but with many buffers the advantage of the clarity of this form of representation is increasingly impaired (see figure 14). This method offers a good rough- and overview planning. This method can be applied to the representation of capacity utilization of individual structural units such as workplaces.[96]

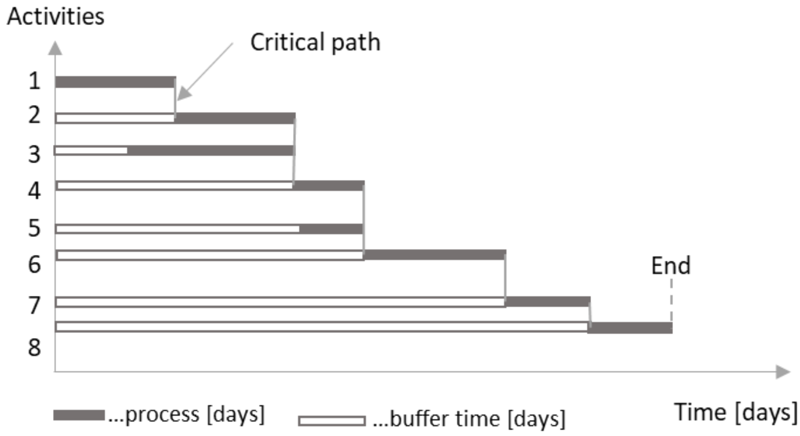

Figure 14: Process visualization with a Gantt-Chart[97]

Material-flow analysis

The material flow analysis serves the traceability of the processes within the production. The results of the material flow analysis have a significant influence on the optimal arrangement of the structural units. The industrial material flow processes can basically be divided into the internal and the external material flows. Modern factory planning considers both internal and external material flows. The material flow optimization then forms continuous material flow chains. Two basic cases can be distinguished for a material flow analysis in the context of a factory planning process. Material flow planning for new systems to be planned, on the other hand, on an existing material flow structure.[98]

The goals of material flow analysis are:[99]

- Creation of a complete overview of the material flow relationships of all objects. (Material flow cross-linking)
- Recognition of orders of magnitude of the main material fluxes considering mutual relation (material flow intensity)

[96] Cf. Kettner et al. (1984), p.86
[97] Cf. Own figure based on Kettner et al. (1984), p.86
[98] Cf. Grundig (2015), p.116ff
[99] Cf. Grundig (2015), p.119

The basis for material flow analysis is the data acquisition. Data is collected from the working plans, the bill of materials, the production program, the operating material file and the layout. The material flow matrix, also called From-To Matrix, represents type-dependent material flow data, including the transport volume or the transport routes between the sources (rows) and sinks (columns). [100]

The detection of the movements between material flow objects results in an orientation of the material flow in the flow direction and return flow. The flows in the flow direction are above the diagonal, while the returns appear below the diagonal. In the transport matrix (TM), which is created in the same way as the material flow matrix, the actual transport effort is based on transport units (TE). To create the distance matrix (DM), an installation plan of the equipment, which includes the position of the operating and transport means in the actual rate, is required. For the distance matrix only those resources are relevant, between which material flows take place, whereby the returning transport routes are to be included. The combination of transport matrix and distance matrix is called transport intensity matrix and includes the products of the corresponding cell entries. The unit of the transport infrastructure is therefore transport unit x meters.[101]

Figure 15 shows the theoretical approach for creation of a transport intensity matrix.

[100] Cf. Martin (2014), p.33
[101] Cf. Arnold et al. (2008), p.395 f.

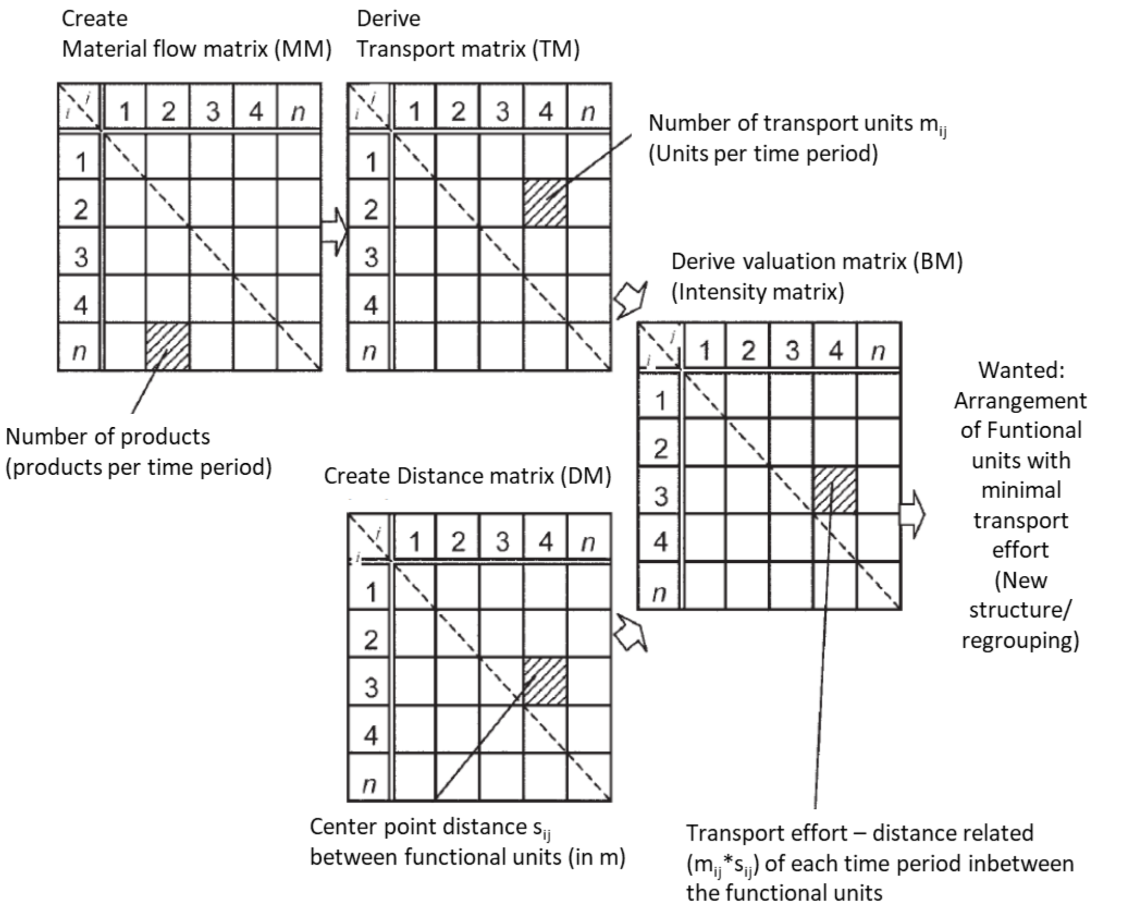

Figure 15: Material flow matrix[102]

[102] Cf. Arnold et al. (2008), p.31

2.7 Rough Planning

The rough phase or structure planning is the most creative and important phase in a factory planning process. In that phase the criteria which have been developed in the target planning are implemented.[103]

Depending on the planning scope, a distinction is made between factory planning in the narrower sense and in the broader sense. Factory planning in the narrower sense refers to the internal site planning and is also referred to as layout planning, and involves calculating the best possible arrangement of the organizational units at the location for maximum efficiency. The extended factory planning also includes the planning of the operational site, in which the geographical placement of the facilities is considered under consideration of various criteria, such as the available infrastructure and the supplier or customer locations.[104]

A central part of the rough planning process is the review, supplementing and refining of the previously determined planning data. The rough planning phase is usually divided into two parts. First, a functional scheme is worked out. Then all relevant dimensioning sizes are determined. On the basis of that an ideal concept is worked out. This stage is called the ideal planning phase. The variant is then adapted to the real situation, which is called real planning.[105]

2.7.1 Determination of Functions

The determination of function starting from the production program defines the required procedures and equipment. Based on that, the functional scheme of the production process can be created. This scheme shows the functional units and their qualitative compounds.[106]

The function scheme can be divided into different detail levels. The highest level is the factory structure, for which the product groups are essential. Within the product groups, there are at area level several product or customer segments.[107] Table 3 shows the steps for creation of the functional scheme.

[103] Cf. Wiendahl/Reichardt/Nyhuis (2009), p.460
[104] Cf. Grundig (2015), p. 44 and Scholz (2010), p.3
[105] Cf. Kettner/Schmidt/Greim (1984), p.19
[106] Cf. Grundig (2009), p. 80
[107] Cf. Wiendahl/Reichardt/Nyhuis (2014), p. 460 ff.

Step	Contents	
A Analysis of production program and bill of material	Product element • Main assembly • Assemblies • Components • Internal-/external production	Production stages • Pre-production • Pre-assembly • Final assembly
B Analysis of work plans	• Work process • Workplace • Process flows	
C Development of working procedure schemes	• Material flow analysis • Distribution into units	
D Derivation of functional scheme	• Allocation of functional units ○ Functional-oriented ○ Material-flow oriented	
E Derivation of area to scale functional scheme	• Determination of space requirements • Area of functional units true to scale	

Table 3: Steps for determination of functions[108]

Step A defines the number of relevant products. With the help of the bill of materials, different production stages and the product elements can be identified[109]

In step B, all processes and process flows for each element are analyzed. The analysis is the basis for the derivation of the material flow linkage. In step C, a detailed material flow analysis is carried out. This includes qualitative information about the material flow. Furthermore, in this step the units are grouped. Principles for the grouping of units can for example be the allocation of cost centers, creation of modules and planned functional-spatial related grouping.[110]

Step D gives a better understanding of the production flow by visualization of the processing logic. This visualization is related to the functions and units and shows the correlation between each function. The aim of step D is to make a first arrangement of the unit-oriented functional scheme. No areas which are true to scale are therefore considered.[111]

[108] Cf. Grundig (2015), p. 81
[109] Cf. Schenk/Wirth (2004), p. 59 ff.
[110] Cf. Grundig (2009), p. 84 f.
[111] Cf. Kettner (1984), p. 100 f.

In the last step, an area to scale functional scheme is derived. A rough estimation or calculation of space requirements is carried out. This functional scheme only takes into account the functional units and not its arrangement.[112]

The function scheme creates an essential starting point for the subsequent steps of the factory structure planning. Thus, all essential functional units are known. In the subsequent planning process, these functional units are dimensioned, structured and serve as a basis for the layout planning.[113]

2.7.2 Dimensioning

During the structural dimensioning process, the number of necessary resources, the required spaces and the personnel required for each operation are determined. The required input variables are the production program, the product characteristics, the future required or existing production equipment and the qualifications of the deployed personnel. The production program is the basis for the calculation of the necessary resources. To be able to carry out the calculation in a future-oriented manner, in addition to the current production program, statements about the future developments of the quantities and possible future products are required.[114]

The next step will determine the type, number, capacity and availability of equipment which are directly involved in production. The remaining resources, such as storage and in-house subsidies, are the result of the number of resources already allocated and their flow relationships with each other.[115]

There are two methods for dimensioning:[116]

- Static dimensioning
  The reference periods are usually whole years, and is thus calculated with averages. The dynamic of demand within the reference period is not included. In practice, this simplistic view has often proven sufficient.
- Dynamic dimensioning

  This method takes time-dependent changes such as seasonal fluctuations or new product launches into account. Due to the complexity of the calculation, the use of a simulation software is recommended.

[112] Cf. Grundig (2009), p. 84 f.
[113] ibidem
[114] Cf. Wiendahl et al. (2014), p. 463 ff
[115] Cf. Wiendahl et al. (2014), p. 463 ff.
[116] Cf. Grundig (2013), p. 88 f.

Space requirement

In each factory planning process, both in a new planning or re-planning of existing sites, the required space must be determined[117]. Determination of exact area requirements is necessary for the following reasons:[118]

- Rising land- and building prices require diligent use of space
- If production facilities are too small, disruptions in the production process may occur. If the production facilities are too large, investment and cost of facilities increase
- Lifetime of products decreases. This reduces the useful life of the equipment. The change in production requires a new or re-planning of the sites, and the question of the optimal use of space must therefore be reconsidered.

The basis for the analysis and the calculation of the area requirement is the area classification. (see figure 16)

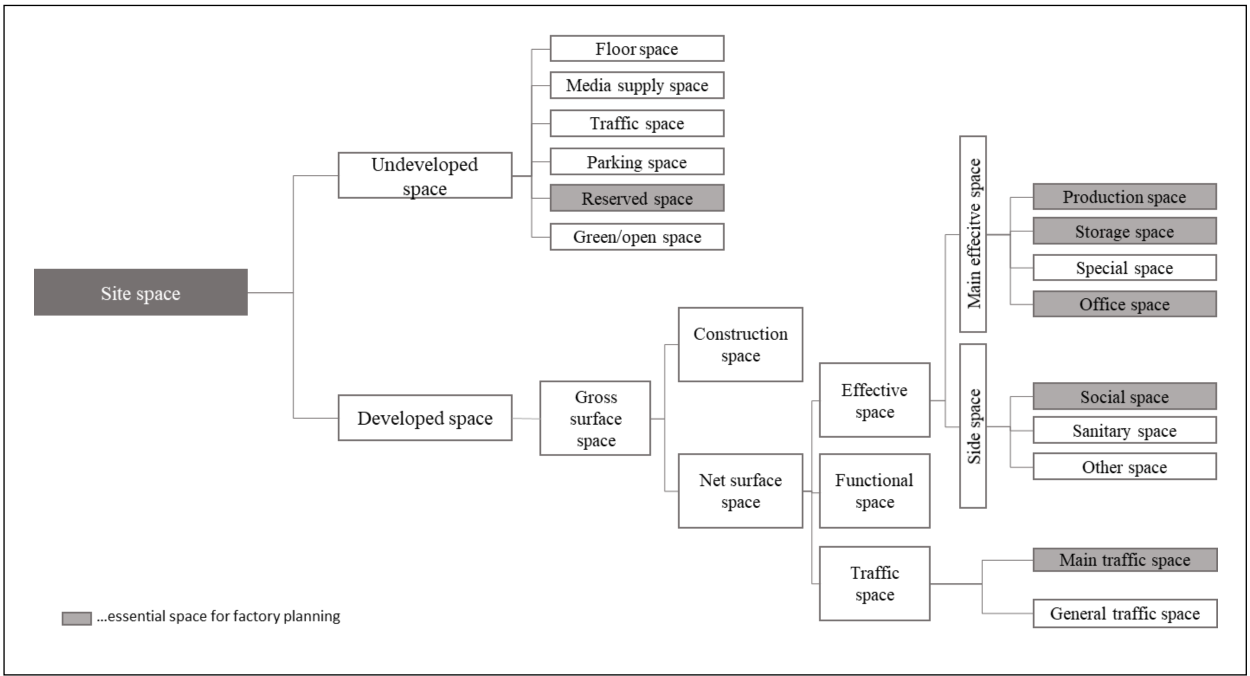

Figure 16: Division of operating areas according to VDI 3644[119]

Reserved areas can be used to extend the factory, in the case of increasing growth of the facility. The space which is required for manufacturing, assembling, checking and handling of materials is included in the production area.[120] The area required for production can be estimated in several ways. In the early phase of the factory planning cycle, the estimation of the area can be carried out based on certain key indicators. This key indicator can be either absolute or relative. If more

[117] Podolsky (1977), p.17
[118] ibidem
[119] Cf. Own figure based on Wiendahl et al. (2015), p.468
[120] Cf. Wiendahl et al. (2015), p. 468

detailed information about the resources is available, the area calculation can be performed more accurately.[121] There are two different approaches for this calculation:[122]

- Top-down
  Begins with the calculation of the total site space and then breaking it down into individual sections for departments and in the end the spaces required of each workplace. This means that a category of a higher order is converted to an area category of a lower order.
- Bottom-up
  Begins with the calculation of space for each workplace (primary production area). The result is the total work space of the factory. This approach follows the theory that higher order area categories are calculated from lower order area categories.

A distinction is made between the following methods in order to determine area requirements concerning methodology, required database, accuracy of results and scope of application:[123]

- Global determination of space requirement
  The requirement for space is derived on the basis of reference quantities such as production volume, number of employees, amount of equipment, size of company, sector and type of building with the help of indicators and reference values.
- Detailed determination of space requirement
  - Determination with space factors:
    The requirement of the area for workstations is derived by multiplication of the area of the machine’s footprint with a space factor. (Information about the area of the machine’s footprint is required in order to use this method)
  - Determination with replacement areas:
    Based on the area of the machine’s footprint, a space strip is added to all object sides, so that a workplace surface is defined and determined by a rough estimate.
  - Determination with supplement factors:
    In this case, the required workplace area is derived starting from the machine base area and expanded by additional factors and by additional space requirements. The machine base areas are usually taken from the manufacturer's instructions. The additional factors for operation, transport, maintenance, intermediate storage and provision are derived from special tables and nomograms. The considered influences, such as manufacturing form, production method and surface overlay allow the introduction of precise ideas regarding workshop design.

[121] Cf. Schenk (2010), p. 96 ff.
[122] ibidem
[123] Cf. Grundig (2013), p. 102 ff.

- Development of experimental layouts:
  In the first step, real estate, building and / or usable areas are determined with the help of key figures. This is followed by an experimental determination of "favorable" spatial allocation within the specified area. Considering criteria such as material flow and work design of the building, two or three-dimensional machines or equipment models are moved within the given areas. From the resulting area-scale sample layout, the area requirement can be determined by measuring relatively accurately.
- Method of functional determination by Nestler:[124]
  This method is based on extensive statistical investigations in workshops of small and medium-sized companies in the mechanical engineering sector. The operating area (A_0), which is directly derived from the area requirements of the equipment forms the reference basis of this calculation method. The total production area (A) is the sum of the operating area (A_0), the area for intermediate storage (A_S), additional area (A_A) and the area for transport (A_T). Formula 3 shows the calculation of the production area (A).

$$A = A_0 + A_S + A_A + A_T \qquad \textbf{(3)}$$

The area required for equipment (A_0) is calculated by the multiplication of width (W_E), and depth (D_E). Additional to the area of the machine supplement factors for operation, maintenance and safety are added to the width and depth of the machine. The result is the total required operating area as a sum of equipment areas of all machines. Formula 4 illustrates the calculation:

$$A_0 = \sum_{i=1}^{E}((W_E + 0{,}8) * (D_E + 1{,}4)) \qquad \textbf{(4)}$$

The factors for the other areas are the following:[125]

A_S……40% of operating area A_0
A_A……20% of operating area A_0
A_T……40% of operating area A_0

With these factors the first formula for production area (A) changes to the following:

[124] Cf. Grundig (2015), p.103ff.
[125] Cf. Grundig (2015), p.105

$$A = A_0 + 0{,}4 * A_0 + 0{,}2 * A_0 + 0{,}4 * A_0 \qquad \textbf{(5)}$$

- Determination using generalized supplement factors:
  This approach is based on a two-stage bottom-up principle. In the first step the workplace area of the equipment based on the equipment´s floor area (A_{EF}) is calculated. The formula for the calculation of the equipment´s workplace area is following:

$$A_{EW} = A_{EF} * f_g \qquad \textbf{(6)}$$

The factor f_G is respecting the area of maintenance, provision of material, handling of the equipment, disposal, and supply. The factor f_G varies depending on the equipment's floor area. Table 5 shows different factors of *Rockstroh* and *Woithe*, depending on the size of the equipment´s floor area:

ACCORDING TO	EQUIPMENT´S FLOOR AREA	FACTOR F_G	REMARKS
Woithe	Small to large	5.8…3.8	Workshop structure
	Small to large	3.8…2.4	Object structure
Rockstroh	> 0.5…..1.0	6	Floor area (in m²)
	> 1.0…..2.0	5	
	> 2.0…..3.0	4.5	
	> 3.0…..4.0	4	
	> 4.0…..12.0	3	
	> 12.0…16.0	2.5	
	> 16.0	2	

Table 4: Additional factors depending on the footprint size[126]

The second step in this method is to calculate the production area based on the results of the first step. This is done using the formula below:

$$A_P = A_{EW} * f_A \qquad \textbf{(7)}$$

[126] Cf. Grundig (2015), p.106

The factor f_A considers areas for quality check, intermediate storage, disposal and supply, transport and production control. The quantified plus factor f_A are illustrated in the table xy below.

ACCORDING TO	KETTNER	ROCKSTROH
f_A	2.0	1.55…1,80

Table 5: Additional factor for workstations[127]

Area for assembling

For the calculation of the floor space required for assembling, six different types of assembly area can be distinguished (see figure 17):[128]

- Type 1: assembly is completed on the ground
- Type 2: benches are used for assembling
- Type 3: work in testing areas
- Type 4: work on conveying equipment
- Type 5: work at workbenches
- Type 6: workstations on machines and plant

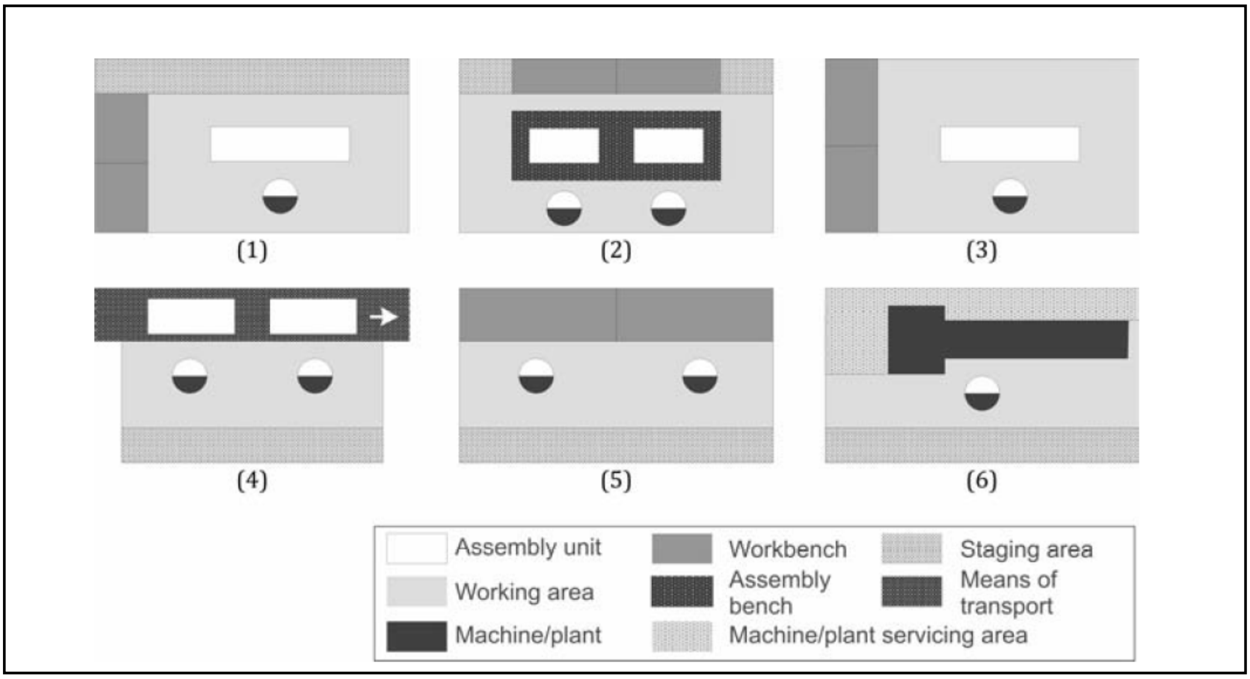

Figure 17: Types of assembly area[129]

[127] Cf. Grundig (2015), p.107
[128] Rockstroh (1982), p.56
[129] Cf. Schenk et al. (2010), p.111

When calculating the floor space for type 1 four different floor space types are composed:[130]

- Assembly unit floor space (A_{AU})
- Workbench floor space (A_{WB})
- Staging area (A_{SA})
- Residual area (A_R)

Thus, the floor space requirement is determined by following formula:

$$A_{AA} = A_{AU} + A_{WB} + A_{SA} + A_R \quad \textbf{(8)}$$

The design of the working area determines the dimensions of the working area. It is divided between a primary working side and up to three secondary operating sides. Furthermore, the length and width of the assembly unit are required in order to carry out the calculation. The assembly area type 1 can be subdivided into six further assembly area types (see figure 18).

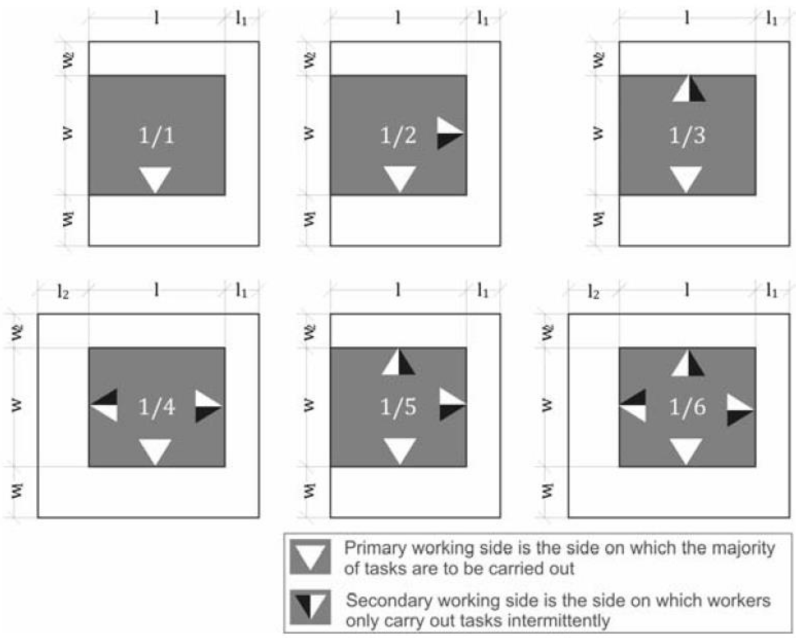

Figure 18: Assembly area 1 sub type[131]

Similar assembly areas in the layout are grouped in the determination of the required floor space. A factor f_1 is determined. This factor is including the number of workers at the assembly unit. It increases with the number of workers. Normally the factor ranges between 0.5 and 1.0. The value can be obtained from tables. The floor space of the assembly unit is then calculated as follows:

[130] Cf. Schenk et al. (2010), p. 112
[131] Cf. Schenk et al. (2010), p.112

$$A_{AU} = (l_{AU} + l_1 + l_2) * (w_{AU} + w_1 + w_2) * f_1 + N_{AU} \quad \textbf{(9)}$$

Table 4 gives information about the assembly area additions for the different assembly area designs.

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 6: Assembly area additions[132]

The floor space for the workbench (A_{WB}) is calculated using formula 10.

$$A_{WB} = 1.2 * N_{AU} * N_{WAU} \quad \textbf{(10)}$$

N_{AU}...number of assembly units

N_{WAU}...number of workers per assembly unit

The area for staging (A_{SA}) is calculated using the following formula:

$$A_{SA} = (A_{LP} + A_{MSP}) * N_{AU} \quad \textbf{(11)}$$

A_{LP}...area of the large parts

A_{MSP}...area of the medium and small parts

The last area to calculate is the residual A area. Formula 12 shows the calculation:

[132] Cf. Schenk et al. (2010), p.113

$$A_R = \left(W_{AU} + 1.4 + \frac{1}{N_R}\right) * 0.6 * N_R \qquad \textbf{(12)}$$

As a result of the structural dimensioning, the dimensioned structural units, the logistics concept as well as an area-scale functional scheme for the factory are available.[133]

Equipment calculation

A variety of detailed methods can be used in order to calculate the equipment requirement, and the method chosen depends on the quality of the database. Therefore methods based on estimates, comparisons but also exact methods are distinguished.[134]

Kettner sets the following basic context for the exact calculation of operating resources. The required equipment is calculated by dividing the total required capacity by the available capacity of the equipment.[135] For that basic context *Kettner* set up following formula:

$$BM_i = \frac{T_{Bi}}{T_{Mi}} = \frac{\sum_{j=1}^{J} T_{Rji} + \sum_{j=1}^{J} (m_{ji} * t_{eji})}{A_i * h_i * S_i * \eta_i} \qquad \textbf{(13)}$$

BM_i	Quantity of required equipment of type i
T_{Bi}	Required process time for BM-type i (min./year)
T_{Mi}	Available machine time for a BM-type i (min./year)

For the determination of required operating time per year:

T_{rji}	Set-up time t_r of a product j to a BM-type i (pieces/year)
m_{ji}	Production quantity j of BM-type i (pieces/year)
t_{ji}	Process time t_e of one unit for product j of BM-type i (min./year)

For the determination of available capacity in the year T_{Mi}

A_i	Number of working days for BM-type i (days/year)
h_i	Available operating time for BM-type i each day and shift (min./day * shift)
S_i	Number of shifts for BM-type i
η_i	Degree of use of time for BM-type i

133 Cf. VDI (2011), p. 13
134 Cf. Grundig (2015), p.91
135 ibidem

The proportion of time utilized effectively is smaller than 1 and takes the type of production into account:

η = 0,7 (pre-production and assembly of individual manufacture)
η = 0,8 (pre-production of series production)
η = 0,9 (assembly of series production)

As a rule, the calculations result in fractional values, leading to the rounding of the amount of equipment but also to the correction of input variables.[136]

Determination of required Personnel

Staffing is an important component in the overall planning process of a factory. Today laws, regulations and collective bargaining agreements severely restrict a company's ability to manage staffing requirements in the short term. In this respect, personnel requirement planning must be considered at least in the medium term and only in the context of an overall staff plenary.[137]

When determining the need for staff, a distinction is made between a qualitative and quantitative personnel requirement. The qualitative personnel requirement refers to the type of personnel. The quantitative personnel requirement deals with the required number of employees.[138]

A method for a detailed determination of the required number of employees is the process of *personal dimensioning*. This method is based on knowledge of the actual time required for all work to be carried out.[139] It consists of the following general relationship:[140]

$$Number\ of\ employees = \frac{total\ process\ time\ of\ the\ work}{available\ working\ time\ of\ one\ employee}$$

The total process time of the work is a result of the total number of the products per year and the required process time for the product. The detailed quantifiable technological process allows for relatively accurate calculations. [141]

[136] Cf. Grundig (2015), p. 94
[137] Cf. Kettner et al. (1984), p.56
[138] ibidem
[139] CF. Grundig (2015), p.97
[140] ibidem
[141] ibidem

2.7.3 Structuring

An important consideration of the ideal planning of the factory is the planning of the structure. The outcome of the previous steps allows for the arrangement of all manufacturing units in the factory layout. According to the process operations which are characterized by different structural layouts, the arrangement of all manufacturing units in the factory layout can be completed . There are three necessary steps in this phase:[142]

- Analysis of the material flow
- Determination of manufacturing concepts
- Creation of the ideal layout

There are different levels of structuring. On the one side is the planning of the general structure of the factory. The areas for production, logistics and administration are aligned. On the other side is the structuring and determination of the levels workplace, area and building. [143] The level workplace includes the structuring of all elements of a workstation and its components. The level area aligns the workplaces, manufacturing cells or handling equipment. The building level includes the structuring of areas and its processes.[144]

Material flow

There are many mathematical assignment methods that can be subdivided into analytical and heuristic methods for the problem of optimization of the arrangement in layout planning as well as graphic assignment methods.[145] All methods are based on minimizing the transport effort Z. The objective function can be described mathematically as follows:[146]

$$Z = \sum_{i=1}^{n} \sum_{J=1}^{n} m_{ij} * s_{ij} \quad \text{=> minimum} \qquad \textbf{(14)}$$

s_{ij}…Distance (meter)

m_{ij}…Quantity of transport (transportation unit)

n…number of structure units

I,j…Structure unit

Z…Total transport effort (meter*transportation unit)

The aim of the arrangement of the structural units is to minimize the sum of the products from the transport quantities m_{ij} and the corresponding distances s_{ij} between all n structural units i and j.

[142] Cf. Grundig (2009), p. 111 ff.
[143] Cf Grundig (2009), p. 112
[144] ibidem
[145] Cf. Schenk et al. (2014), p.326
[146] Cf. Kettner et al. (1984), p. 228

This means that it is to find the optimum arrangement of the structural units in which the total transport effort (meter * transport unit) is at a minimum.[147]

Analytical methods of material flow-optimal arrangement of the structural units are:[148]

- Decision tree method
- Procedure of enumeration
- Branch-and-bound method

Heuristic methods are:

- Exchange process
- Construction method
- Combined procedures

Graphical methods are:

- Circle method of *Schwerdtfeger*
- Sankey chart
- Try method

Manufacturing concept

Another part of the structuring is the selection of the manufacturing process. Production processes can be characterized by special forms of their temporal and spatial organization. The forms of the spatial organization are characterized by special principles of the spatial arrangement of the workplaces within the production areas and their allocation to the material flow.[149]

Arrangement principles of assembly processes can be divided into different production forms. Assembly processes are essentially determined by the assembly of individual parts, assemblies to intermediate and end products. A distinction is made between stationary and sliding assembly. The assembly work can be realized either purely locally based on a fixed installation location or at several stations with moving assembly objects. Sliding assembly processes are also characterized by an intermittent flow of materials analogous to parts production processes.[150]

Figure 19 summarizes different arrangement principles of assembly processes.

[147] Cf. Grundig (2015), p.160
[148] Cf. Grundig (2015), p.164
[149] Cf. Grundig (2015), p.132
[150] Cf. Grundig (2015), p.152

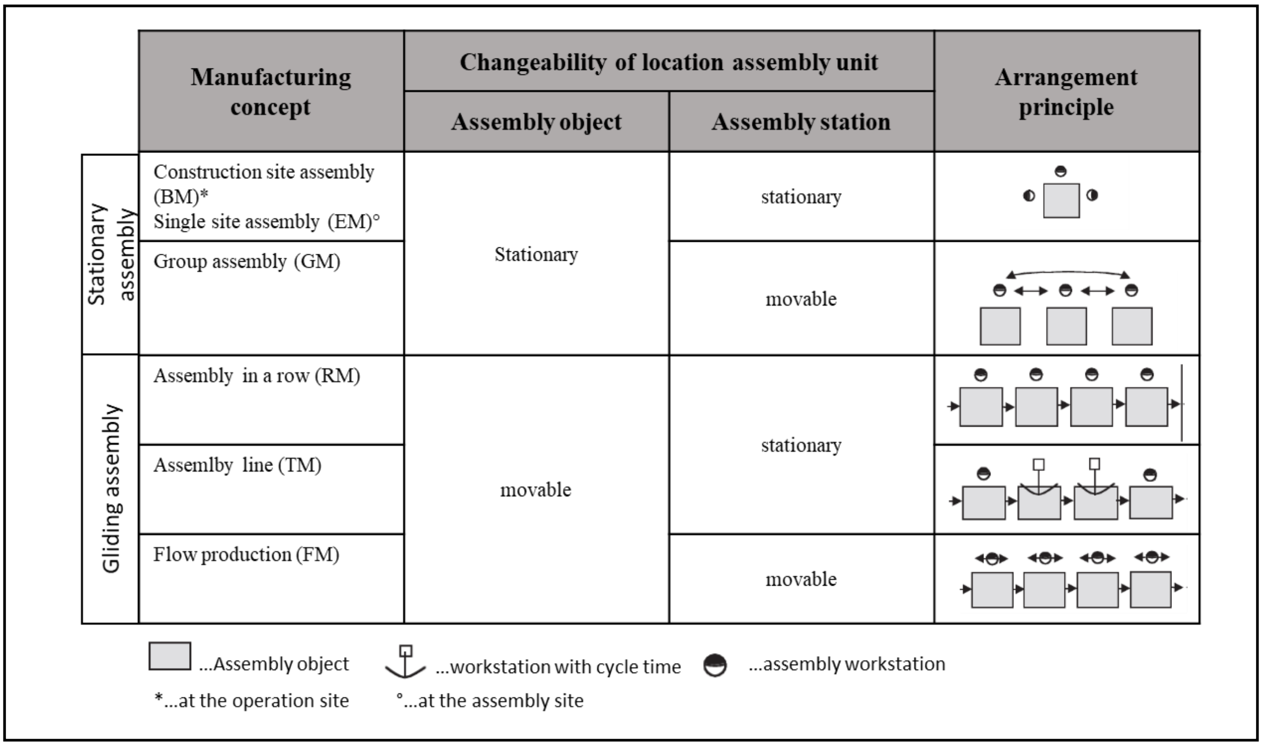

Figure 19: Manufacturing concepts for assembly[151]

The presented arrangement principles are to be regarded as abstracting basic spatial types of production forms of assembly. In conjunction with capacity and area specifications (dimensioning), they are the basis for structural planning in the context of ideal planning. In order to predetermine the type of structure, table 5 shows assignments of production forms to production types.

TYPE OF PRODUCTION	TYPE OF STRUCTURE	SPATIAL ARRANGEMENT ASSEMBLY STATION
Single-production	Construction site assembly	Point structure (cell)
Small-batch production	Single site assembly	Point structure (line)
Single-, small-batch production	Group assembly	Line
Series production	Assembly in a row	Line, ring (network)
Large series production	Assembly line	Line (network)
Mass production	Flow production	Line (area)

Table 7: Type of production and spatial arrangement[152]

[151] Cf. Own figure based on Grundig (2015), p.153
[152] Cf. Grundig (2015), p.157

In principle, assembly processes should represent a significant potential for rationalization and automation due to their considerable cost structure and high share in the value-added process, and thus special care must be given to factory planning during these processes.[153]

With the optimized material-flow and the chosen type of production, an ideal layout can be designed. The 2D layout can now be converted into a 3D layout to achieve a spatial idea of the arrangement of the structural units.[154]

With planning of an ideal layout basically two goals are pursued. On the one hand, there should be a detachment from operational blindness and the disadvantages arising from existing circumstances. On the other hand, ideal layout planning should lead to the substantial realization of the advantages of the ideal layout in real planning. The implementation of at least one rough layout variant according to the ideal layout is recommended.[155]

The ideal layout represents an idealized starting solution for the real- or detailed planning. In the most cases the ideal layout requires a clear processing.[156]

2.7.4 Real-Layout

The real layout planning of variants serves the generation and evaluation of layout and building variants, considering existing restrictions.[157]

In the planning phase of the real layout, a layout adjustment process takes place. Considering a variety of factors, the ideal layout is detailed, changed and expanded. The aim of this phase is the classification of functional units and arrangement forms in real surface and spatial structures.[158]

The layout variants obtained in this way represent realizable spatial arrangements of the structural units and pursue the goal of an overall optimum of the objective and the restrictions.[159] The different consideration of competing goals leads to solution variants with different foci. These solution variants are then evaluated on a monetary, quantitative and qualitative basis according to weighted evaluation criteria. The monetary valuation being based on an investment cost estimate. Monetary, quantitative and qualitative assessment are to be merged in order to determine the preferred variants.[160]

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[153] Cf. Grundig (2015), p.158
[154] Cf. Wiendahl et al. (2009), p.473
[155] Cf. Aggteleky (1982), p.580f.
[156] Cf. Grundig (2015), p.166
[157] Cf. VDI (2011), p. 14
[158] Cf. Grundig (2013), p. 167
[159] Cf. Schenk et al. (2014), p.341
[160] Cf. VDI (2011), p. 14 and

The approach of the real-planning is divided as following:[161]

1. Design of real-layouts (Variants)
   Adaptation Ideal layout under consideration of restriction factors and material flow principles to real area and spatial structures through the design of alternative solution variants.
2. Allocation of logistic elements
   Selection and assignment of logistics elements for material flow linkage of functional units based on material flow networking and real surface and spatial structures.
3. Choice of variants – preferred variant
   Evaluation of solution variants and derivation of the preferred variant.

In a first step, an attempt is made to implement the ideal layout within the given real area and spatial structure. As a rule, a rearrangement of structural and area units is required. This reorganization takes place under consideration and weighting of adjustment factors and material flow principles.[162] Figure 20 shows an overview of possible restrictions.

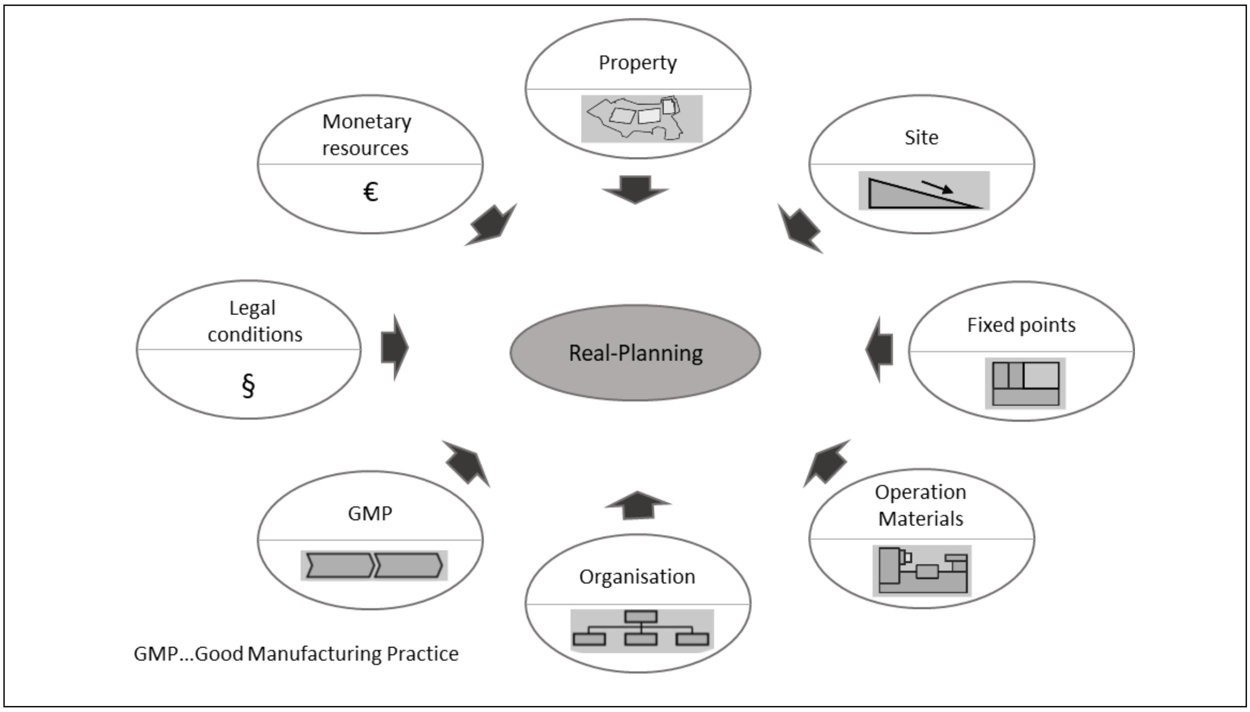


Figure 20: Restrictions in rea planning[163]

Adjustment factors:[164]

- Adjustment to shape of the building

[161] Cf. Grundig (2013), p. 167
[162] Cf. Grundig (2013), p. 168
[163] Cf. Wiendahl et al. (2014), p.501
[164] Cf. Grundig (2013), p. 171 ff. and Schenk/Wirth/Müller (2014), p. 343

- Arrangement of functional units only on assigned functional zones
- Functionally correct, location-flexible, installation-flexible arrangement of the functional units
- Connection points supply and disposal
- Selection, dimensioning and classification of logistical elements
- Compliance with general assignment and location preferences such as:
    - Goods receipt, goods receipt storage at the beginning of material flow
    - Storage for tools and devices near production area
    - Supply and disposal technique at the outermost area of the layout
    - Outgoing goods and storage at the end of the material flow
- Compliance with legal regulations
- Securing the option for future expansion
- Securing the flexibility of building and layout

Material flow principles:[165]

- Area assignment in buildings, flow-oriented in forward direction
- Enforcement of the directional flow principle
- Minimizing the required conveyors, storage and provision areas as well as the definition of main transport axes
- Securing a material flow connection of the different areas
- Provide options for expansion in the material flow
- Define the width of the transport routes sufficiently

Different methods for creating real layouts exist. The biggest difference between the methods is whether they are created manually or with the use of software. A manual method for example is the alignment of areas on paper. In that way, different variants can be created by pushing areas to different positions. With the aid of software like AutoCAD, different layout variants can be designed. Furthermore, for the visualization and simulation of the material flow within the plant simulation, tools such as PlantSim or ExtendSim can be used.[166]

After determining the ideal and real arrangement structures in the context of the structural or layout planning, the linkage elements between the structural units must be defined. The assignment of the logistical elements takes place during the layout adjustment process of the real planning. It is

[165] Cf. Grundig (2015), p.174
[166] Cf. Grundig (2015), p.175 ff.

important to make the selection for the equipment of the logistics elements and to classify them into the respective solution variant in terms of function and space.[167]

The following elements must be specified:[168]

- Transportation process
    - Determination of transportation and storage tools
    - Determination of necessary conveyers
- Storage process
    - Determination of necessary storage tools

The selection of the logistical elements usually leads to a large influence or change in the layout structures. The goal is the holistic design of the material flow processes. This requires designing cross-company material flow chains. There are internal and external material flow process to consider. Selective solutions, which only lead to partial optimization and leave the entire process unaffected, should be avoided.[169]

2.7.5 Evaluation of the Layout Variants

The variants resulting from the adaptation process are to be evaluated in terms of their advantages and disadvantages. The evaluation of the real layout variants is subject to a multiplicity of criteria, whereby a multi-dimensional decision problem exists. An assessment is made based on quantitative and qualitative variables, which are characterized by monetary and non-monetary elements. The process of evaluation is done by comparison and comparative evaluation. The goal is the well-founded selection of a preferred variant. It should be noted that many evaluation criteria are of a qualitative nature and the evaluation has a strong subjective character.[170]

The determination of the evaluation criteria has the goal of providing requirements for costing and a rating scale for planning variants. In doing so, a determination of quantitative and qualitative evaluation criteria which are suitable for the factory goals is carried out. These criteria must be weighted relative to each other.[171]

The evaluation method most commonly used in practice is the utility analysis. This method makes it possible to quantify the monetarily unquantifiable benefit of a solution variant by means of evaluation in order to support a selection decision.[172]

[167] Cf. Grundig (2015), p. 182
[168] ibidem
[169] ibidem
[170] Cf. Grundig (2015), p.201
[171] Cf. VDI (2011), p.10f
[172] Cf. Grundig (2015), p.203

The following points have to be carried out for the creation of a utility value analysis:[173]

- **Definition of evaluation criteria:** Suitable and measurable criteria are determined for the evaluation and divided into areas. In this case, a multiple capture of targets should be avoided. There are also criteria to distinguish types such as required, target and desired criteria.
- **Determination of weighting factors:** Each criterion is assigned a weighting, with the increasing utility being assigned an increasing numerical value. One method for determining the weighting is the pair comparison method.
- **Execution of the evaluation:** Each evaluation criterion of each variant is evaluated by points.
- **Determination of the utility value:** The multiplication of the individual evaluations with the associated weighting factor results in a utility value for the respective evaluation criterion. The sum of these individual utility values for a variant gives the total utility value. The highest total utility value is subjectively the most suitable variant.

2.8 Detailed-Planning

As part of the detailed planning process the previous planning principles are checked, supplemented and detailed. The selected rough layout can therefore be further developed and refined.[174] The methods and tools to be used correspond to those of the rough planning.[175] The results of the detailed planning are ready-to-implement and ready-to-realize planning documents.[176]

In the fine planning phase, a demand-oriented and undisturbed interaction of people, equipment and material must be guaranteed at each workstation. The results of the detailed planning phase form the basis for decisions to approve the project for the subsequent stages of project implementation.[177]

Because of the enormous scope of work, a subdivision of the further planning work is generally made in the most important operating functions:[178]

- Manufacturing- and assembling system
- Material-flow-, storage- and transportation system

[173] Cf. Zangemeister (1976), p.45ff.
[174] Cf. Kettner et al. (1984), p. 26
[175] Ibidem
[176] Cf. Grundig (2015), p. 208
[177] Cf Gundig (2015), p. 209
[178] Cf. Pawellek (2008), p. 188 and Schmidt et al. (1984), p.26 f.

- Organization-, planning-, steering system
- Building system and infrastructure

The detailed layout includes the following information:[179]

- Location and dimensions of all equipment, machines and workplaces
- Building information (room height, arrangement of windows, stairs, etc.)
- Transportation routes
- Safety related objects (escape route, fire protection, etc.)
- Supply and waste pipelines (air, compressed air, chips, etc.)

In the detailed layout, all areas are bindingly dimensioned and the architectural, technical, economic and legal problems are clarified in the planning application. Any possible impossibilities regarding capacity or performance differences, climatic conditions and disruptive factors such as vibrations and vapors are eliminated. In addition, the subject-specific plans and documents for the areas of construction planning, operational planning, scheduling and cost planning will be coordinated.[180]

The entirety of the created documents form the final solution which can now be implemented. This is thus an exact, ready-to-use final design of the solution. Experience shows that the more detailed the detailed planning, the easier and faster the solution can be implemented.[181]

2.9 Execution Planning

The implementation planning contains all preparatory activities for the structural realization of the planning project. In addition, all necessary measures to ensure on-time and complication-free execution are to be initiated in this phase.[182]

The tasks of the execution planning include, amongst others:[183]

- Check and adjust existing planning documents
- Continuation the operational planning: preparing the requirement lists, detailing the assembly plans for the operating areas
- Structure and define work packages
- Obtaining permits
- Relocation planning

[179] Cf. Ketter et al. 1984), p. 28 f.
[180] Cf. REFA (1985), p. 208 f.
[181] Cf. Grundig (2009), p. 2016
[182] Cf. REFA (1985), p. 222
[183] Cf. Grundig (2015), p. 217 ff.

- Set the schedules

This means that all preparatory planning-related activities for the organizational, technical and structural realization of the planning object are included. Execution planning has the goal of timely implementation of the planning object.[184]

2.10 Execution

As part of the execution the creation of the structural site, constructions and installations, the installation of technical equipment and facilities as well as the execution of relocation are carried out.[185]

In the case of large projects, very often a separate project management is set up, which should ensure a smooth process as well as the adherence to deadlines and costs during this phase.[186]

The execution phase can be divided into three sections.[187]

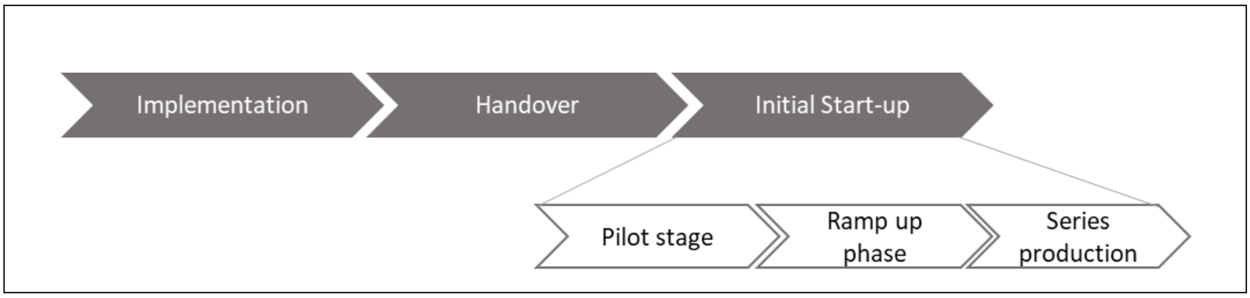


Figure 21: Subdivision of execution phases[188]

The implementation phase deals with building, installing, moving, and facilitating activities. It controls the work, monitors the implementation status, the final check and approvals.[189]

The handover of the entire plant will take place after the execution of the works and the acceptance, during which logs of defects and their deadlines will be prepared for disposal. All planning and execution documents as well as warranty declarations, maintenance regulations are handed over to the client in this phase.[190] The focus of this phase is to make sure that all processes are secure. To fulfil that, interim and final checks are required.[191]

[184] Cf. Grundig (2015), p. 217
[185] Cf. REFA (1985), p.222
[186] Cf. Pawellek (2014), p. 336
[187] Cf. Grundig (2015), p. 219 ff.
[188] Cf. own figure based on Grundig (2015), p.219 ff.
[189] Cf. Grundig (2015), p.219 f.
[190] Cf. REFA (1985), p.230
[191] Cf. Kettner et al. (1985), p. 30

The initial start-up phase represents the start of production. It is divided up into three phases.[192] By reaching the series phase, the project is given formal authorisation. Finally, control and evaluation of the planning process are carried out regarding the degree of fulfillment of the initially formulated project goals. Part of the assessment is a root cause analysis of target deviations, such as schedule delays or cost overruns. Furthermore, a preparation and documentation of the knowledge acquired during the factory planning process for utilization for future applications takes place. This is summarized in the final documentation of the project.[193]

[192] Cf. Grundig (2015), p. 219 f.
[193] Cf. VDI (2011), p. 21 f.

2.11 Conclusion of the Literature Research

As part of the literature research on the subject of factory planning, the works of various authors were examined. It was identified that the approaches of different authors have many similarities with regard to the approach for factory planning. However, as already mentioned in chapter 2.4, most of the planning approaches are top-down oriented. As a rule, an ideal concept is worked out. Only the planning approach which is examining from the beginning the strengths and weaknesses of the current situation and respecting them while planning the target layout is the counterflow planning process by the RWTH Aachen.

In the context of this work, as can be seen in the following chapters, the arrangement of an ideal layout according to the procedure of the classical theory was not possible as the necessary data, concerning material data was not available. For this reason, the planning approach of this project was more "bottom-up" then "top-down" oriented.

That means that from the start of the current-state analysis, the strength and weaknesses of the current situation have been analyzed and summarized in a catalog of requirements for the new layout (see chapter 4.2.7). This also includes the analysis and when necessary the optimization of current assembly processes already in the early stage of the planning process (see chapter 4.2.4).

For the investigation of the production program, the usage of the ABC-Analysis was waived because only the assembly of important products have been considered for the planning process. Instead of that in the early stage the required number of assembly areas as have been dimensioned already on the basis of the production program (see chapter 4.3.2).

In the dimensioning phase the strengths and weaknesses of the current state analysis were taken into consideration. The dimensioning of the required assembly area was carried out based on theory but also took into account the experience of the employees and under consideration of real restrictions such as the sizes of individual parts. (see chapter 4.3.2)

The structuring of the assembly units was not possible in terms of an optimal material flow explained in the literature because of the missing material data. Instead, the shortest distances between the relevant components have been achieved, as well respecting the accessibility of individual assembly stations with forklift trucks or with the already existing crane system.

In summary, the applied planning approach was a mixture of classical "Top Down" approaches with elements of "Bottom-Up" approaches to create a new, optimized and value-oriented target plant layout.

3 Work Package I – Material Flow Planning

This chapter concerns the solution of the practical task assignment (see chapter 1.1) using the theoretical foundation described in chapter 2. The first chapter explains the approach and results of Work Package I.

3.1 Objective and Approach

Work Package I includes a detailed analysis and investigation of the current material flow within the company's production network. The data provided by the company served as the basis:

- Article structure incl. modules (Bill of materials)
- Production programme and planned quantity structure (for the year 2018)
- Structure of order incl. order distribution
- Total process time (REFA-time measurement or current specified time as basis)

Figure 22 shows the objectives and the approach of the material flow planning.

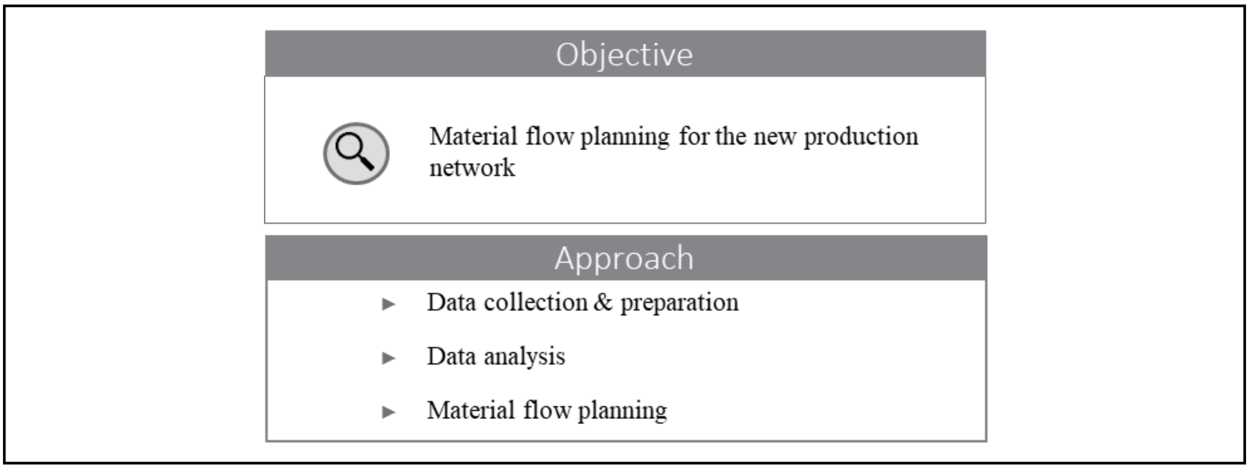


Figure 22: Objective and approach of the Work Package I

3.2 Collection and Processing of Data

The current production network of the company comprises four plants: Plant 1 and Plant 2 in Slovenia, Plant 3 in Austria and Plant 4 in Germany. In order to plan the future distribution of material, the current material flow between the plants should be defined and analysed. Plant 1 currently includes the steel construction for individual parts and assemblies, which are relocated to Plant 2 in Slovenia after being processed. It is planned that all components and assemblies which were manufactured in-house will be painted in Plant 2. Furthermore, individual F-products and assemblies are pre-assembled in Plant 2 and subsequently transported to Plant 3 in Austria for final assembly. F-articles are main assembling modules of the individual machines. Plant 2 includes the pre-assembly for the product groups CR, AX and TR. In addition, the TT product family is completely assembled at Plant 2. As part of the project Reloaded, the machinery which are currently being assembled at Plant 3, are to be relocated to the environmental technology assembly at Plant 2. In the future, only prototypes will be manufactured and the service for machines will take place in Plant 3. Figure 7 shows the production network as it is planned in the future.

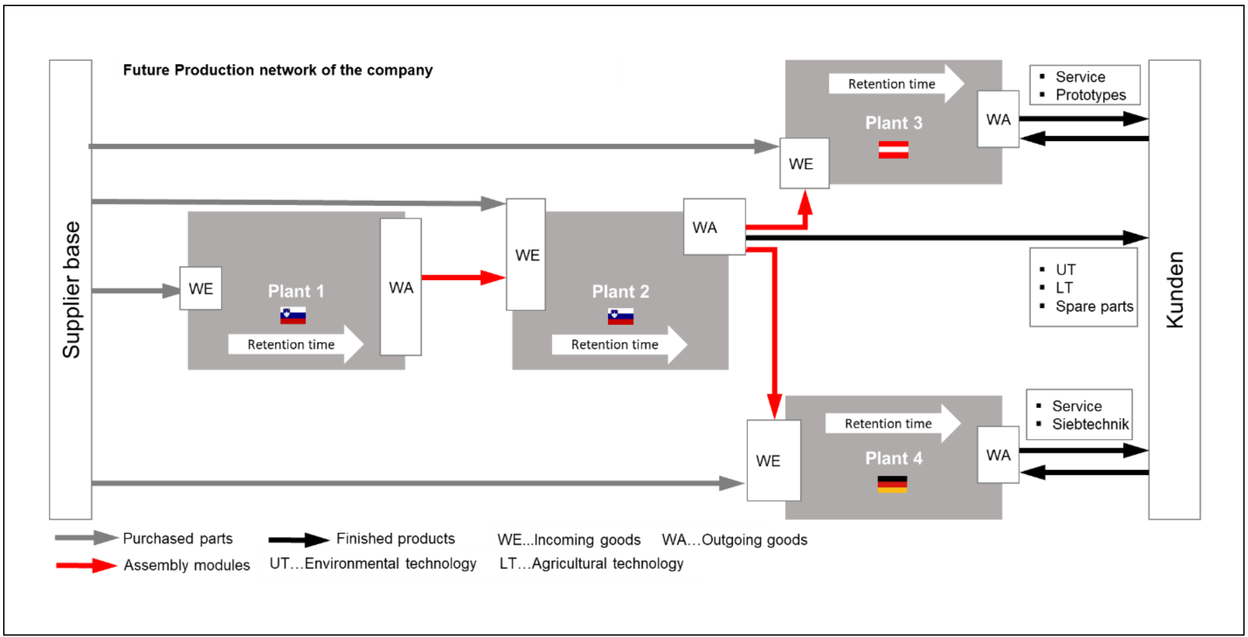


Figure 23: Future production network of the company

The objective of Work Package I was to define the current flow of material between the plants in order to obtain an overview of the required charge carriers and charge volumes. As a basis for the analysis, the bill of materials of the individual products of the company were handed over to the project team of the Graz University of Technology.

As the first step in the data analysis, the bill of material for the product AX was analysed. The aim of this analysis was to break down the individual main assemblies into their individual parts and to identify the place of manufacture and the place of further processing. During the analysis of the bill of materials, some challenges arose. These challenges did not allow a standardized material flow analysis. In the further progression of this project these challenges were presented to the company and a catalog of recommendations for action was created, which sought to help the company change the current data structure in future projects. In total, six problems were identified, which are explained in more detail in the following chapter. These issues occurred in all bills of material submitted by the company for each machine. For each of these issues, the effects were identified and a corresponding recommendation for action was drawn up. Before the identified challenged are explained in more detail, the current structure of data at the company is explained in the following chapter.

3.3 Current Structure of the Bill of Materials

Before discussing the problems encountered when analyzing the BOMs, the current structure of the BOMs is shown in this chapter. Figure 8 shows the example of the product AX for the BOM for Slovenia with its most important components. It is to mention, that the company maintains two kinds of BOMS (see chapter 3.4).

Step	Plant	Component number	Object short text	Key number
1	1200	FAX60K003	Siebkorb 100mm x 100mm	FAX60K0031200
1	1200	FAX60R001	Reibboden geschlossen	FAX60R0011200
1	1200	FAX60UT	AX 6010 Trailer	FAX60UT1200
1	1200	FAX60Z012	Planetengetriebe für 2 Trommeldrehzahlen	FAX60Z0121200
1	1200	FAX60Z021	Verkleidungsblende Vorfahreinrichtung	FAX60Z0211200
1	1200	FAX60Z111	Abwurfband 5,5m	FAX60Z1111200
1	1200	FAX60Z057	Schurrenbleche Abwurfband	FAX60Z0571200

Figure 24: Extract of the bill of material for the product AX

The BOMs are generally intended to be read from top to bottom. The level indicates the respective production level. Thus, the F-articles, which represent the main assemblies have level one. These will then be broken down into their components as the BOM progresses. In addition, the component numbers and a short description of the object are specified.

In addition, the procurement type or information about the stock transfer is specified for each assembly and individual parts. An individual part or an assembly can be marked with "E" or "F" as the procurement type. "E" means that the respective part is self-made, whereas "F" means that the part was procured externally. In addition, the combination can occur with "F" as the procurement type and with "41" or "50" in the case of special procurement. This means that the respective part or assembly has been relocated from another plant (see Fig. 9). Information regarding dimensions and weight is given in the parts lists. It is important to mention that the parts lists contain so-called dummy modules. The definition and effects of these assemblies are described in more detail in chapter 3.5.

Componente number	Object short text	Procurement type	Special procurement	Planat	Addition
FAX60K003	Siebkorb 100mm x 100mm	E		1200	Eigenfertigung
FAX60R001	Reibboden geschlossen	E		1200	Eigenfertigung
FAX60UT	AX 6010 Trailer	E		1200	Eigenfertigung
FAX60Z012	Planetengetriebe für 2 Trommeldrehzahlen	E		1200	Eigenfertigung
FAX60Z021	Verkleidungsblende Vorfahreinrichtung	E		1200	Eigenfertigung
FAX60Z111	Abwurfband 5,5m	E		1200	Eigenfertigung
FAX60Z057	Schurrenbleche Abwurfband	E		1200	Eigenfertigung
FAX80Z100	Funkfernsteuerung AXTOR	E		1200	Eigenfertigung
FAX80Z150	Verstärkte Zugöse 50	E		1200	Eigenfertigung
FAXS603A	AX 6010 Tier 3/Stufe IIIA	E	50	1200	Dummybaugruppe

Figure 25: Extract of the bill of material for the product AX with different contens

In the following chapter, the difficulties in the data structure are described in more detail.

3.4 Plant Allocation of Current BOMs

Current state

The company currently maintains two different bills of materials for its products in its data structure: Bill of Materials 1200 is used for the plant in Austria, and bill of Material 3200 is used for the plant in Slovenia. The difference between these two lists is that the Slovenian list also lists the raw materials used for the components manufactured in Slovenia. In the current data structure there is currently no distinguishment between Plant 1 and Plant 2 in Slovenia. There is only a list of assembly contents with a coding system for the individual workstations, at which the raw materials are processed or assemblies or individual components are finsished. It should be noted that the bills of material of the company were not only used as a production BOM but also for distribution and construction all in one list.

Impact

In order for each work step to be assigned to a plant (either the Austrian or Slovenian plant), the BOM's with all components would have to be considered and compared individually. Currently, however, it is still unclear from when a component is installed and in which factory, as some assemblies are partially assembled in one factory, but are finally assembled in another. The analysis of the material flow between plants 1 and 2 is not possible with the current BOMs, since the two plants are considered as the same plant in this data structure. The transfer of components between Plant 1 and Plant 2 is not defined in the BOMs. Currently, the components are being transferred from Plant 1 to Plant 2 after being processed to be painted. However, there is no data collection on the current storage location, neither for Plant 1 nor for Plant 2. Another problem is that the transportation of components between plants by truck are unplanned.

Recommendation for action

In order to counteract the current data structure with the two different bills of material for Austria and Slovenia, the two bills of material are to be dissolved and the parts and assemblies to be recorded in a single BOM for each product. For this data acquisition, a production BOM is to be created which contains only content relevant to the production. In addition, sales and construction should have their own bill of materials.

3.5 Dummy-Modules

Current state

The BOM for Slovenia and Austria contain so-called dummy modules. These only represent a constructive level where it is neither self-manufactured nor externally produced. When a new order is received, this level is skipped and the components of the product ordered are now needed. It should be mentioned here that dummy modules are generally not ordered. These dummy modules have no relevance for production. The individual groups in turn consist of further dummy modules. However, the designation of the article number does not apply to the dummy modules, making a standardized analysis of the parts lists impossible.

Impact

Dummy assemblies prevent transparency of material flow, as they are fictitious. There is no connection between the article numbers of dummy modules and those of real components, thus making standardized material flow planning more difficult using BOMs. The following figure shows an excerpt of a bill of material and three difficulties, which are described in more detail below.

①   ②   ③

Step	Plant	Component number	Object short text	Key number
1		FAX60UT	AX 6010 Trailer	FAX60UT
2		B00003964	Deichsel kpl	B00003964
3	1200	249140000C	Deichsel sz	249140000C1200
3	1200	910124016	Sechskantschraube M24x160	9101240161200
3	1200	910124005	Sechskantschraube M24x130	9101240051200
3	1200	910124011	Sechskantschraube M24x40	9101240111200
3	1200	911224001	Scheibe A25 (M24)	9112240011200

Step...Hierarchical breakdown of assemblies and subassebmlies

...Dummy assembly Deichsel kpl

Plant	
1200	Austria
Component number	
B....	Dummy module

Figure 26: Excerpt of a bill of materials and three challenges

1. As an example, the dummy assembly "*Deichsel komplett*" is used. This module is fictitious and therefore not relevant to production. This consists of a "*Deichsel sz*," "*Sechskantschaube M24x160"* etc.
2. No plant assignment is possible because it is not a real assembly. A dissolution of the dummy modules and a content assignment to workstations would correspond to the actual production.
3. The logic of the article number designation does not apply to dummy modules. The current name is structured as shown in the following figure:

www – x – yyyy - z

a b c d

a) Type of Machine b) Function module

c) Parts allocation to functional modules

d) Revision level

Figure 27: Current logic of the article number designation

Recommendation for action

In order to counteract the problem regarding the dummy modules and their consequences, these problems should be resolved in the BOMs. As an alternative, real assemblies should be created and workspaces must be clearly assigned. The basis for this new structure could be the REFA time recording system. For the designation of the individual components and assemblies, a uniform system should be used for all elements in order to ensure transparency.

3.6 Workstation Assignment

Current state

Currently, the areas where individual parts and welded assemblies are assembled are not known. Only the coding system for the workplaces in Plant 1 and for the final assembly exists. In addition, the sequence in the progression of work stations is currently not visible and the current cost center list for the work stations is not complete. Furthermore, the process "painting" in Plant 2 is currently not recorded in the system.

Impact

It follows that the sequence of the work steps is not recognizable, and which workpieces are painted after which step is also unknown. The following figure shows the current status in the current BOMs and the resulting challenge.

Description of Work Station (WS)	Nr. WS	Material Short Text	Plant	Component
Presse Exzentrisch 315T	1305	Stirnwand h	3200	167120025A
Biegemaschine ZA 650Tx6200 RNC	1425	Stirnwand h	3200	167120025A
LASER 1500x3000 (4KW)	2595	Stirnwand h	3200	167120025A

Plant	
3200	Slovenia

1

Figure 28: Description of work stations

1. Different components each perform different jobs. However, the process order is not apparent from the bill of material.

Recommendation for action

The order of the workspaces including the coating must be defined in the BOMs. In addition to the work center, the (destination) storage location should be defined after the respective work step. Thus, the material flow for the individual parts / assemblies would be comprehensible. The following structure for the storage location-/ workstation assignment using the example of AX, substructure "*Deichsel sz.*" as an example, was determined (see Fig. 29).

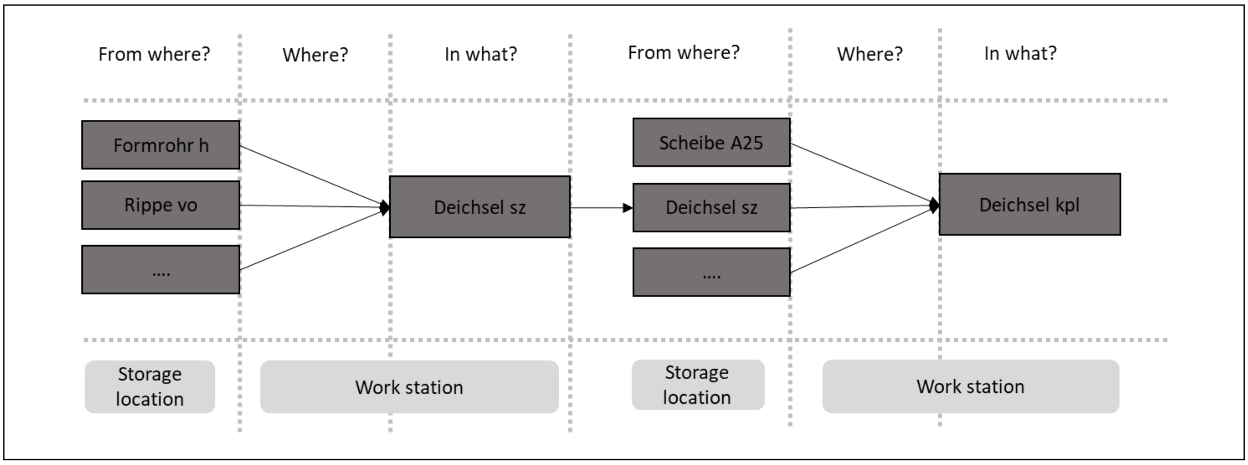


Figure 29: Proposal for allocation of storage location and workstation

This description of articles would provide improvements regarding:

- Assignment of workstation
- Clear definition of the process order
- Clear definition of storage locations

3.7 External Procured Materials/Relocation/Subcontractor

Current state

Externally procured items are single parts or assemblies that are purchased externally. Items listed with 'Stock Transfer' are relocated between plants. Items that are labelled as 'Subcontractor' are provided for external processing. The BOMs also list the individual parts that are integrated in externally procured assemblies. This is to simplify the procurement of spare parts, but prevents the transparency of the BOMs and is irrelevant to a manufacturing list. The BOMs do not contain any information about the place of delivery (plant) on which the individual parts or assemblies are delivered.

Impact

BOMs do not contain production-relevant information. Furthermore, errors occur in the consistency of the externally procured components in the parts lists. As an example, the welded component *"Siebkorb sz."* is externally procured according to bill of materials 1200 (Austria). In the parts list 3200 (Slovenia), the items are self-made. Since no information regarding the delivery / storage location is given, the material flow is not recognizable. The following figure shows an example of the error source "*Siebkorb sz"* in both parts lists.

Extract BOM Austria

Step	Object ID	Assembly	Production type	FR
1	FAX60K003	Siebkorb 100mm x 100mm	in-house production	
2	249933000B	Siebkorb 100x100 sz	externally procured	X
2	249933000B	Siebkorb 100x100 sz	externally procured	
3	249933010	Siebkorb 1100 100x100	externally procured	X
3	249931020	Befestigungsblech	externally procured	X
3	249931030	Seitenblech a	externally procured	X
3	249931040B	Seitenblech i	externally procured	X

①

Extract BOM Slovenia

Step	Object ID	Assembly	Production type	FR
1	FAX60K003	Siebkorb 100mm x 100mm	in-house production	
2	249933000B	Siebkorb 100x100 sz	externally procured	
2	249933000B	Siebkorb 100x100 sz	externally procured	
3	249933010	Siebkorb 1100 100x100	externally procured	
3	249931020	Befestigungsblech	in-house production	
3	249931030	Seitenblech a	in-house production	
3	249931040B	Seitenblech i	externally procured	

② ③

FR…Component is relevant for processing in the respective plant
Step…hierachical breakdown of assemblies and subassemblies

Figure 30: Extract BOM Austria and Slovenia referring to externally procured components

1. *"Siebkorb 100x100 sz"* is defined as externally procured in the bill of materials 1200 (Austria). The parts of the externally procured component are listed in the bill of materials, although they have no relevance to the production. These items are also referred to as externally procured.
2. In the bill of materials 3200 (Slovenia), the "*Siebkorb 100x100 sz"* is also labelled as externally procured.
3. The items of *"Siebkorb 100x100"* are partially labelled in the bill of materials 3200 (Slovenia) as in-house. This represents an error in the data acquisition.

Recommendation for action

In the future, the delivery and storage locations should be clearly defined. Assemblies which are procured externally should no longer be broken down into their individual components in the production BOM. Individual components and assemblies are to be designated according to the following structure:

- Externally procured parts (purchased externally) = FB
- Rearrangements between plants = U1, U2, U3, U4
- Subcontracting = LB

3.8 FAXS(set)-Articles

Current state

FAXS products are functional assemblies whose parts and assemblies are either partially finished or finished in Plant 3, as well as Plant 2 and Plant 1. There is current no transparent limit in the BOMs as of which process step the FAXS (set) article is assembled / processed in which plant. These modules appear in the list 1200 and 3200 as in-house production with production-relevant dummy modules.

Impact

If assemblies or individual components are transferred between plants, it is not clear from the data structure between which two plants and at what stage the rearrangement takes place.

Recommendation for action

In the future, the workplaces where the individual parts are assembled will be clearly defined. If the two BOMs are resolved into a total BOM, the problem of the FAXS article is also resolved.

3.9 Proposal for an Improved Structure of Data

Appropriate recommendations for action were identified for the challenges identified during the current state analysis. The following figure gives an overview of the structure of the material tree and the information for the individual parts and assemblies. The numbers inside a red circle represent the respective challenges and the corresponding recommendations for action, which were shown in the previous chapter.

(1) …Plant allocation of current BOMs (see chapter 3.4)

(2) …Dummy-modules (see chapter 3.5)

(3) …Workstation assignment (see chapter 3.6)

(4) …External procured materials/relocation/subcontractor (see chapter 3.7)

(5) …FAX(set)-articles (see chapter 3.8)

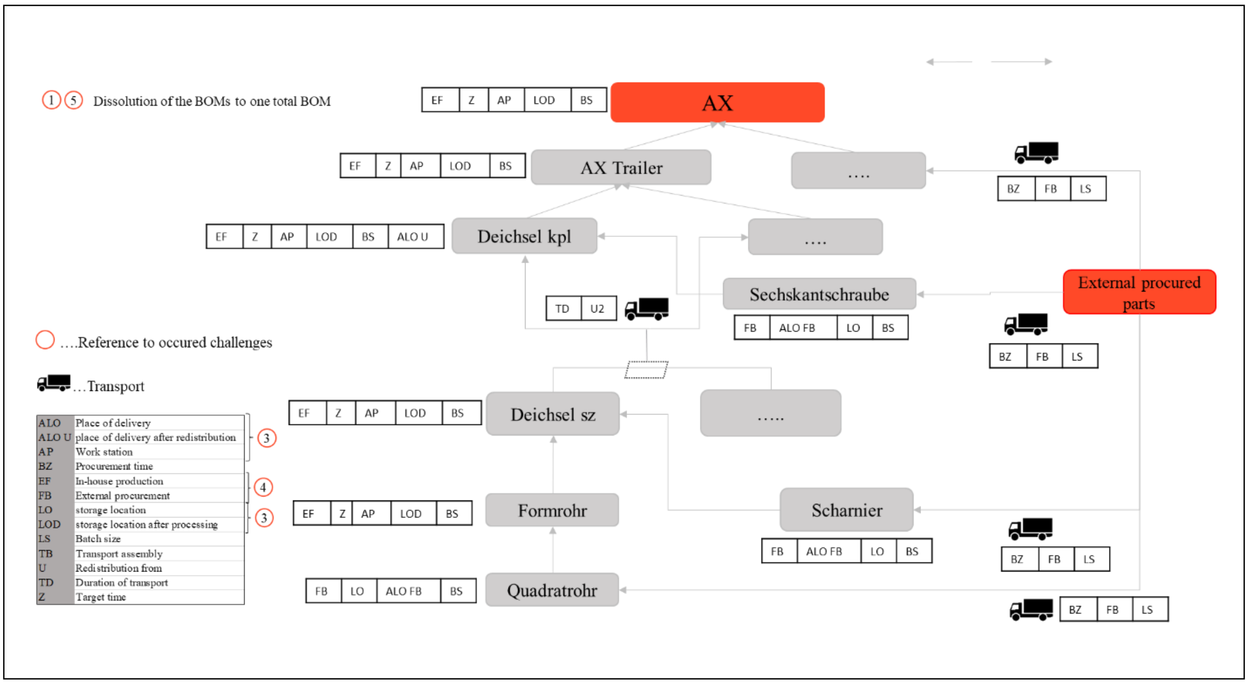


Figure 31: Proposal for a material tree with relevant infromations

For an optimized BOM, in which the recommended actions are included, the structure would look like the following figure. This provides information about the storage locations, workplaces, throughput times, component specifications and type of procurement.

The following scheme is suggested for the structure of the component designation:

New designation of components:

<u>XXXX</u> - <u>YY</u> - <u>ZZ</u> - <u>WW</u> - <u>VV</u> – <u>SSHHHH</u>

XXXX ....Designation for F-Article
YY ....Assembly 1
ZZ ....Subassembly 1
WW ....Subassembly 2
VV. ....Subassembly 3
SS..........FB/EF

Figure 32: Propsoal for the new article structure

With this new article structure, a clear assignment of individual components to assemblies and the corresponding F article is possible.

3.10 Summary of Results

The aim of Work Package I was the analysis of the current material flow within the company production network on the basis of existing data. The results of this should create the basis for the subsequent layout planning.

The company handed over the following data for Work Package I:

- Article structure including assemblies
- Production program and planned quantity structure
- Order structure including order distribution
- Order time (based on REFA time measurement or current default times)

The first step of the planned approach was the collection and preparation of data. This was followed by the analysis of this data and subsequent material flow planning. However, Work Package I was discontinued after data collection and processing as the data transmitted did not allow a standardized analysis. The result was the recommendation for an improved data structure. Figure 33 once again shows a summary of all problem areas, the resulting effects and the resulting recommendations for action.

	Current State	Impacts	Recommendation for action
Bill of Materials	► Two different BOMs for one product (Austria/Slovenia) ► No separation between plant 1 and plant 2 in the data acquisition ► Existing BOMs are not production BOMs	► Assignment of the work steps between Frohnleiten and Slovenia at great expense ► Allocation of work steps and storage location in plant 1 and plant 2 (both Ljutomer) not possible	► Dissolve the two BOMs ► Recording of parts / assemblies / ... in only one complete BOM per product ► Creation of production BOMs with exclusively production-relevant content
Dummy-assembly	► BOM contains fictitious assemblies ("dummy assembly") ► Dummy assemblies are not relevant for manufacturing ► Dummy modules in turn consist of further dummy modules ► The logic of the article number designation does not apply to dummy modules	► Transparency of the material flow is prevented ► No connections between article numbers of the dummy modules and the article numbers of real components	► Dissolve the dummy modules in the BOMs ► Create real assemblies with clearly defined workspace assignments ► The REFA time recordings can serve as the basis for the new structure ► Uniform system for the creation of article numbers for all elements of the BOM
Workstation allocation	► Mostly, there are no work assignments for individual parts and welded assemblies ► No recognizable order in the sequence of working stations ► No comprehensive cost center list for jobs ► Process "paint" in plant 2 not recorded in the system	► Process sequence of the work steps not recognizable ► Not visible which workpieces are painted after which step	► Determine workplace order (including painting) ► In addition to the work center, define the (destination) storage location after the respective work step ► Thus, the material flow for the individual parts / assemblies can be comprehended
Procurement	► BOM contains non-relevant items from external procured assemblies ► No information about the place of delivery (	► Non-production-relevant information in the parts lists (source of error) ► Material flow not recognizable due to missing delivery / storage location information	► Definition of the delivery / storage location ► externally procured assemblies should not further be broken down ► Designate assemblies and individual components according to the following structure: ► Externally procured parts (externally purchased) = FB ► Rearrangements between the plants = U1, U2, U3, U4 ► Wage provision = LB
FAXS(set)-Article	► No transparent bound from which process step the FAXS (set) article is installed / processed in which plant ► Assemblies appear in the list 1200 and 3200 as in-house production with production-relevant dummy modules	► Rearrangement between production locations from data structure not clearly recognizable	► Creation of clearly defined workplaces for respective individual parts and assemblies ► A resolved bill of material (BOM) solves the problem with the FAXS articles

Figure 33: Summary of identified challenges, impacts and recommendation for action

4 Work Package II – Layout Planning

After a provisional completion of Work Package I, Work Package II was continued. Work Package II is divided into the following three phases:

1. Analysis of the current state (see chapter 4.2)
2. Rough layout planning (see chapter 4.3)
3. Fine (detailed) layout planning (see chapter 4.4)

4.1 Impact of the Challenges

The challenges encountered in Work Package I influenced Work Package II. The following challenges had an impact on Work Package II:

Challenge: With the current data structure, it is unclear which components are needed for each work step

Impact: Production planning and balancing of the line assembly cannot be carried out with a high degree of detail.

Challenge: No transparent distinguishment between process steps and at which plant the FAX(set) articles are assembled and processed

Impact: It is not known which parts are assembled/processed in the pre-assemble and main-assemble

Challenge: In the case of externally procured/redistributed parts, no information about the place of delivery is available in the bill of materials

Impact: Material flow is not recognizable due to missing delivery/storage location information

Challenge: No work assignments for individual parts and welded assemblies

Impact: No workstation assignment for pre-assembly

The first step in the layout planning was the analysis of the current state of the relevant Plants 2 and 3. The approach and results of this planning phase are explained in detail in the next chapter.

4.2 Analysis of Current State

The analysis of the current state of plant 2 and 3 includes a detailed examination and investigation of the current production program, the means of production and the assembly processes.

Several visits to plants 2 and 3 provided a good insight into the production program and the various assembly processes. Subsequently, the master and production data provided by the company were analysed. Based on the investigation of the current state, optimization potentials were derived, which were incorporated in the brownfield layout planning. The goals and procedure of the analysis of the current state are shown in Figure 20.

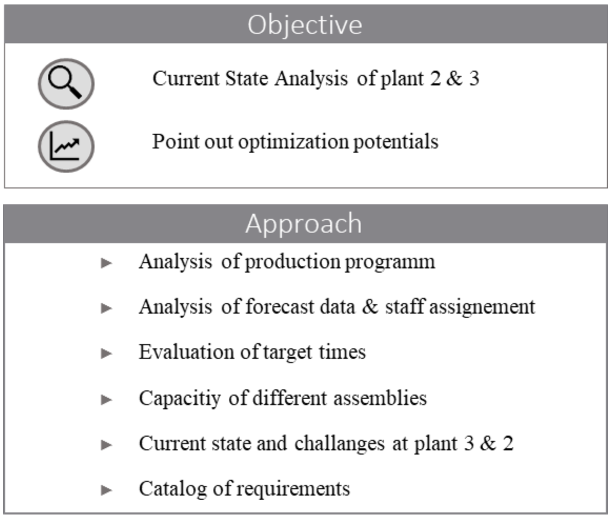


Figure 34: Objective and approach of the current state analysis

4.2.1 Production Program

For the analysis of the production program the company provided the following data:

- Order quantity in the last business year (2017)
- Order situation for the business year 2018
- Forecast until 2025 (6% annual increase)

A goal of the layout planning in the context of the project was to make a statement about the future capacity utilization after the restructuring in Plant 2. An important aim was to meet the order demands for the year 2018, as this year the number of machines to be produced is known. The table below shows the number of machines produced in 2017 and the forecast for 2018. The products CR/TR are listed togethers, as they have the same target times.

YEAR	AX [#]	CR/TR [#]	TT [#]	TOTAL [#]
2017	17	50 CR 28 TR	35	130
2018	17	63 CR 48 TR	43	171
2020	19	71 CR 54 TR	49	193

Table 8: Number of machines produced in 2017 and the forecast for 2018

As can be seen in the table above, the number of machines to be produced will increase by 25% in 2018. In order to make a realistic forecast for the year 2025, the number of machines to be produced was calculated with an annual increase of 6%. Figure 21 gives an overview of the percentage of machines produced in the business year 2017 and the order situation for 2018. It should be noted that production of the CH machinery group will cease in 2018 and will therefore not be considered further in this project.

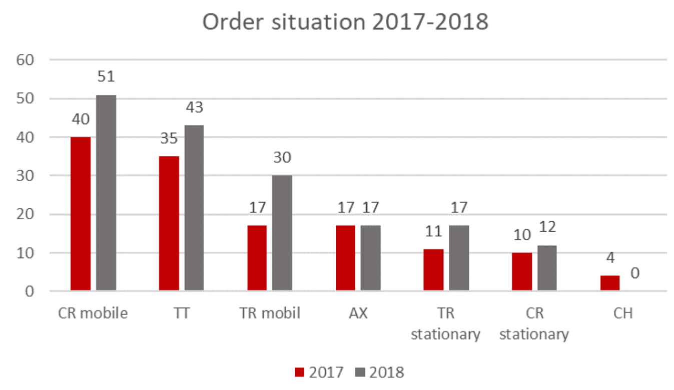


Figure 35: Order situation for 2017-2018

4.2.2 **Limitation of the Production Program**

Work Package II deals with the re-planning of the assembly of environmental technology products in Plant 2 (Slovenia). Currently, the product families AX, CR and TR are assembled at Plant 3 (Austria). The TT is fully assembled in Plant 2. Individual pre-assemblies for AX, CR and TR are also pre-assembled in Plant 2. The planned restructuring aims to relocate the final assembly from Plant 3 to Plant 2. Table 9 shows the machines that are considered in this project and the previous distribution of the assembly contents to the plants.

TYPE OF MACHINE	PLANT 2	PLANT 3
AX	Pre-assembly	Final assembly
CR mobile	Pre-assembly	Final assembly
CR stationary	Pre-assembly	Final assembly
TR mobile	Pre-assembly	Final assembly
TR stationary	Pre-assembly	Final assembly
TT	Final assembly	

Table 9: Distribution of the assembly contents to the plants

4.2.3 Current Staff Assignment

The company handed over organizational charts concerning employees from both plants.

Plant 2: The following table shows a rough overview of the number of employees and their activities in Plant 2. The employees are defined according to their main assembly activity and used as required. Thus, e.g. the employee who is responsible for paint repairs, also install CR and TR.

PLANT 2	CR/TR	TT	AX	LANSER	CLADDINGS	QUALITY-CONTROL
Employees [#]	3	10	2	1	2	1
Total [#]				**19**		

Table 10: Overview of the number of employees in Plant 2

Plant 3: The work assignment is better organized at Plant 3, which currently comprises four assembly teams. Each of these teams is responsible for two assembly stations and is divided into these two assembly locations depending on the assembly contents and requirements. Six electricians are responsible for the electrical installation. However, an electrician is always responsible for one machine from the start of the installation to the end of the electrical installation. The four assembly teams consist of the following number of employees:

- Team 1: 3 mechanical fitters (responsible for assembly area 1 and 4)
- Team 2: 3 mechanical fitters (responsible for assembly area2 and 5)
- Team 3: 4 mechanical fitters (responsible for assembly area 3 and 6)
- Team 4: 5 mechanical fitters (responsible for assembly area 7 and 8)

Three employees are responsible for the pre-assembly of the engine and the belts. Two employees are scheduled for the quality control process. Summarized in Plant 3, currently 25 employees are responsible for the assembly, electric installation and the final check.

In order to plan the necessary capacity of the factory, the net performance share in hours per employee is essential. This was set at 1290 h per employee per year and is based on the average in the past six years. This value takes into account holidays, 5% sick leave and 15% auxiliary process time. With 15% personal allowance time there is still potential to increase the net performance share.

With 1290 hours of capacity, capacity utilization was calculated later.

4.2.4 Editing of REFA Target Time

As no working plans for the assembly of the product families AX, TT, CR and TR are available, the REFA time measurement was taken to account in order to examine current processes. The company handed over data from a REFA time study, which was carried out for the TT, CR and AX machines, both at Plant 2 and at Plant 3.

No REFA time study was carried out for the TR product family, but the target time for CR should be used for the consideration and planning of the factory layout. The assembly contents of the TR are almost identical to the CR.

In future, times measured from the REFA time study should serve as the target time for the assembly. The aim of the analysis of the REFA time study was to define the sequence of steps in the assembly process and to separate possible assemblies as pre-assembly from the main assembly and to shorten in this way the lead time of the products. The REFA time study includes the F articles of the respective assemblies, but no sequence of the assembly process was recognizable. The following figure shows the process of preparing and analysing the existing data. The data analysis is discussed in more detail in chapter 4.3.3 in the selection of the pre-assemblies.

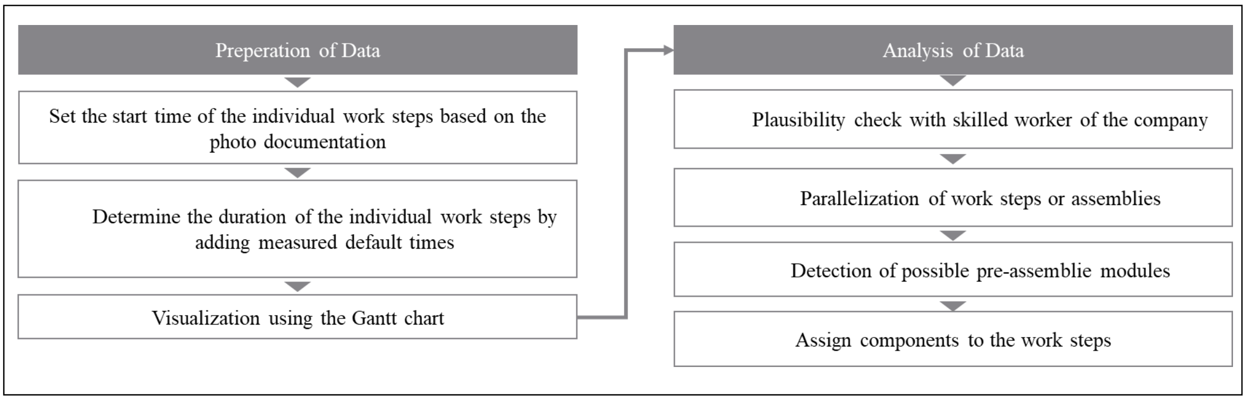


Figure 36: Approach of data preparation and analysis

In order to define the chronological sequence of the assembly steps for the respective F articles, the starting point of the recorded assembly activity was defined with the help of photo documentation. The photo documentation of the REFA time recording served as a database. During this process, a photo was taken at each step of the assembly process. The recording time of the respective photos was read out and serves as starting time of the respective assembly step. The measured target time including the distribution time of 15% was added to the start time. Thus, the order of the assembly steps could be determined. Figure 23 shows an example of how to define the process order.

Var-Nr	EZeit	LGrad	Zeitart	Ak	n	Ablauftext	Zusatztext	SZ/BZM*AK	Startzeit	Endzeit	Datum
0	621	101,47	thb	1	2	Montage hydr.	abwurfband ventil vorbereiten u.mont. 60,61,63	630,15	7:34:21	07:40:39	2015-10-08
0	217	100	thb	1	2	Montage hydr.	kanban 25,27 [schrauben holen]	217	5:50:14	05:52:24	2015-10-08
0	86	100	thb	1	1	Montage hydr.	kanban 66	86	7:52:31	07:53:23	2015-10-08
0	192	100	thb	1	1	Montage hydr.	kanban 885	192	14:55:43	14:57:38	2015-10-21

Defined target time is added to the starting time (15% additional time already included)

Figure 37: Example of how the process order was defined

The evaluated data was then visualized in a Gantt chart (see Appendix A, example of AX). The visualization grouped together the F-articles in order to see when an assembly begins and when it is finished. The aim was to identify further pre-assembly modules. The procedure and results of this analysis are described in more detail in Chapter 4.4.3.

4.2.5 Layout of the Current Assembly

As a data basis for the investigation of the current assembly layouts, the CAD files of plant 2 and 3 were handed over by the compan. For the analysis of the current state, the assembly layout of Plant 2 and Plant 3 was considered in more detail, as the feasibility of relocating the assembly content from Plant 3 to Plant 2 should be examined in the course of this project. Plant 3 currently contains the final assembly for the product families CR, TR and AX. Individual pre-assembly modules for the mentioned products are assembled at Plant 2. The product family TT is pre-assembled and assembled as a whole at Plant 2. Figure 38 (see Appendix B) gives an overview of the current assembly arrangements in the two plants.

The maintenance for all product groups takes place in Plant 3. This should remain after the restructuring. Agricultural machines were originally assembled at one work station in Plant 2. This assembly is to be outsourced and the recovered area can be used for the assembly of the relevant machinery.

4.2.6 **Potential for Optimisation**

In the course of analysing the current state, the existing assembly layouts were also examined in terms current challenges. More and more problems have arisen for which solutions have been worked out within this project and are then included in the new planning of the assembly.

The following problems occurred in Plant 3:

1. Assembly stations CR/TR have a small longitudinal movement area. (Longitudianl movement area less than 1m)
2. Drop belt transport routes are obstructed during assembly (see figure 38)

Figure 38: Conveyer assembly at Plant 3[194]

3. Assembly of the chassis for CR/TR takes place at the loading area, which is the hub in the production hall. (see figure 39)

Figure 39: Assembling of the Trailer on the loading point[195]

4. There are no defined staging areas.
5. Wagons for small parts obstruct the transport routes.
6. When the machines are relocated for the assembly of the conveyer, the transport routes must be cleared.

For the problems mentioned in Plant 3 the following possible solutions were worked out in advance:

[194] Cf. REFA-Times Study (Austria, 21.06.2016)
[195] Cf. REFA-Time study (Austria, 21.06.2016))

Ad 1.) As longitudinal movement area a total of 3m in addition to the machine length (see chapter 4.3.1)

Ad 2.) The assembly of the discharging conveyer should take place at its own assembly site or at an assembly site which is sufficiently long.

Ad 3.) Assembly of the trailers should take place at a separate assembly location

Ad 4.) Clearly define the pick-up spaces for each assembly site

Ad 5.) Only required small parts wagons should be present on the assembly site

Ad 6.) No parts and wagons on the transport routes

The following problems occurred in plant 2:

1. Workbenches are put on the assembly area
2. Unused C-parts wagons are in the assembly area
3. Very little movement area at the main assembly site (see figure 40)

Figure 40: Current situation of the assembly area in Plant 2[196]

4. There are no marks for the buffer areas.
5. Unused pre-assembly racks stand on the assembly stations (see figure 41)

Figure 41: Assembly areas used for storage in Plant 2[197]

6. Free assembly stations are used as pre-assembly / storage space.
7. Storage rack is unused at the loading point.
8. Uncoordinated provision of pallets with small parts at assembly stations.

[196] Cf. Own picture (12.08.2017)
[197] Cf. Own picture (12.08.2017)

Possible solutions for the above-mentioned problems in Plant 2 can be the following:

Ad 1.) Move workbenches to the side of the hall

Ad 2.) Two manouverable C-part shelves per workstation, a central C-part warehouse

Ad 3.) Planning the size of the mounting surface sufficiently

Ad 4.) Clearly assign the buffer zone to individual assembly stations

Ad 5.) Clearly define pre-assembly stations and space for assembly racks

Ad 6.) Use the area at the loading point as one of two central C-part bearing

Ad 7.) Areas for the supply materials are clearly marked on the assembly area

4.2.7 Results of the Analysis of the Current State

Through analysis of the production program and the current assembly, requirements for the new layout have been derived. These are summarized and presented in table 11.

Catalog of Requirements			
Criteria	Challenge	Impact	Approach
Assembly area	Low lateral and longitudinal work space (P2/3)	Complicated, e.g. the assembly of cladding parts	Allocate enough work space for the main assembly area
	Assembly of discharge conveyer on assembly area (P3)	Transport routes are obstructed during assembly	Own assembly area for trailer assembly
	Trailer assembly at the loading point (P3)	Obstruction of the material flow in the central point of the production area	Own assembly for trailer assembly
	Implementation of machinery hampered by material provision (P2/3)	Transport routes must be cleared for implementation	Defined areas for material supply at each main assembly area
	Pre-assembly not clearly defined (P2/3)	No optimal usage of area	Define pre-assembly clearly to individual modules
Material supply	No defined areas for material supply (P2/3)	Obstruction of assembly areas by pallets and small component carts	Defined areas for material supply for each main assembly arera
	Unstructured buffer zones (P2/3)	Unclear material supply	Structured buffer zone
Means of production	C-part supply by two service providers (P2/3)	Double C-part storage	Only one C-part supplier
	C-part shelves scattered over the entire hall layout (P2)	Long distances to C-part carts, double C-part storage	Only one central C-part storage
	Workbenches set up in the assembly area (P2)	Space wastage at the main assembly area	No workbenches in the main assembly area
Employees	Division of labor for main assembly not clearly defined (P2/3)	Unstructured work procedure	Defined assembly team for each pre-assembly area
	Division of labor for pre-assembly not clearly defined (P2/3)	Unstructured work procedure	Defined assembly team for each pre-assembly area

Table 11: Catalog of requirements

4.3 Rough Layout Planning

In the second project phase of Work Package II, several rough layout variants were designed, analysed and evaluated on the basis of data determined in chapter 4.1

Figure 42 shows the goal and approach of this project phase.

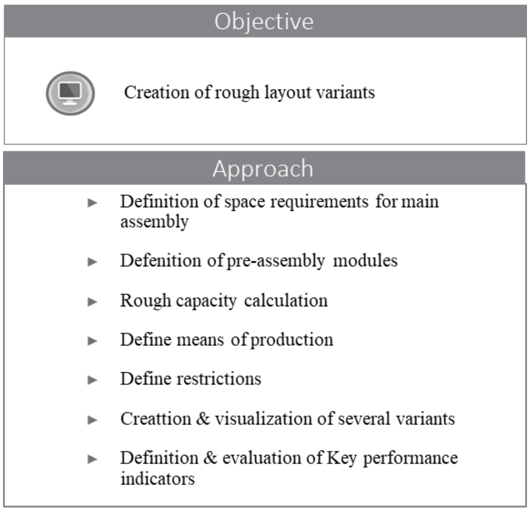


Figure 42: Objective and approach of rough layout planning

The first step in the rough layout planning was the determination of functions and the dimensioning of subsystems.

4.3.1 Determination of Workspace Requirement

One of the important taks in the layout planning process was the determination of the optimal area which is required for assembly. The required area planning carried out within the project took place in three steps:

1. Actual analysis of the mounting surface currently used in Plant 2 and Plant 3
2. Area planning based on the theory (see chapter 2.7.2)
3. Workshop for determination of required space and adaptation of the selected areas

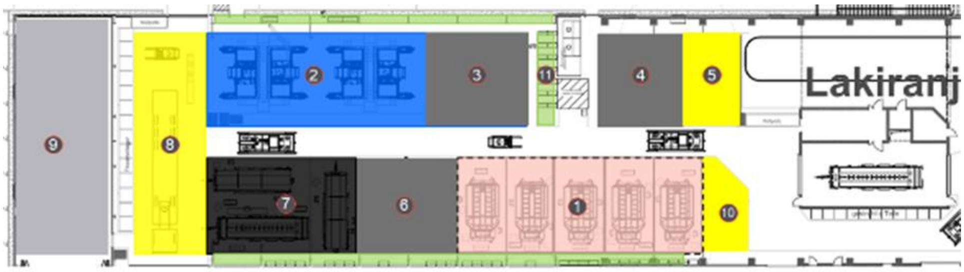
4.3.1.1 Analysis of the current assembly area

For the analysis of the current assembly area, the mounting surfaces in the AutoCAD file were measured and summarized. Figure 43 shows the assembly areas in Plant 3.

Nr.	Assembly content	Lenght [m]	width [m]	area [m²]
1	AX	15,77	7,25	114
2	AX Trailer	20	7,3	131
3	AX	9,85	6,55	64
4	CR	10,6	6,55	69
5	CR	9,76	6,55	63
6	CR/TR (stationary)	7,95	9,06	72
7	CR/TR (stationary)	7,95	8,15	64
8	CR/TR (stationary)	7,95	8,27	65
9	Trailer assembly/loading area	9,8	7,5	71

Figure 43: Current layout of Plant 3

Currently, Plant 2 still has an assembly area for agricultural technology products (see figure xy, number 2), but this is to be relocated as part of the restructuring. In addition, the existing paint shop is changed, which was taken into account in the later fine layout planning. Figure 44 shows the existing mounting surfaces and their sizes.



Nr.	Assembly content	Lenght [m]	width [m]	area [m²]
1	CR/TR pre -assembly	9,6	5	48
2	TT assembly	22,4	9,6	214
3	TT pre-assembly	10	9,6	96
4	Pre-assembly for CR/TR	8,5	9,42	80
5	Painted parts	5,85	9,3	54
6	AX pre-assembly	10	9,6	96
7	Acriculture products	15,3	9,6	147
8	Loading area	25	7,5	187
9	Endcheck	25	10	250
10	Commissioning area	9,5	5,5	44
11	C - parts			

Figure 44: Current layout of plant 2

An important aspect of the new planning was the future required movement area for the assembly for the employees. As mentioned in chapter 4.2.5, there are very small movement surfaces between the machines and their assembly stations, especially in Plant 2. In order to obtain an insight from the currently used motion surface, the distances between the machines were measured in the current layout of the two plants from the AutoCAD file. The aim of this analysis was to develop an optimal and standardized movement surface for the future plant. Figure 37 shows the actual situation with regard to the available movement area for the CR and TR pre-assembly at plant 2.

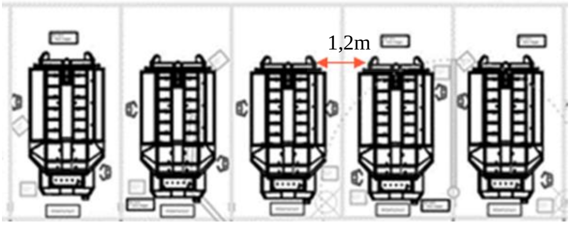


Figure 45: Current movement area between machines in plant 2

Currently, the movement area between the machines at Plant 2 are the followings:

- Lateral movement area: 0.60 m•
- Longitudinal movement area: 1.50 m

The work tables, C-section shelving and small parts wagons are currently located on the assembly areas. In the catalog of requirements (see chapter 4.2.7) the challenges with the actual sizes of the assembly areas are mentioned.

At Plant 3, where the CR and TRs are currently assembled, the current movement area is as follows:

- Lateral movement area: 2,50 m•
- Longitudinal movement area: 0.50 m

Also in this plant, the work benches, C-part shelves and small carts are placed on the assembly site. The use of equipment, such as the C-section shelf and material supply, is discussed in greater detail in Chapter 4.4.2 in the fine-layout planning.

4.3.1.2 Area planning based on the theory

For the required space for machines and assembly, the methods for the space calculation (see chapter 2.7.2) have been taken into account. The results served as an indication but have been further developed in several steps. One problem was large components, for which the space required to assemble must be taken into consideration when determining the movement area around the assembly areas.

4.3.1.3 Workshop for planning the area

As the aim of this project was the re-planning of the assembly layout, in the first step the current dimensions of the assembly areas of Plant 2 and Plant 3 have been used to create different layouts. The second step was to recalculate the areas required for assembly using methods found in literature. However these methods do not take large parts into account. Next, different layout variants were created in a workshop, together with the responsible people in the company using maps in the scale of 1: 100 laid out on a layout to see the relations of the selected assembly's. In these workshops the structuring of the assembly areas was done in a first attempt. Figure 46 shows an example of the procedure for the rough layout creation and structuring. This step was carried out several times with different sizes of the individual assembling areas.

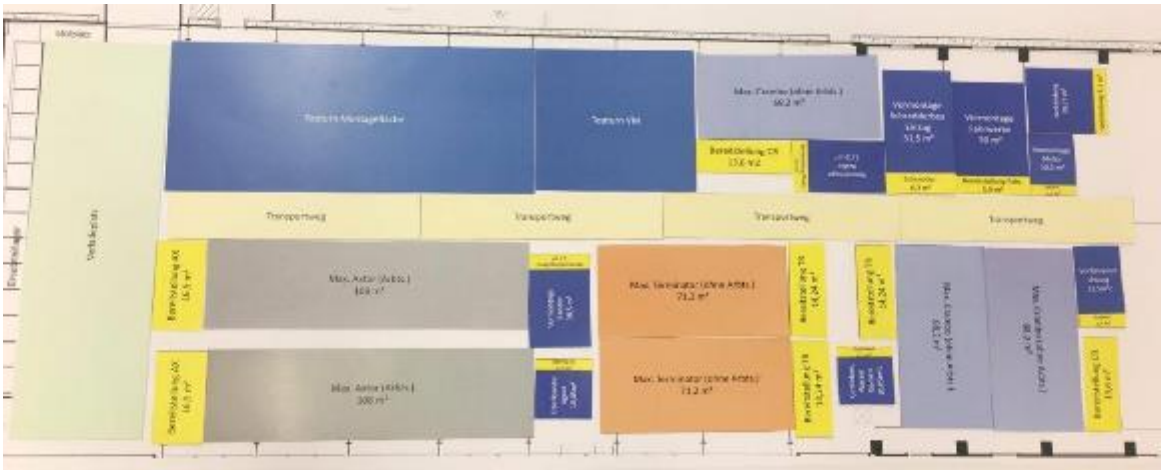


Figure 46: Structuring of layout variants in a workshop

A surcharge of 20% of the required main assembly area was used for the supply areas of the individual assembly areas. This size is derived from the theoretical calculation for required areas. The factors for the additional surfaces for shavings and waste, repair and maintenance, which were used in the theory mentioned in chapter 2 have been omitted, since these are only relevant for the design of production machines. The required space for work benches has not been taken into account as these benches were located on the walls at the plant next to the assembly areas.

When designing the required movement surface, certain conditions had to be considered:

- Minimum width of the movement surface 2m (dimensions of cladding elements CR / TR)
- Sufficient space for the movement of mobile C-section trolleys and small parts racks in the workplace

From these framework conditions and based on the theory (see chapter 2.7.2) a lateral movement area was chosen for the main assembly sites of 2.5m laterally and 1.5m longitudinally movement area for all machines. For the pre-assemblies, a movement area of one meter was chosen both laterally and longitudinally.

Figure 47 shows a summary of the currently used areas and the selected areas for the new plant layout.

Type of machine	Current area plant 3 [m²]	Current area plant 2 [m²]	Suggested area [m²]
CR	48	Ø 66	82,5*
TR	48	Ø 66	82,5*
AX	/	131/114	142**
TT	214		214

*…without conveyer assembly
**... Wieth conveyer assembly (working position)

laterally 2,5m movement area
longitudinally 1,5m movement area

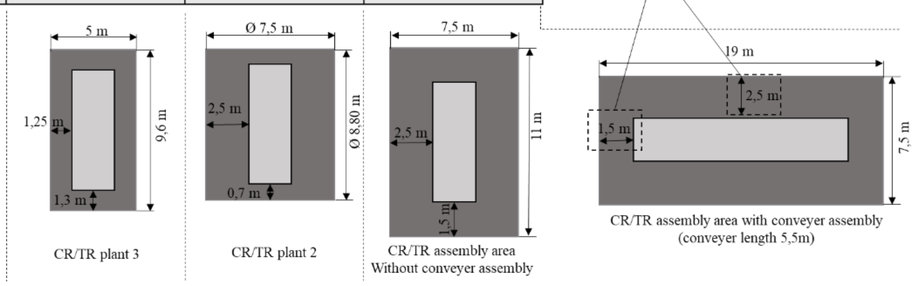


Figure 47: Dimensionning of required assembling area

4.3.2 Dimensioning of the Number of Assembly Stations

For the planning and structuring of the rough layout, the number of assembly areas for the respective machine groups was roughly dimensioned in advance. This was done by considering the production volume of the business year 2017 and the forecast for 2018 multiplied by the respective default times of the machine groups. Due to the dimensions of the given hall layout, the boundary condition for a maximum number of different assembly locations for the modules was defined (see figure 48). The machine assemblies CR and TR have the same area for assembly (see chapter 4.3.1). Figure 42 shows the percentage distribution of required assembly hours of the machine groups CR/TR, AX and TT for the business year 2018 and the proportional distribution to assembly sites for the respective machine group with the following number of assembly stations:

- CR/TR: 5 assembly areas
- AX: 1 assembly area
- TT (see chapter 4.3.4): 3 assembly areas

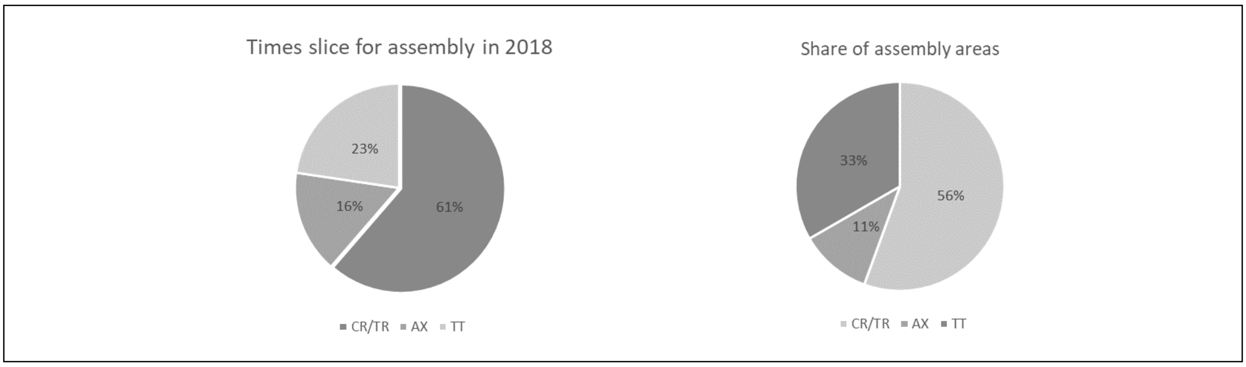


Figure 48: Time slice and share of assembly areas

4.3.3 Planning of the Assembly Process

As already described in chapter 3.3.1, in the rough layout planning an analysis of the predefined times from the REFA time study has been carried out. The procedure and evaluation of the data is described in Figure 49.

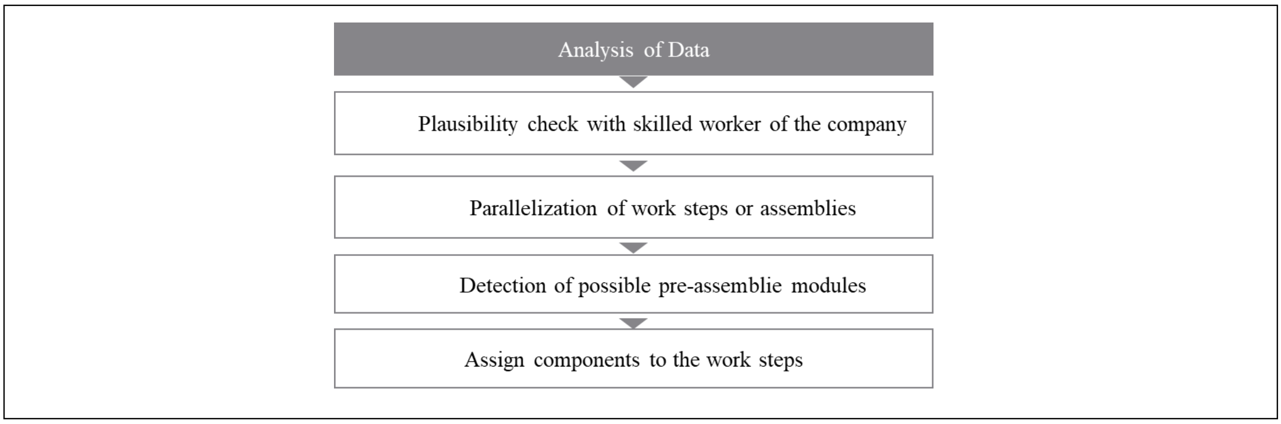


Figure 49: Approach for the analysis of the REFA tim study

The aim of this analysis was to define new pre-assemblies in order to reduce the lead time of the main assembly. An enhanced process sequence was used to identify at which assembly step an assembly is mounted on the basic machine and which work steps can still be realized in the pre-assembly. In addition, existing pre-assembly modules were examined and reference was made to possible further subdivisions of pre-assembly modules. These were discussed with the company.

Following the definition of the final selection of the pre-assembly modules (see Apendix C), the process sequence for the respective groups was developed with the help of the Gantt-charts from the REFA data processing (see chapter 3.2.1). This is the basis for the placement of the pre-assembly modules in the plant layout and an overlay of pre-assemblies and main assemblies. The aim was to make the best possible use of the defined areas for pre-assembly.

The following example shows the process sequence of the assembly steps for the pre-assembly of the AX. This was visualized using a Gantt chart. (see Fig. 44)

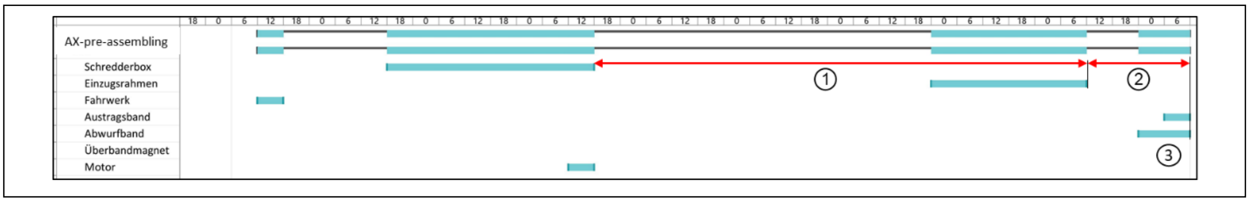


Figure 50: Procesc oder of the pre-assembly for AX

1. Between the assembly of the *Schredderbox* and the *Einzugsrahmen* on the base machine, 44 hours pass with other assembly contents. The target time for the installation duration of the *Einzugsrahmen* is 39 hours. Thus, the *Einzugsrahmen* can be pre-assembled at the same place as the *Schredderbox*.
2. Between the assembly of the *Einzugsrahmen* and the *Abwurfband* to the basic machine, 9 hours of work is carried out on different processes. The duration of pre-assembly for the *Abwurfband* is 12 hours. Thus, the *Abwurfband* can be pre-assembled with an increased staff deployment at the same installation site as the *Schredderbox* and the *Einzugsrahmen.*
3. 84 hours elapse between the installation of the *Abwurfband* and the completion of the assembly. Thus, the pre-assembly area already can be used after the installation of the discharge belt for the pre-assembly of the trailer (track, trailer) for the subsequent AX. The time needed for pre-assembly of the trailer is between 17 and 25 hours, depending on the model.

This overlap of pre-assembly models increases the area's use potential. Table 12 shows the potential of the example AX mentioned above. The pre-assembly modules would require a total assembly area of 78m² if these were to be integrated individually into the plant layout. This mounting area is calculated from the base area of the assembly to be mounted and an additional movement surface of 1m each side. The overlaying of these three pre-assemblies requires an area of only 31.5 m², which means a space saving of 59%.

PRE-ASSEMBLING MODUL	REQUIRED AREA BY INDIVIDUAL WORKING STATIONS [M²]	REQUIRED AREA BY OVERLAPPING [M²]
Schreddebox	18	
Einzugsrahmen	31,5	31,5
Abwurfband	28,5	
Gesamtfläche [m²]	78	31,5

Table 12: Example for increasing the area´s use potential by overlapping pre-assembly modules

Together with the company, the pre-assembly modules (see Appendix C) were selected. The overlapping of the individual pre-assemblies and the definition of pre-assembly modules are considered in more detail in the detailed capacity calculation (see chapter 4.4.1).

Subsequently, the target times were summarized for the individual machine types. The REFA time recordings were made for the assembly contents of Plant 2 and Plant 3. Thus, the target times of Plant 2 must be added to the target times of Plant 3, as after the restructuring the machines are completely assembled in Plant 2. Target times for loading of pre-assembly modules onto the truck to transport them to Plant 3 have not been taken into account in the new compilation of the target times.

The time required to assemble the *Schredderbox* on to the *Einzgsrahmen* (14.6 hours) at Plant 2 was no longer considered. During the analysis of the REFA times, several subassemblies could be identified, which will be pre-assembled further after relocation from Slovenia to Austria. This work content could still be included in the pre-assembly. This would mean a further reduction of the lead time for the main assembly.

For CR, the target times and pre-assembly modules were evaluated using the same approach. During the project period there were no REFA times for the product group TR available. However, the times of the CR can be used for the calculation, since the assembly contents are very similar to the product group TR. It should be noted that it was identified by the analysis of the REFA time study that the pre-assembly time of the trailer is 12 hours rather than 20. The remaining 8 hours already includes the steps for mounting the trailer to the basic machines

According to the company, the current situation for the assembly of the TT is to remain with already defined pre-assembly modules. For the sake of completeness, the summary of the default times is also investigated. In Chapter 4.3.4, the optimization potential for the TT is described in more detail.

4.3.4 Potential for Optimizing the Assembly of the TT Product Family

For assembly of the TT product family, four assembly areas are currently available in Plant 2. In addition to these four assembly areas, there is a subsequent pre-assembly area measuring 96 m². During the analysis of the production program and the target times for the TT, it was identified that a reduction in the number of assembly areas for the TT is possible. In the following chapter the optimization potential for the TT assembly is shown.

Currently, two fitters are responsible for the main assembly. When examining the target times using the REFA time study, a required assembly time of 120 hours for the main assembly was outlined. With a labour input of 7 working hours / shift and 210 working days / year, two employees are able to mount 24 TT at one assembly site per year. The following figure should visualize the composition and potential of TT assembly.

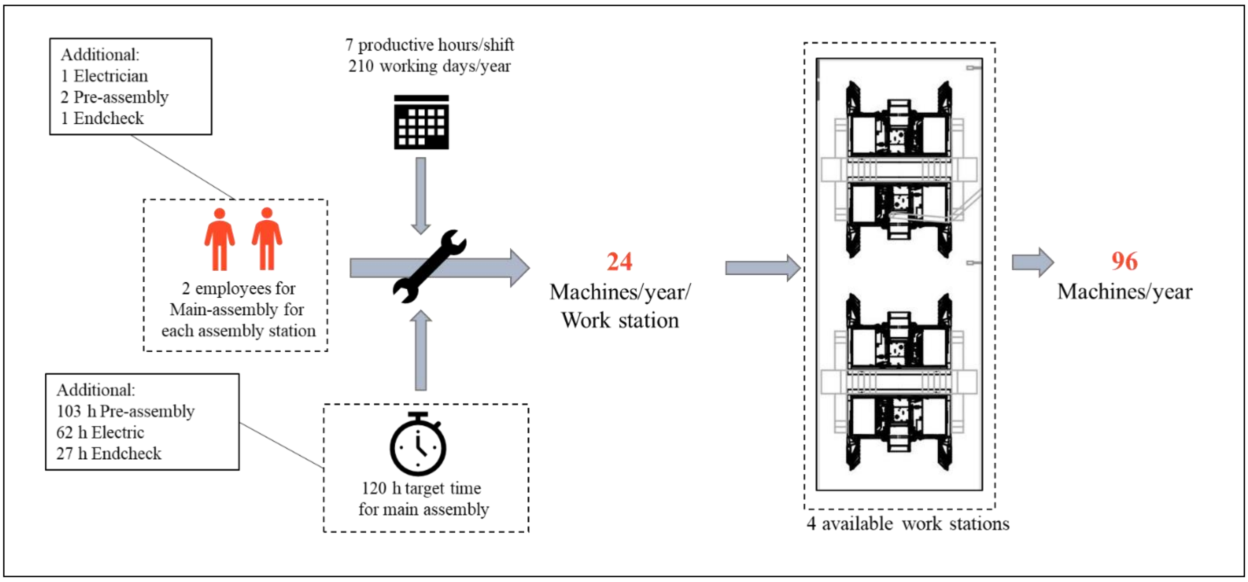


Figure 51: Calculation of the utilization of the TT assembling area

In 2017, a total of 35 TTs were assembled. With a capacity of four assembly areas, an annual output of 96 machines would be theoretically possible. For the year 2018, 43 machines are planned for assembly on the TT assembly area. Thus for the calendar year 2018, the TT assembly would only be utilized to 44% of its capacity.

In order to meet the forecast for 2018, two variations would be possible:

1. Assembly on two main assembly areas in one shift (48 machines output)
2. Assembly on one main assembly area in two shifts (48 machines output)

By arrangement with the company, a reduction of the main assembly of the TT from four to three was possible. One assembly area was kept as a buffer area for when needed, when for example some parts for the machine are not delivered.

4.3.5 Restriction for the Rough Layout Planing

Since this is a brownfield layout planning, the future surface area of the plant is already determined. The height of the hall, load-bearing columns and accessibility to the adjacent building areas must be taken into account. Figure 52 shows the available free space for re-designing the assembly. The existing restrictions are highlighted in the figure.

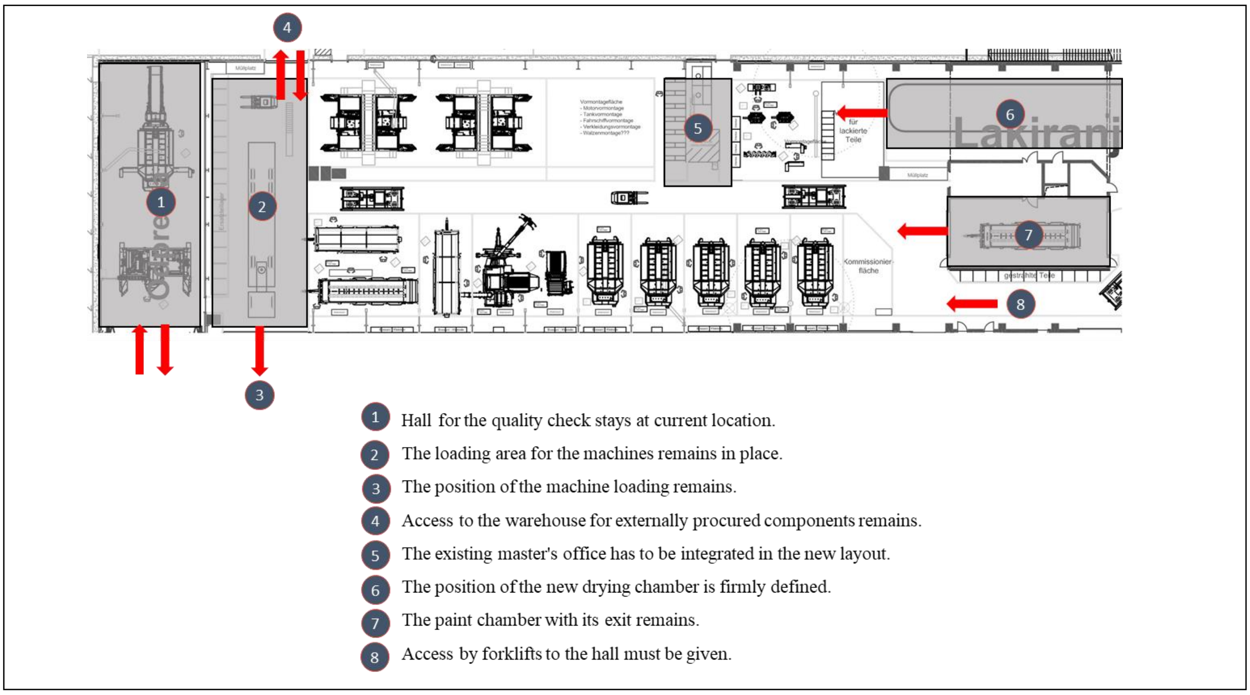


Figure 52: Restrictions for rough layout variants

4.3.6 Variants of Layouts

In real planning, a total of seven layout variants were created. In order to incorporate the experience and the production knowledge acquired throughout the years by the production manager into the redesign of the assembly arrangement, a further layout workshop was held.

With the aid of to-scale assembly maps (scale 1:100) and taking into account information which had already been collected, various variants were laid out in different layout variants in cooperation with the company. This workshop resulted in the layout variant *Company/ TU Graz*. The models *Standing CramTer*, *Skinny Box* and *Flowing CramTer* were designed without the company. The other layouts were created before the workshop to determine the required area and upon agreement with the company no longer included in the final decision, since they use dimensions for the assembling area which is currently used in Plant 2 and Plant 3. The layout variants *Standing CramTer*, *Skinny Box* and *Flowing CramTer* were digitized in AutoCAD and enclosed in the Appendix D.

4.3.7 Evaluation of the Layout Variants

For the evaluation of the individual layout variants, a utility analysis for the individual variants was originally planned. The criteria were already determined before the second steering meeting. The selected criteria are based on a subjective comparison of the various solution options. The following criteria were selected:

Maximum Capacity: This criterion evaluates the maximum workload for the total number of employees in shift.

Employee assignment: Provides information about the differences in the required number of employees for main and pre-assembly for a given forecast.

Transport performance number: Evaluates the layout indicator [load carrier * meter] for the material flow between pre-assembly and main assembly (not possible due to missing data).

Flexibility / expansion options: Size of the deployment areas and potential to integrate further pre-assemblies

Accessibility assembly area: Accessibility of assembly stations with conveyor (e.g. stacker)

Standardization / Process Control: Monitoring of assembly processes and material supply

Material flow connection internally: Complexity of material transport (e.g. implementation with gantry crane)

On the basis of these criteria, the submitted layout variants were discussed with the authorities at the company.

After presenting the four concepts in the second steering meeting, the company decided which layout should be carried over to the detailed planning phase. The pairwise comparison and utility analysis was not applied as too few people were involved in the project and thus the pairwise comparison would have held little significance. The company opted for the variant *Company/TU Graz*. However, the variant *Flowing CramTer* should also be included in the detailed layout planning, as it is seen as a strategic layout for future assembly. According to the company, the line variant is not conceivable in the current state.

In the next chapter the chosen layout are explained more in detail and the advantaged and disadvantages of each are listed.

4.3.8 Selected Layout Variant Company/ TU Graz

This chapter introduces the selected layouts. The two other layout variant options can be found in the Appendix C. However this is still a rough layout, which should represent the arrangement of the main assembly, pre-assembly and material flow. It also serves as a basis for discussion of any advantages and disadvantages which may arise from the selected plant layout. In addition, an approximate capacity estimation should be carried out in the rough layout phase.

The layout *Company/TU Graz* was created in a joint workshop with the company. A fixed-site production is used as type of production, and a total of four main assembly stations are planned for the assembly of CR/TR. The trailer and discharge conveyer assembly should be carried out at a separate assembly site in order to shorten the lead time at the main assembly area.

One assembly station is planned for the AX machine group. Using the process sequence of the assembly, it is designed to install individual pre-assembly modules such as the *Schredderbox* and the *Einzugsrahmen* in the same place for optimum area-use potential.

The pre-assembly modules are centrally located and overlap depending on their required mounting area and capacity utilization. Furthermore, these are located close to the painting chamber, which shortens the transport route.

The following table summarizes the advantages and disadvantages of this layout variant:

ADVANTAGES	DISADVANTAGES
CR / TR assembly sites with sufficient movement area Transport flow from left to right	Kink in the transport path increases dislocation complexity
Chassis and discharge conveyor assembly for CR / TR on own assembly place	Inclination required for CR / TR and AX during conveyer assembly
No obstruction of the transport routes by the discharge conveyer assembly	Left CR / TR mounting place is cut off
Loading area only used for loading	Space wastage due to machine tilt for assembling conveyers
Large area for painted parts	Incline of machine adjusts deployment area
CR / TR trailer and discharge belt assembling station also used as pre-assembly station	Low supply area for CR / TR at the main assembly area
Assembly teams with defined assembly activity can switch between construction sites (group assembly)	Disruption of material flow by moving the machines
Route to walk between hall wall and mounting surface	

Table 13: Advantages and disadvantages of the layout variant *Company/TU Graz*

As part of the rough layout planning, a rough capacity assessment was carried out for the individual layout variants. The number of employees required was calculated for the respective product groups, which are needed for the number of machines in the production year 2018. In addition, the maximum annual capacities and the number of staff required for this were calculated. Because a detailed capacity calculation is carried out in the fine layout phase, the results for the rough estimation are not shown here. (see chapter 4.4.3)

4.3.9 **Selected Layout Variant Flowing CramTer**

The variant *Flowing CramTer* differs amongst other things from the layout *Company/TU Graz* in the selected type of production. For the product group CR/TR a line production was chosen.

In future the CR/TR will be manufactured in a line assembly, which will result in an increase in standardization. The contents of the main assembly for the CR/TR have been separated into three assembly sites. The fourth and final assembly area includes the conveyer assembly and trailer assembly for mobile machines. The determination of the cycle time for line assembly is described in more detail in chapter 4.4.8 in the fine layout planning.

The TT assembly remains as described in the previously described layout with four assembly stations. For assembly of the TT, additional staging areas for the small parts weighing were planned in the layout.

For the AX, this layout defines an assembly space which is 19m long, which avoids the need to rotate the machinery.

Compared to the layout variant *Company/TU Graz*, the layout *Flowing CramTer* has the following advantages:

- The kink is avoided - there is therefore a straight transport path
- The mounting space AX has a sufficient length of 19m for belt assembly without the need for an incline
- Line production results in increased standardization of assembly
- In a line production, implementing a second shift is easier
- The material flow and production process becomes clearer

Table 14 shows advantages and disadvantages of the Flowing CramTer layout:

ADVANTAGES	DISADVANTAGES
Short transport routes (pre-assembly next to main-assembly)	In case of disturbance of one assembly station the whole assembly line is blocked
Low personnel qualification	Investment costs for conveyor technology (estimate: 250,000, -, according to the company)
Clear material flow	Additional time required to move the machines
Clarity of the production process	Default times for pre-assembly modules must be adjusted to the cycle time of the main assembly e.g. engine pre-assembly
Easier implementation of a second shift	
Fewer employees needed	
Strict standard times for employees	
Increases the standardization of assembly	
Potential to shorten the lead time through standardization in the future	
More space available for new pre-assembly next to the main assembly line	
Increase in output through overtime	
Short transport route to the AX assembly station	
Transparency - errors are pointed out and causes can be remedied	

Table 14: Advantages and disadvantages of the variant *Flowing CramTer*

For this variant a rough capacity estimate was also made. It should be noted that this layout consists of one assembly area for the CR/TR assembly less and thus also reduces the number of employees. A cycle time of 13 hours was decided upon (see chapter 4.4.6). It should be mentioned that in comparison to the layout *Company / TU Graz*, the maximum capacity of the CR/TR assembly is less in the *Flowing CramTer* layout, as this version has one less assembly space than the previous version.

The rough-layout planning phase follows the fine-layout or detailed layout planning phase. The next chapter explains the approaches and the results of this phase.

4.4 Fine – Layout Planning

In the fine-layout planning, two layout variants which were chosen in the evaluation of the variants in the rough-layout planning phase are further detailed. The approach of that phase is shown in figure 53.

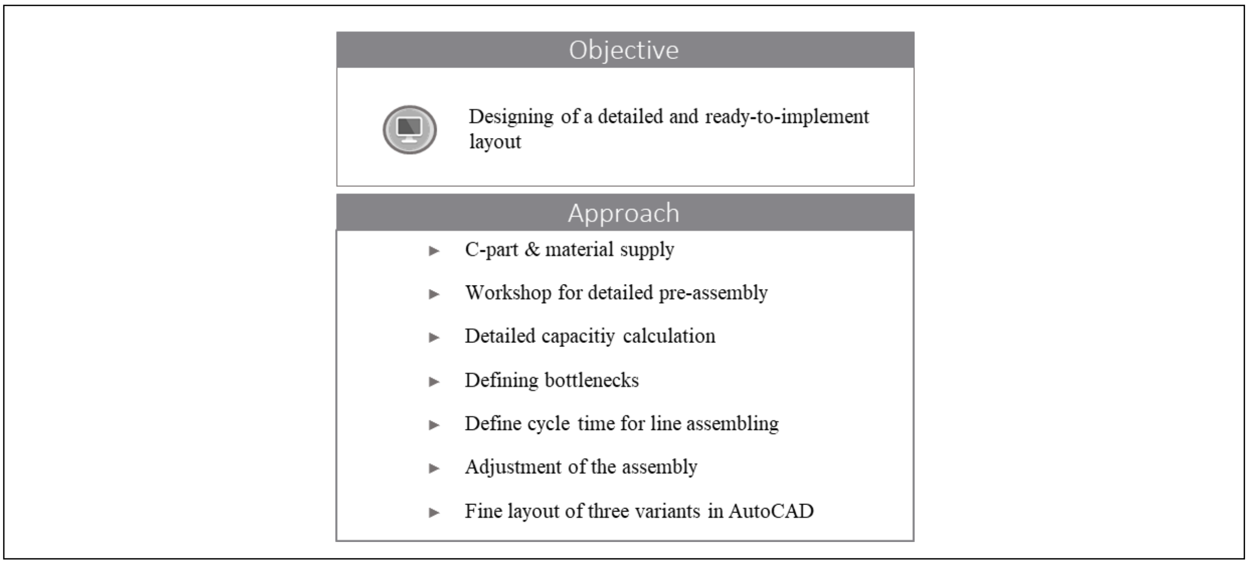


Figure 53: Objective and approach of the fine-layout planning

The first variant (*Company/TU Graz*) can be implemented immediately. The second variant, which contains the line-assembly should serve as a strategic variant requiring further optimization of the processes and data structure. For this layout a second variant is worked out which is called the implementation variant. This has almost the same arrangement of assembly units as the line-assembling variant, but the type of production is still a fixed - site production concept.

4.4.1 General Requirements

The fine layout planning should as far as possible take into account all the requirements which were determined in the current state analysis (see chapter 4.2.5). The planning of the C-part supply and material supply is also seen as general planning for all variants. In addition, the evaluation criteria for all selected variants should be taken into account in the fine layout planning. These are the following:

Maximum capacity: This criterion evaluates the maximum workload for the total number of employees in a shift.

Employee assignment: Provides information about the differences in the required number of employees for main and pre-assembly for a given forecast.

Transport performance number: Evaluates the layout indicator [load carrier * meter] for the material flow between pre-assembly and main assembly (not possible due to missing data)

Flexibility / expansion options: Size of the deployment areas and potential to integrate further pre-assemblies

Accessibility assembly area: Accessibility of assembly stations with conveyor (e.g. stacker)

Standardization / Process Control: Monitoring of assembly processes and material supply

Material flow connection internally: Complexity of material transport (e.g. implementation with gantry crane)

4.4.2 Detailed Equipment Planning

The planning of the future C-part supply and material supply should counteract the problems of the current situation. Figure 54 shows the actual situation in the plant layout of Plant 2. The areas marked in orange are the areas where C-part shelves are currently stored.

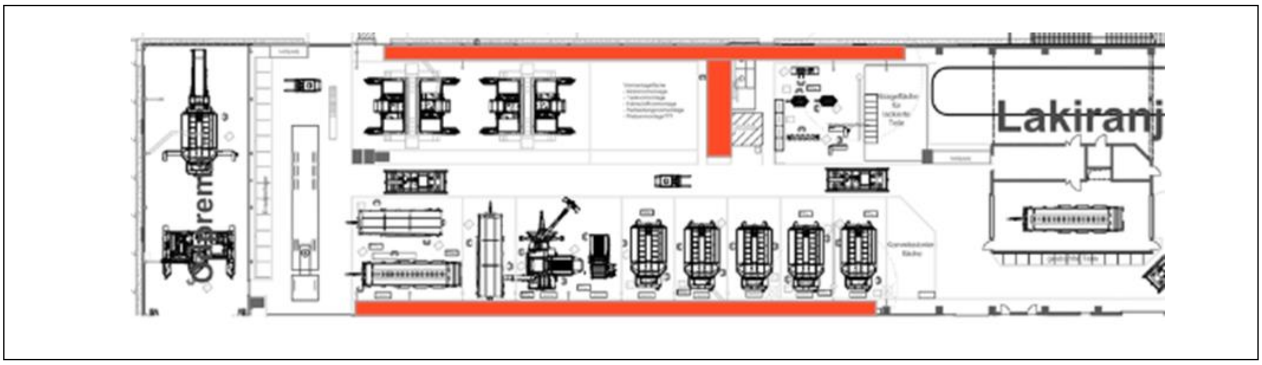


Figure 54: Current state of c-part supply in Plant 2

The current situation in Plant 2 results in the following problems:

- Two C-part service providers
- Repeating C-parts due to two suppliers
- Many unused C-parts wagons on the assembly sites
- No central C parts warehouse

Based on these problems, the following solutions have been worked out and have been incorporated into the fine layout:

- A central C-part warehouse
- Two mobile C-section shelves per workstation
- The future central C-part warehouse should contain 20% more racks than currently used in Plant 3 for final assembly

Figure 55 shows the target for the new plant layout. The advantage of this central C-section warehouse is that it can also be used for the second existing plant in which agricultural technology products are assembled.

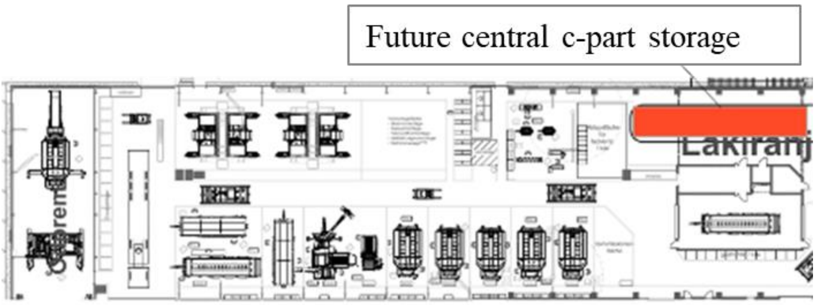


Figure 55: Planned C-part storage in Plant 2

In the current plant layout, these workbenches were for the most part placed directly on the main assembly area, resulting in a waste of space in the assembly area. In the new layout, the workbenches are to be located at the sides of the hall to allow unimpeded assembly.

Small parts shelves are currently used for the supply of small parts. Figure 56 shows an example of a small parts wagon:

Figure 56: Example for a C-part shelve

This type of small parts supply is to be maintained in the new layout. Components that are too big for the small parts racks are supplied by means of pallets. However, the current state analysis revealed the following deployment issues:

- The small parts carts are usually not completely filled
- Several small parts racks stood unused on the assembly sites
- The small parts carts are increasingly moved to neighbouring assembly stations as there is not enough space on the actual assembly site

In order to counteract these problems, the following approaches should be included in the new layout:

- Areas for small parts carts should be designated at the assembly site
- Employees can push the small parts carts onto the assembly site

- Pre-picking of small parts weighing on the bill of materials and assembly instructions
- Designate an area at the assembly site for pallets with larger attachments

For the calculation of the staging area see chapter 4.3.1.

4.4.3 Detailed Calculation of Capacities

The basis for the capacity planning is provided by the target times of the REFA time study, the forecast data and the average working time of the employees.

The forecast data was used to define the percentage of each main and pre-assembly module. These are taken from the Forecast List 2018. The resulting annual quantity was then multiplied by the respective target time in order to obtain the required assembly hours for this year. The following formula shows the calculation of the required assembly hours for the business year 2018.

$$Total\ assembly\ hours_{WJ\ 2018}[h] = number\ of\ products[\#]_{WJ\ 2018} * target\ times\ [h] \quad \textbf{(15)}$$

The result is the number of assembly hours for all main and pre-assembly modules for the production year 2018. The total assembly hours for each of the main and pre-assembly modules has now been divided by the annual available working time of an employee in order to obtain information about capacity utilization. The pre-assembly modules were merged depending on the required mounting surface. Pre-assemblies that require an equal area were overlapped.

In the rough layout planning, an average of 210 working days were used, each with seven working hours per employee. For the fine layout planning, the exact values have been used for the calculation. These values represent the average for the past six years in the company.

In personnel planning, the company deducts the following from the gross performance share:

- Holidays (depending on the location of the plant)
- 5% sick leave
- 15% idle time (there is potential to increase the net performance level)

On the part of the company, TU Graz received the net level of performance of 1290 hours per year and employee. This value, which reflects the average of the past six years at the company, already includes holidays, sick leave and non-productive time. For further capacity calculations, this value should be used. A limit has also been set for the number of employees per machine who work at the same time on the same machine, since after a certain level an increase in the number of employees does not lead to an increase in productivity. This limit is defined as follows for the individual machine assembly:

- CR/TR: max. 3 employees for the main assembly
- AX: max. 5 employees for the main assembly
- TT: max. 3 employees for the main assembly

The pre-assembly modules which were defined in the rough layout phase were merged into modules in the fine-layout phase. For these, the capacity utilization was calculated and the amount of manpower required manpower was defined.

The following chapters describe the layout variants in terms of detailed capacity calculation, required employees and characteristics of the individual assembly areas.

Layout Variant Company/TU Graz

The first step was to calculate how many employees are needed for each major assembly in order to meet the forecast for 2018. The same procedure was used to calculate the number of electricians required and those responsible for quality control.

The following table summarizes the number of employees required for the pre-assembly modules and the main assembly of each budget machine for the year 2018 and 2025. Since no forecast was submitted by the company until 2025 at the time of the project, an annual increase in production of 6% was agreed upon.

Assembly modules/electric/quality control	Employees 2018[#]	Employees 2025 [#]
Pre-assembly module	10	13
CR/TR main assembly	11	16
TT main assembly	4	6
AX main assembly	3	5
Electric	6	8
Quality control	4	6
Total employees required	**38**	**54**

Table 15: Number of employees for *Company/TU Graz* Layout

Furthermore, the maximum possible number of machines produced in single-shift operation would be for the respective layout variant was calculated (see table 16). It was assumed that of the four main assembly stations, one is used only for stationary machines of CR/TR.

Products		AX	CR/TR	TT	∑
Capacity (One shift)	**Maximum capacity [#/year]**	24	91 mobile 38 stationary	96	**249**
Number of employsees	Employees in total	10	26	19	**55**
	Employees in main assembly	5	12	9	
	Employees in pre-assembly	3	7	4	
	Employees electric	1	4	4	
	Employees Quality control	1	3	2	

Table 16: Maximum output of *Company/TU Graz* Layout

In the calculation of the required capacities for the pre-assembly, the pre-assembly modules intended for the layout were summarized. For the respective modules, the required employee input was calculated. The basis for the calculation of the assembly capacities was the forecast data for the business year 2018. Appendix E shows the selection of the respective pre-assembly modules and the calculation of the required employee.

Layout Variant Flowing CramTer

For the layout variant *Flowing CramTer*, the calculation of the capacity utilization was the same as for the variant *Company/TU Graz*. However, other pre-assembly modules have been put together. During the preparation of the pre-assembly modules, it was important to ensure that the total assembly time for the respective pre-assembly modules was smaller than the cycle time of the line for the CR and TR products. The calculation of the line assembly is described in more detail in chapter 4.4.8. In the variant *Flowing CramTer*, one assembly area is planned for the processing of the stationary machines CR and TR. Thus, for the calculation of capacities, the proportion of stationary machinery must be deducted from the mobile products that are mounted in the production line. For the business year 2018, 25% of all CR and TR are stationary machines. In the default time of these machines, the assembly of the chassis and the discharge conveyers was not considered. However, the exact assembly contents for the stationary machines are unknown during the project period as no REFA time studies are available. Table 17 shows the number of employees required for the assembly content for 2018 and 2025.

Assembly modules/electric/quality control	Employees 2018 [#]	Employees 2025 [#]
Pre-assembly Module	10	13
Product B main assembly	11	16
Product C main assembly	4	6
Product A main assembly	3	5
Electric	6	8
Quality control	4	6
Total employees required	**38**	**54**

Table 17: Number of employees for *Flowing CramTer* Layout

The maximum possible number and required employees are shown in Figure 67. It is possible to produce more CR/TR than in the variant *Company/TU Graz*, since there is one more mounting station intended for the stationary machines. Due to the cycle time of 13 hours (see chapter 4.4.8), all four line assembly stations are fully utilized.

Products		AX	CR/TR	TT	∑
Capacity (One shift)	**Maximum capacity [#/year]**	26	100 mobile 38 stationary	96	**249**
Number of employsees	Employees in total	10	27	19	**55***
	Employees in main assembly	5	13	9	
	Employees in pre-assembly	3	7	4	
	Employees electric	1	4	4	
	Employees Quality control	1	3	2	

Table 18: Maximum output of *Flowing CramTer* Layout

The capacity for pre-assembly modules for 2018 was also calculated for this variant. It was important to ensure that the required times for the respective pre-assembly modules can be mounted in the cycle time. (see chapter 4.4.8) The table with the pre-assembly modules and the required employees can be found in Apendix E.

Figure 57 shows a comparison between the capacities for the variant *Flowing CramTer*, the situation of last year (2017) and the planned capacity for the year 2018. Furthermore, the second figure shows the number of employees required for the business year 2018, in order to meet the forecast for 2018 and the number of employees in the current situation in plant 2 and 3 for 2017 and in comparison, the number of required employees with the current output rate for the forecast 2018.

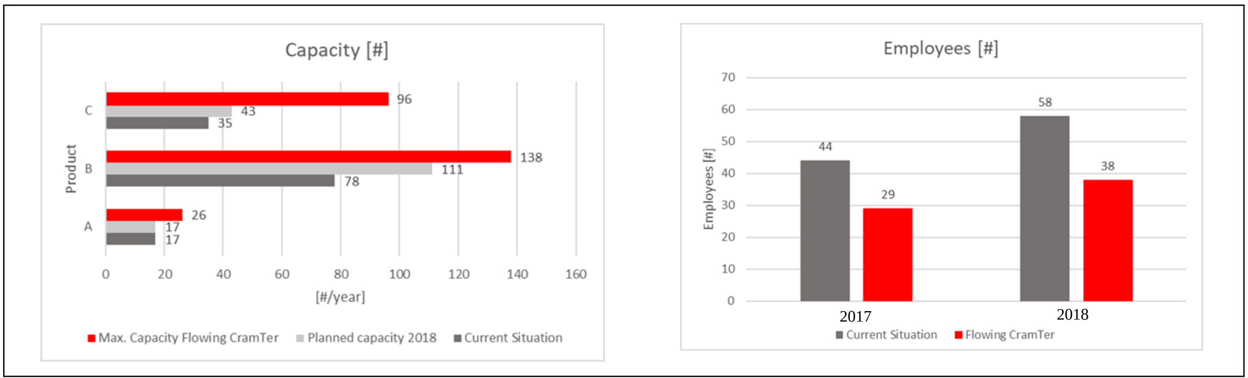


Figure 57: Comparison of capacity and employees

Layout Variant Flowing CramTer Implementation

The capacity calculation for the layout *Flowing CramTer Implementation* was the same as for the calculation of the other two variants. In this variant, only three main assembly stations are provided for the CR and TR assembly. These are used as fixed site production. No pre-assembly has been relocated parallel to the line as the area is needed for lifting in and out of the machines. Thus, the area used in the line variant *Flowing CramTer* for the assembly of stationary machines is used for pre-assembly. The total number of employees needed to meet the forecast for 2018 remains the same as for the other variant, however, a second shift must be introduced for a CR/TR assembly station. A difference to the other variant exists for the maximum possible capacity in a single-shift operation. With this arrangement, the forecast for 2018 cannot be fulfilled.

The required employees are calculated the same as in the other variants presented. Pre-assembly of the CR/TR modules will require fewer employees because of the lower maximum number of pieces. This variant should serve as an implementation aid to integrate the future structure of the flow production variant into the hall layout. With increasing process standardisation, the pre-assemblies can then be implemented next to the line and the resulting area can be used as an assembly area for the stationary machines.

4.4.4 **Utilization of the Quality check**

After final assembly, all machine groups must each undergo a quality check. The target time is different for each of these machines. Currently there is a specific hall for the quality check, separate from the assembly area. As part of this work, the utilization of this quality check station was considered a possible bottleneck in the future production process. For the final check, one employee is planned per machine. Increased employee assignment to a machine is not reflected in increased productivity or lead time reduction. Figure 67 shows the respective throughput times for the quality check and the total hours required for 2018 and 2025 with an annual increase of 6% per machine group (see table 19).

Quality check		AX	CR/TR	TT
Business year	Cycle time [h]	37	27	27
2018	Pieces [#]	17	110	43
	Total hours [#]		4760	
2025	Pieces [#]	24	158	61
	Total hours [#]		6801	

Table 19: Respective throughput time for the quality check

In table 20 the respective available capacities, depending on shift operation is shown.

	Number of assembly areas	Number of shifts	Number of employees	Capacity per year [h/year]
Qualitiy check	2	1	2	2580
	2	2	2	5160
	2	3	2	7740

Table 20: Available capacities

It can therefore be seen that from 2018, a two-shift system is already required. It should be noted that for the models of the AX product group with a length of more than 15 metres, the entire final check station is required and thus during this time no final check can be carried out for machines.

The next chapter contains the detailed layout variants drawn in AutoCad and descriptions about the characteristic of each assembly area.

4.4.5 Fine – Layout in AutoCAD

Layout Variant Company/TUGraz

The detailed layout was drawn in AutoCAD (see Apendix F). In this chapter, the characteristics of each assembly area are summarized.

- **Main assembly for CR/TR**

  In the variant *Company/TUGraz*, the CR/TR are assembled at a total of four assembly stations. The assembly of the discharge conveyer and the trailers takes place at a separate assembly area. For the assembly of the discharge conveyer, inclination of the machine is necessary. It should be noted that the outermost assembly station is cut off since this area is needed for manoeuvring the frames out of the paint booth. This smaller assembly area can be used for the assembly of CR/TR stationary machines with separate units, which do not require as much space as mobile machines.

- **Pre-/ main assembly for AX**

  One workstation is planned for the assembly of the AX. The *Schredderbox* and the *Einzugsrahmen* are pre-assembled parallel to the main assembly in the required process sequence. For the assembly of the discharge conveyer, a rotation of the machine is necessary. The conveyers can also be pre-assembled on the pre-assembly site of the *Schrederbox* and the *Einzugsrahmen*.

- **Main assembly of TT**

  There are three main assembly stations available for the TT assembly. It is possible to dissolve a main assembly site and to use the area gained for further pre-assembly in case of high demand for AX or CR/TR. An example would be to use the recovered area for pre-assembly of the *Schredderbox* and *Einzugsrahmen* when assembling a special type of AX with a transport length of 11.5 m (see chapter 4.4.10).

- **Pre-assembly of TT**

  The pre-assembly of the cab, trolleys and rollers for the TT were placed on a sufficiently large assembly area.

- **Pre-assembly of belts**

  The pre-assembly of the belts for all machine groups (discharge belt and overband magnet) takes place in this variant at an assembly area with a sufficiently large supply area more than 2 metres wide. This width is needed for lifting the discharge belt.

- **Pre-assembly of claddings**

  For the claddings of the CR/TR and the claddings for the TT, a common pre-assembly area was defined.

- **Pre-assembly of engines**

  The engines for CR, TR and TT are placed all together on one pre-assembly site. In addition, there is separate a pre-assembly area for the engines of the TT. The required capacity for both engine pre-assemblies for the forecast 2018 can be reached with two employees.

- **Pre-assembly CR/TR**

  The pre-assembly for transmission, radiator, belt tensioning console and rollers for CR/TR are merged into one pre-assembly station. The mounting of the roller bearing requires a fixed work table. The pre-assembly of the trailer for CR/TR was located in this area.

- **C-Parts storage**

  There is a large C-part warehouse with 63 shelves for the entire assembly. There is therefore also the possibility for agricultural machinery, which is located in the second hall wing, which can also be used by employees.

- **Master office**

  The master office is placed at an elevated level above the future drying chamber. This ensures unrestricted visibility over the entire assembly area.

Layout Variant Flowing CramTer Implementation

The detailed layout was drawn in AutoCad (see Apendix E) In this chapter the characteristics of each assembly area are summarized.

- **Main assembly CR/TR**

  The implementation of the variant Flowing CramTer serves as an implementation variant for the final line variant. The advantage of this variant is that the principle of fixed site production still remains. The pre-assembly modules are not yet set parallel to the CR/ TR assembly line, but are instead located on the opposite side of the hall. However, this has the consequence that for individual pre-assembly modules cranes are used for the implementation, since they are not directly accessible by forklifts. The accessibility and generous provisioning area should be used as an intermediate storage area for pre-assembly modules. This serves as a bridge until the process becomes suitable reliable.

- **Pre-assembly discharge conveyor / trailer CR/TR**

  In this variant, the landing gear and discharge conveyor for the CR/TR are pre-assembled on a separate assembly site and then merged with the basic machine at the same workstation.

- **Pre- main assembly AX**

  A workplace is provided for the installation of the AX. The *Schredderbox, Einzugsrahmen* and discharge belt are pre-assembled parallel to the main assembly area in the required process order. For the assembly of the discharge belt, no tilting of the machine is required.

- **Main assembly TT**

  There are three main assembly stations available for TT assembly. It is possible to dissolve a main assembly site and to use the area gained for further pre-assembly in case of high demand for AX/CR/TR. In chapter 4.4.6 an alternative use of the mounting surface is described in more detail.

- **Pre-assembly TT**

  The pre-assembly of the cab, trolleys and rollers for the TT were placed on a sufficiently large assembly area.

- **Pre-assembly discharge conveyor / overband magnet**

  In this variant, the pre-assembly of the discharge belts and over-belt magnets takes place on a common assembly station.

- **Pre-assembly cladding**

  For the engine claddings of the CR/TR and the claddings for the TT a common pre-assembly area was defined.

- **Pre-assembly engines CR/TR**

  The assembly of the engines for Crambo and Terminator were placed on a pre-assembly site.

- **Pre-assembly of main parts CR/TR**

  The pre-assembly for transmission, radiator, belt tensioning console and rollers for CR/TR are merged into one pre-assembly station. The mounting of the roller bearing requires a fixed work table. On this area, the pre-assembly of the *Vorfahreinrichtung* for CR/TR was located. A crane must be used in order to transfer modules from the pre-assembly area to the main assembly area.

- **Pre-assembly AX engine**
  The pre-assembly of engines for the AX machines are placed next to the main assembly area.
- **Pre-assembly TT engine**
  The motor for the TT is pre-assembled next to the TT main assembly
- **C-part warehouse**

  There is a large C-part storage for the entire assembly. There is therefore also the possibility for agricultural machinery, which is located in the second hall wing and is accessible to employees.

- **Master office**

  The master office is placed at an elevated level above the future drying chamber. This ensures unrestricted visibility across the entire assembly area

Layout Variant Flowing CramTer

- **Main assembly CR/TR**

  The variant *Flowing CramTer* provides a line production for the product groups CR/TR. The pre-assembly modules are arranged parallel to the assembly line. Thus, the pre-assembly modules can be assembled directly on the required assembling area. This prevents further movement of the modules. The contents of the main assembly are divided into four assembly sites (see chapter 4.4.3).

- **Pre-assembly discharge conveyor/trailer CR/TR**

  In this variant, the trailers and the discharge conveyer's CR/TR are pre-assembled on a separate assembly station and then merged with the base machine on the same workstation.

- **Pre- and main assembly AX**

  One assembly area is provided for the assembly of AX. The *Schredderbox, Einzugsrahmen* and discharge conveyer are pre-assembled parallel to the main assembly in the required process order. For the assembly of the discharge belt, tilting of the machine is not necessary.

- **Main assembly TT**

  Three main assembly areas are available for TT assembly. It is possible to dissolve a main assembly site and to use the area gained for further pre-assembly in case of a strong demand for AX/CR/TR. In chapter 4.4.6, an alternative use of the mounting surface is described in more detail.

- **Per-assembly TT**

  The pre-assembly of the cab, trolleys and rollers for TT were located on a sufficiently large assembly area

- **Pre-assembly discharge conveyor / overband magnet**

  The pre-assembly of the discharge belts and over-belt magnets takes place in this variant on a common assembly area directly next to the assembly line.

- **Pre-assembly cladding**

  For the assembly of the claddings of CR/TR and the claddings for TT, a common pre-assembly place was defined.

- **Pre-assembly engine CR/TR**

  The engines for CR/TR are placed on a pre-assembly site next to the assembly line.

- **Pre-assembly CR/TR**

  The pre-assembly for the transmission, radiator, belt tensioning console and rollers for CR/TR are merged into one pre-assembly station. The assembly of the roller bearing requires a fixed work table. On this area, the pre-assembly of the *Vorfahreinrichtung* for CR/TR was also located.

- **Pre-assembly engine AX**

  The pre-assembly of the engines for AX machines are located directly next to the main assembly site.

- **Pre-assembly engine TT**

  Engines for TT are pre-assembled towards the TT main assembly

- **Assembly CR/TR stationary machines**

  For the main assembly of stationary machines, which have a different process sequence than the machines in the line assembly, a separate assembly station is provided.

- **C-Part storage**

  There is one central C-part storage for the entire assembly. There is therefore also the possibility for agricultural machinery, which is located in the second hall wing to be accessed by employees.

- **Master office**

  The master office is placed on a raise above the future drying chamber. This ensures unrestricted visibility over the entire assembly area

4.4.6 Define the Cycle Time of the Assembly Line

For the product group CR and TR, the layout *Flowing CramTer* uses a line assembly process. For flow production, the cycle time of the machinery can be carried out continuously or at intervals. Flow production requires the creation of simultaneous work sequences for rigidly linked resources. Initially, the current data regarding workflow structuring does not meet these requirements. For this reason, several work steps must be combined to form a workstation unit in order to achieve a suitable balance.[198]

The planning calculation of the output cycle time is simplified in the theory calculated using the following formula.[199]

$$t_{at} = \frac{(T_{AZ} - \sum t_r) * f_{Be}}{m * f_v} \quad \textbf{(16)}$$

T_{AZ} (min/year): ……………...Net working hours, Scheduled breaks, holidays

T_r (min/year): ……………….Setup time

f_{BE} …………………………..Occupancy rate, downtime, material availability

m (Pieces/year):……………..Number of pieces to be produced per year

f_V:……………………….......Distribution time factor, includes the personal distribution time not performed by the floating employee

t_{at} (Pieces/year)……………...Discharge-cycle time

A limitation in the design of the cycle time for the CR/TR line is the maximum number of available assembly areas. A total of four assembly areas for line assembly can be integrated in the hall layout. This means the entire content of the machine must be divided into four assembly stations.

If the formula above is applied, the following cycle time would result for the production year 2018.

T_{AZ} (min/year) = 1290 h

m (Pieces/year) = 110 machines

t_{at} = 11,7 hours

Set-up time (Tr), occupancy rate (fB), and distribution time factor (fv) were not included in the calculation, as the net performance level of working time of 1290 hours had already taken this into account.

[198] vgl. Kettner, Schmidt, Greim (1984), S. 206
[199] vgl. Konold, Reger (2009), S. 111

The data for the calculation of the cycle time came from the REFA time evaluations. The main assemblies were sorted according to their assembly order, as recorded in the REFA time study. The time recording was taken daily, allowing the assembly contents of each assembly to be broken down into a sequence of operations. An attempt was then made to combine the work carried out on respective days into work packages. The aim was to distribute the entire assembly contents of all days to four assembly stations.

The following restrictions were taken into account during the calculation:

- Stationary machines with a separate or assembled unit must be mounted on a separate mounting bay
- Cycle time depends on employee deployment at the main assembly site
- Workstation 4 is used as a pre-assembly and final assembly for the discharge conveyor and trailer
- Installation sequence of stationary machines during the project period unknown because there are no REFA data and assembly plans

Thus, based on the REFA time study, the default times of the respective main assemblies were recorded. Figure 58 shows the work content for each day.

Tage		Day 1	Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9	
Content plant 2				33														
Base machine						3,8		1,8		1,5		2		3,92		5,8		0,63
Austragsband						0,8		1,6										
Add Blue						0,15				2,5								
Überbandmagnet						2				1,75								
Mechanschier Antrieb								0,41						0,83				
Motor						1,13		0,41		2		0,6		2,8		1		
Abwurfband								0,12		0,16				0,56		4		
Verkleidung												5,6		0,81				
Wände														2,15				
Aufkleber														2		1		
Trailer						0,83								0,33		3,3		8,78
Schaltgetriebe						0,23		3,43		1				3,6				
Hauptkonsole										0,36				1,2				
Zentralschmierung												5,7						
Total target times[h]				33		8,94		7,77		9,27		13,9		18,2		15,1		9,41

Figure 58: Wort content for each day for CR assembly

This table includes the work contents on the basic machine in Plant 2. The pre-assembly, electrical and quality check times have not been recorded because they are separate from the main assembly site. Figure 59 shows a proposal for a possible timing of the CR/TR assembly line. The work schedules for each assembly site, which were taken from the REFA time study, have been created. For Workstation 4, the pre-assembly for the chassis and the discharge conveyor are additionally included.

		AA 1							AA 2				AA 3				AA 4	
FT GRM				33														
GRM										9,1				10,4				
Austragsband										2,4								
Add Blue										2,65								
Überbandmagnet										3,75								
Mechanschier Antrieb										0,41				0,83				
Motor										4,14				3,8				
Abwurfband																		4,84
Verkleidung														6,41				
Wände														2,15				
Aufkleber														3				
Trailer														0,33				8
Schaltgetriebe										4,66				3,6				
Hauptkonsole										0,36				1,2				
Zentralschmierung										5,7								
total time [h] *15%				38		0		0		38,1		0		36,4		0		37,8
AA…Assembly area																		

Figure 59: Possible target times for workstations in the assembly line

The work contents are now divided among the four assembly stations in the line. The cycle time is now determined by the number of employees per workstation. The maximum number of technicians per assembly site is set at three workers. Thus, the minimum cycle time would be 13 hours.

With an annual commitment of 1290 hours per employee, 100 machines would be assembled annually. An advantage of line assembly is the high degree of standardization. Thus, new, unskilled fitters can be taught faster on a mounting site than in a fixed site production setting. This facilitates the introduction of a second layer. For the transfer of the machines along the production line, either the existing crane system can be used or conveyor vehicles are used. These already exist and transport the base frames from the paint shop to the assembly areas. For the line two more of these trucks would be needed. The estimated investment cost would be € 250,000.

4.4.7 **Possibility of Assembly Adjustment to Volatile Order Situation**

This chapter shows the possibility of individual layout variants to restructure individual assembly sites in order to be able to react to fluctuating order situations. The layout planning for Plant 2 was based on the forecast for 2018 and the respective product demand. If you compare the order situation for the past business year 2017 with the forecast for 2018, it can be seen that the percentage distribution of the ordered machines is constant, but that the order situation is increasing by 25% overall.

The number of assembly stations for the individual machine groups has been adapted adequately to the changing order situation of each machine group.

For machine group AX, the number of machines required in the forecast for 2018 is at 17 machines the same as the number of machines required in 2017. For this reason, only ne main assembly area was planned in the layout variants.

With the current planned assembly areas for AX, a maximum of 25 machines can be produced annually (One-shift operation, 5 main fitters). However, the future order situation for the AX machine group is not predictable and an increase of 25% in the following years is possible. In the case of an order backlog for AX, an adaptable main assembly location for the variant *Flowing CramtTer implementation* and *Flowing CramTer* was planned. For the variant *Company/TU Graz*, an adaptable assembly station was designed for the machines from the AX product group with a length of more than 15 metres.

Assembly adjustment for the layout Company / TU Graz

For the layout *Company/TU Graz* to use mounting place for the pre-assembly of the *Einzugsrahmen*, *Schredderbox* or trailers with low utilization of the TT assembly. This allows the assembly of the type of AX with semi-trailer with a total length of 11.5 metres. Without the relocation, it would not be possible to mount the *Einzugsrahmen* unimpeded next to the main assembly area for AX machinery with a length of 11.5 metres.

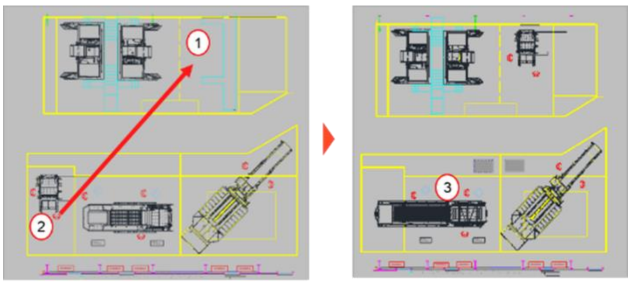


Figure 60: Assembly adjustment for *Company/TU Graz*

For machines with a total length of more than 11.5 metres, the pre-assembly is moved to a spare TT assembly station (see Fig. 60, Nr. 1 and 2). In a first step, one TT assembly area is dissolved (Nr. 1). At the free area the pre-assembly of the *Schredderbox* and *Einzugsrahmen* is moved (Nr. 2). After this process, enough space for the assembly of AX with a length of more than 11,5 metres on the main assembly area is available (Nr. 3).

Assembly adjustment for the layout Flowing CramTer

In the layout *Flowing CramTer* and *Flowing CramTer / Implementation*, which is designed for the forecast for 2018, there is a large assembly area with integrated pre-assembly for the Schredderbox, *Einzugsrahmen* and trailers for the AX. The main assembly area has been dimensioned so that a discharge belt assembly is possible without inclination. In the case that the order situation for the AX increases sharply, the pre-assembly of the *Einzugsrahmen* and the *Schredderbox* can be placed on the main assembly place of one TT. (see Fig. 79, Nos. 1 and 2). This assumes that the order situation for the machine group TT does not rise in parallel to that of the AX. Figure 61 shows the layout, designed for the forecast for 2018 and the possibility to relocate the pre-assembly to a resolved TT main assembly area.

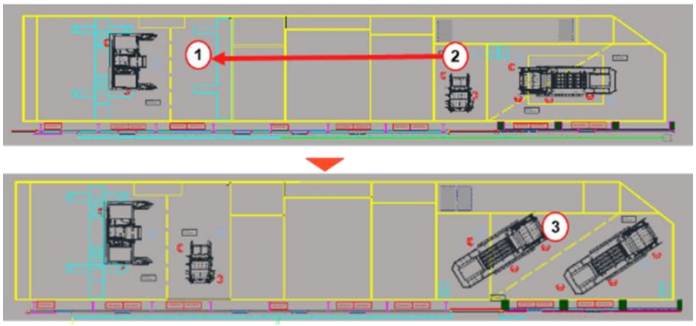


Figure 61: Assembly adjustment for *Flowing CramTer*

By relocating the pre-assembly, additional space is gained for the main assembly of the product group AX. This allows two AX to be mounted in parallel when the machines are tilted at the main assembly site (Nr. 3). The boundary conditions for this arrangement is that an AX must be lifted out of the main assembly area for conveyer assembly.

Depending on the shift operation, assembly of 34 AX can be produced in a one-shift operation with this arrangement. This would require three technicians to take over the pre-assembly. For the main assembly, three technicians and one floating employee are needed per machine for a given default time, switching between the two main assembly locations. A maximum of 48 AX could be mounted in a one-shift operation every year in this constellation. Five fitters would be needed for the two main assemblies and four fitters in total for the pre-assembly.

5 Summary and Outlook

The initial situation of this project was the planned production relocation of the environmental technology products from Plant 3 in Austria to Plant 2 in Slovenia. The project was divided into the analysis of the future material flow between the production sites (Work Package I) and the planning of the layout for the assembly of the environmental technology products at Plant 2 (Work Package II). The aim of this thesis was to make a statement about the future capacity utilization of the environmental technology assembly in Plant 2.

In a first step, the data provided by the company was processed and analysed. This should serve to examine the current material flow between the plants. When analysing the article data, however, some issues arose that made it impossible to plan the material flow. The BOMs do not indicate which processes are carried out in which plant. The so-called dummy modules prevent the transparency of the material flow and there is no connection between the article numbers of the dummy modules and the article numbers of real components. Furthermore, no process sequence of steps is recognizable and it is therefore not apparent which workpieces are painted after which step. With regard to the procurement type of the individual components, sources of error have been identified in the parts lists.

Because of these issues in the database, no material flow analysis and subsequent planning for the new production network could be carried out. After identifying the weaknesses in the data structure and the resulting consequences, the work package was completed. The result of the first work package was the identification of problems in the current data maintenance, the proposal for a new data structure and the recommendation for the design of BOMs for production.

The second work package included the layout planning of the assembly of environmental technology products at Plant 2. This was divided into two phases. The first phase involved the current state analysis and the creation of the rough layout. In the second phase, the fine layout was developed.

At the beginning of the current state analysis, all data provided was prepared and analysed. During the project period no assembly plans for the individual product groups were available. The only data provided to Graz University of Technology have been REFA time studies of the most important machines and the forecast data for 2018.

An important aim of the current state analysis was to evaluate target times. In a first step, a process order was defined with the help of the photo documentation of the recorded times. This process order was visualized for all machines using Gantt charts. The aim was to identify and redefine pre-assemblies. With the help of the visualization of process order regarding the chronological sequence of the assembly of pre-assembly components to the main machine superimpositions of pre-assemblies could be defined. An example is the pre-assembly for the AX. By determining the process order, the module *Schredderbox, Einzugsrahmen* and discharge conveyer can be mounted on one assembly area, meaning the area requirement is reduced by 59%. When investigating the TT assembly, a possible reduction of the four assembly sites to two could be identified. After the second checkpoint, a reduction to three assembly areas for the TT was agreed upon.

From the analysis of the REFA data, the final selection of the pre-assemblies, which in the future will be integrated in the hall layout of the environmental assembly, was created. In a second step, the current state of the layouts of Plant 3 and Plant 2 was examined. The aim was to obtain information about previously used assembly areas, equipment and staff deployment. During this phase, problems increasingly occurred in the assembly. These were compiled into a catalog of requirements and should already be included in the planning of the coarse layout variants.

As a first step in the rough layout phase, the space required for the main assembly sites was determined. The basis for this was the currently existing assembly sites and the resulting problems. In a joint workshop, the final sizes for the assembly areas were defined. Furthermore, the number of assembling areas for each machine group were dimensioned on the basis of the production program and the forecast. During the rough layout phase, seven layouts were worked out. Four of them were presented at the second steering meeting to the company. For these four variants, approximate capacity calculations were already carried out in the rough layout phase. To decide which layout to finalize, various criteria were considered and discussed with the company.

The company decided to continue with two variants, which have been further developed in the fine layout planning phase. One variant included a construction site production, the second a flow production, realized by an assembly line for the product groups CR/TR.

In the fine layout phase an elaboration and refinement of the two selected variants was carried out. For the variant *Flowing CramTer,* another variant was to be worked out. This variant had the same arrangement of assembly areas but instead like the *Flowing CramTer* does not contain a line production for the products CR/TR. Instead, the type of production is still a fixed site production arrangement. In the fine-layout phase, the C-part supply as well as logistical elements were defined. In addition, a detailed capacity calculation was performed for all variants. The basis was the forecast for the years 2018 till 2025. The calculation showed that both selected variants meet the forecast for the year 2018 of 170 machines in one shift. The implementation variant has to implement a second shift for the CR/TR assembly in order to be able to make the forecast for the year 2018.

In a further step, the bottleneck of the quality control hall was shown. As early as 2018, a two-shift operation must be implemented in order to provide the necessary capacity.

For the variant *Flowing CramTer,* REFA assembly plans were created for each assembly site. The company can use these assembly plans now to create work schedules by connecting the individual assembly steps with the respective component. The basis was the analysis and evaluation of the

REFA time study during the current state analysis. In order to be able to react as flexibly as possible to order fluctuations, the AX assembly area has been adapted in such a way that increase in capacity is possible in the variant *Flowing CramTer*.

As part of this project, proposals for a new data structure and recommendations for a BOM for production have been derived. Furthermore, employee-related output could be increased by 30%. Due to the optimal arrangement of the assembly areas with the highest area use efficiency, the area-related output could be increased by 29%. The planned layout variants counteract most of the problems that were identified during the analysis of the current situation.

Within this project, the company were handed over three layout variants. The variant *Company / Tu Graz* realizes a variant that can be implemented directly. For the variant *Flowing CramTer*, the company is recommended to increase the process reliability. This variant, realizing the assembly line as the type of production requires a faultless material supply management. Furthermore, it is recommended that the employees work only at one defined workstations and that the teams are no longer allocated to different assembly stations at the same time. To improve the standardization of the assembling process the company is also recommended to prepare work schedules, containing information about the target time for individual work steps and the corresponding required material to this work step.

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List of Abbreviations

ARIS …………Architecture Integrated Information System

BOM …………Bill of Material

E …………Self-made parts

F …………Procured parts

HM …………Main-assembling

LT …………Agricultural technology

UT …………Environmental technology

WE …………Incoming goods

WA …………Outgoing goods

WS …………Work station

VDI …………Verein Deutscher Ingenieure

VM …………Pre-assembling

Appendix A

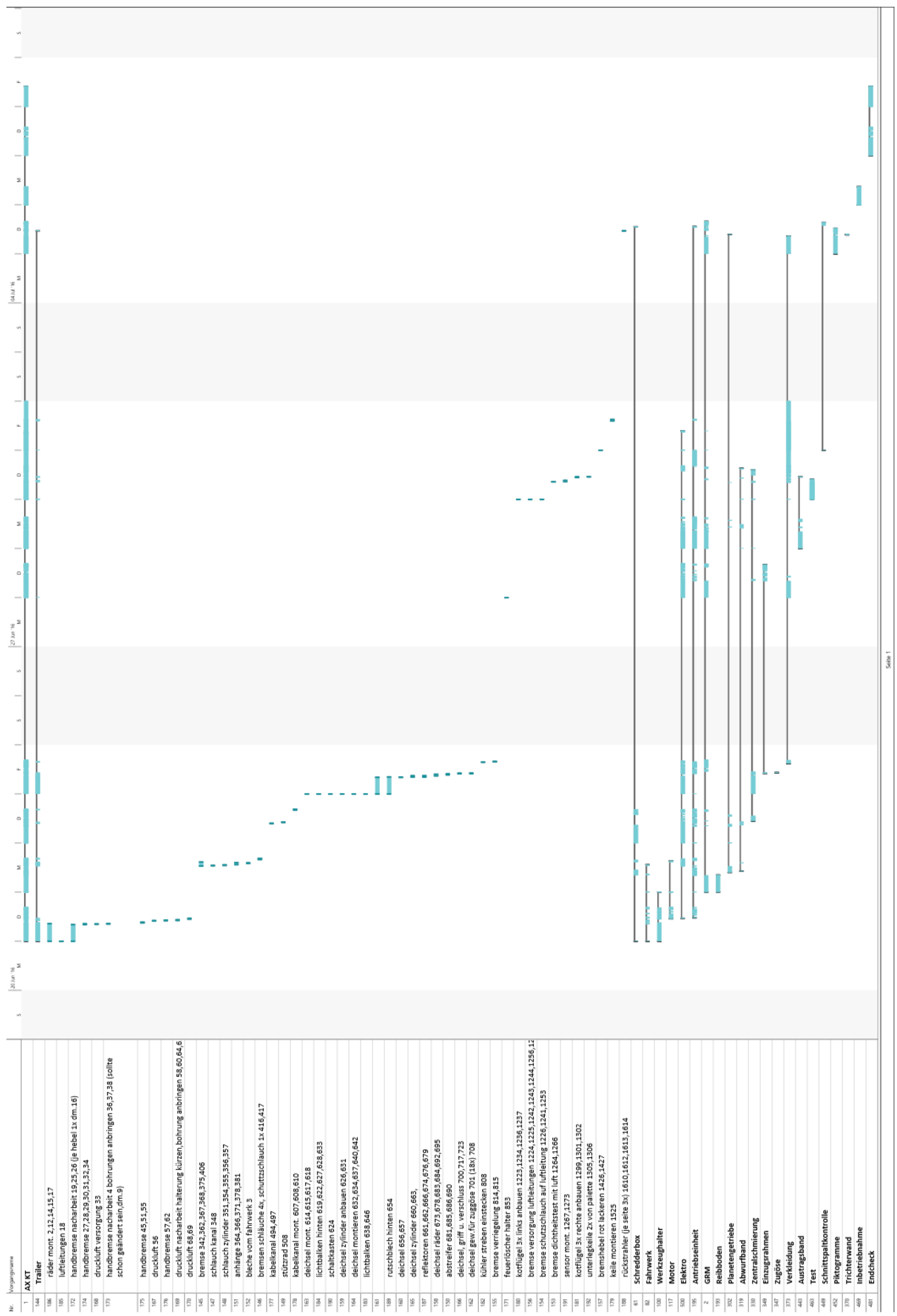


Figure 62: Example for Gantt-Chart for AX with detailed information about pree-assembly trailer

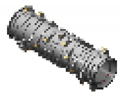
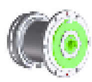
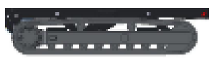
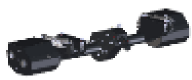
Appendix B

Nr.	Assembly content
1	AX
2	AX/Trailers
3	AX
4	CR/TR
5	CR/TR
6	CR/TR (stationary)
7	CR/TR (stationary)
8	CR/TR (stationary)
9	Loading area/ Trailer assembly

Nr.	Montageinhalt
1	CR/TR pre-assembly
2	TT assembly
3	TT pre-assembly
4	Pre-assembly
5	Painted parts
6	AX pre-assembly
7	Acriculture products
8	Loading area
9	Endcheck hall
10	Commissioning area
11	C - parts

Figure 63: Current layout of Plant 2 and Plant 3

Appendix C

Planned Pre-assembly modules				
Id.Nr.	Pre-assembly module	Machinery	Quantity of machnies per year (2018) [#]	
1	CR Drums	CR	3	
2	TR Drums	TR	48	
3	Pre-assembly Schredderbox	AX	17	
4	Schredderbox	AX	17	
5	Einzugsrahmen	AX	17	
6	Drum bearing	CR	4	
7	Cladding	CR/TR	68	
8	Track	CR	24	
9	Track	TR	15	
10	Track	AX	7	
11	Trailer	CR	40	
12	Vorfahreinrichtung	CR/TR	35	

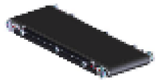
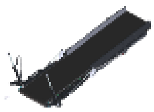
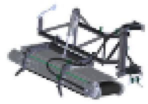
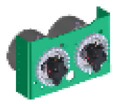
13	Conveyer belt	CR/TR	49	
14	Conveyer belt	AX	17	
15	Discharge conveyer	CR/TR	79	
16	Discharge conveyer	AX	17	
17	Overband magnet	CR/TR/AX	55	
18	Gear	CR	63	
19	Engine	CR/TR	111	
20	Engine	AX	17	
21	Water cooling	CR/TR	79	
22	Belt tensioner	CR	34	
23	Cabine	TT	43	
24	Trailer	TT	43	
25	Cladding	TT	43	
26	Engine	TT	43	
27	Drums	TT	43	
28	Track	TT	43	

Table 21: Planned pre-assembly modules

Appendix D

Figure 64: Rough layout variant *Company/TUGraz*

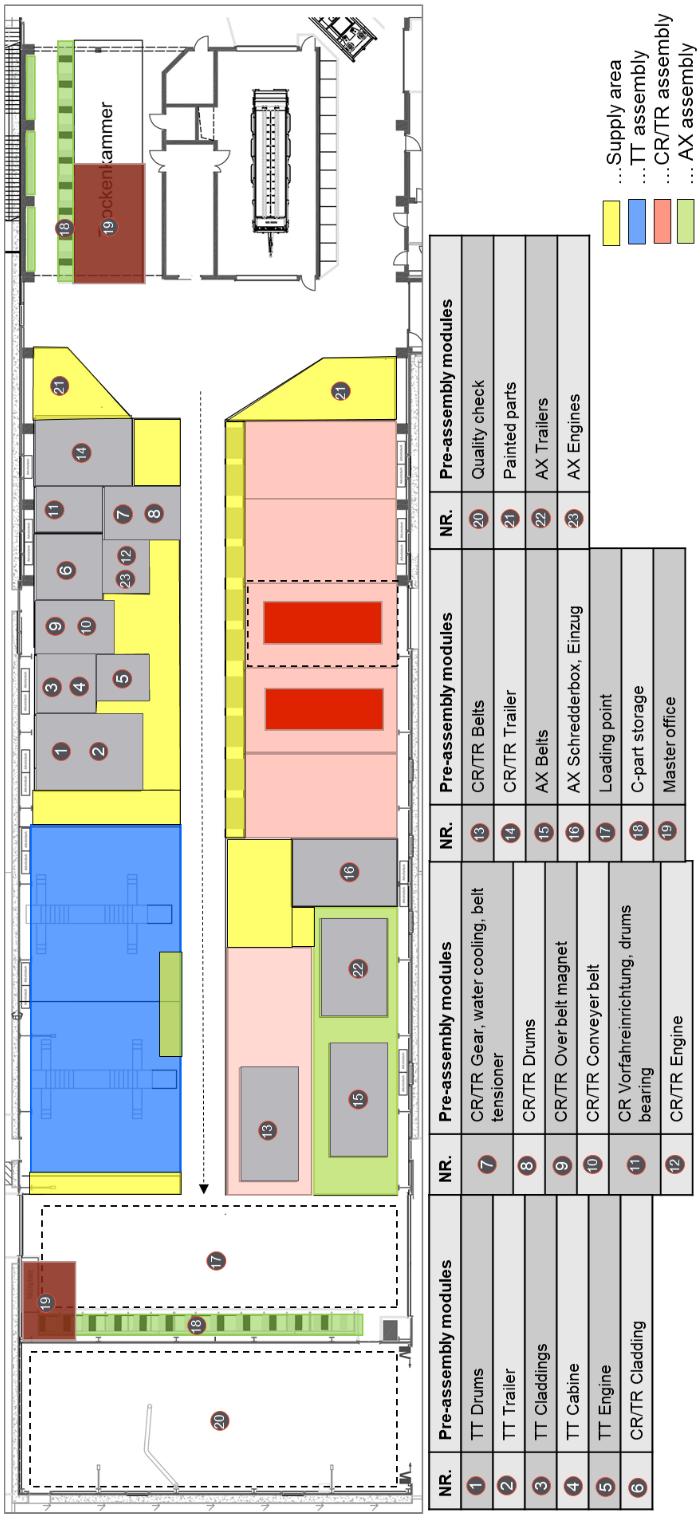


Figure 65: Rough layout variant *Skinny Box*

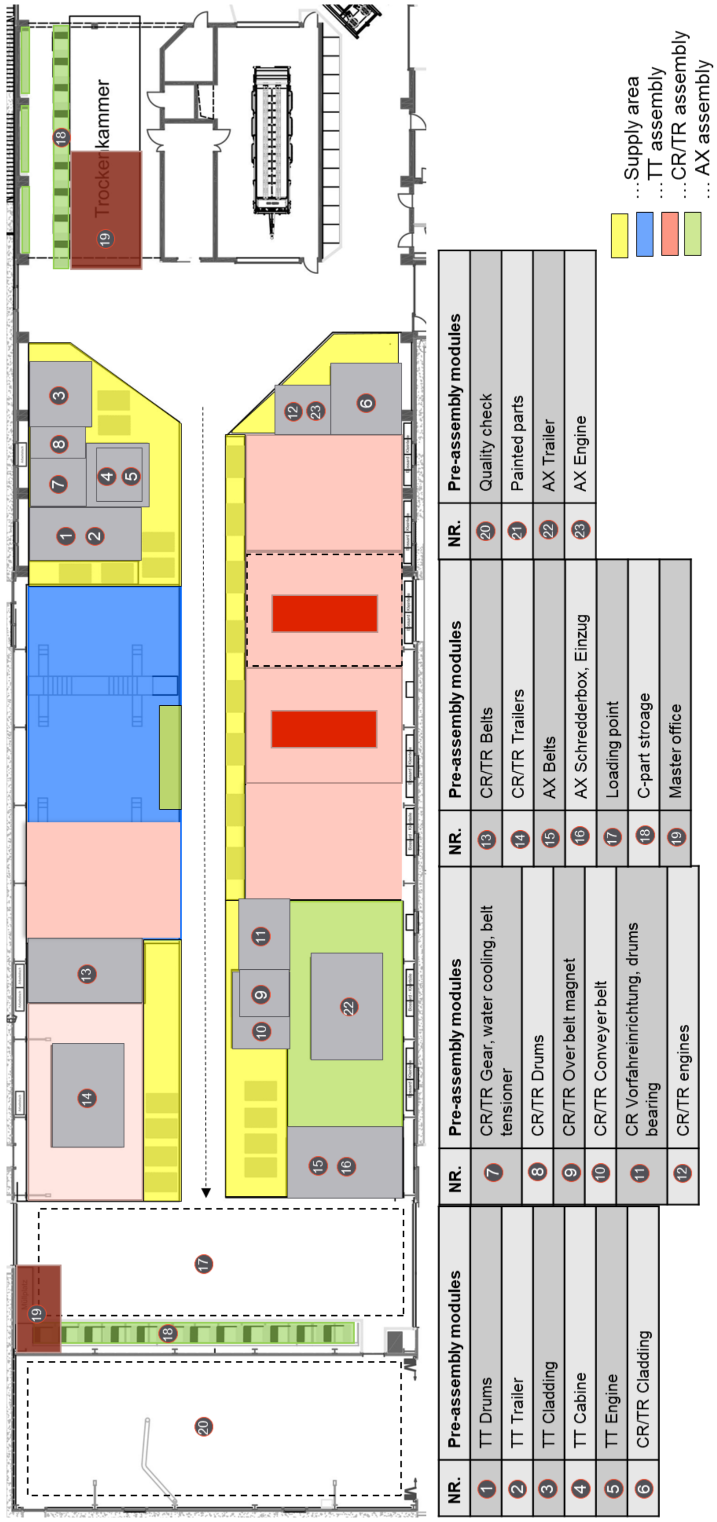


Figure 66: Rough layout variant *Standing CramTer*

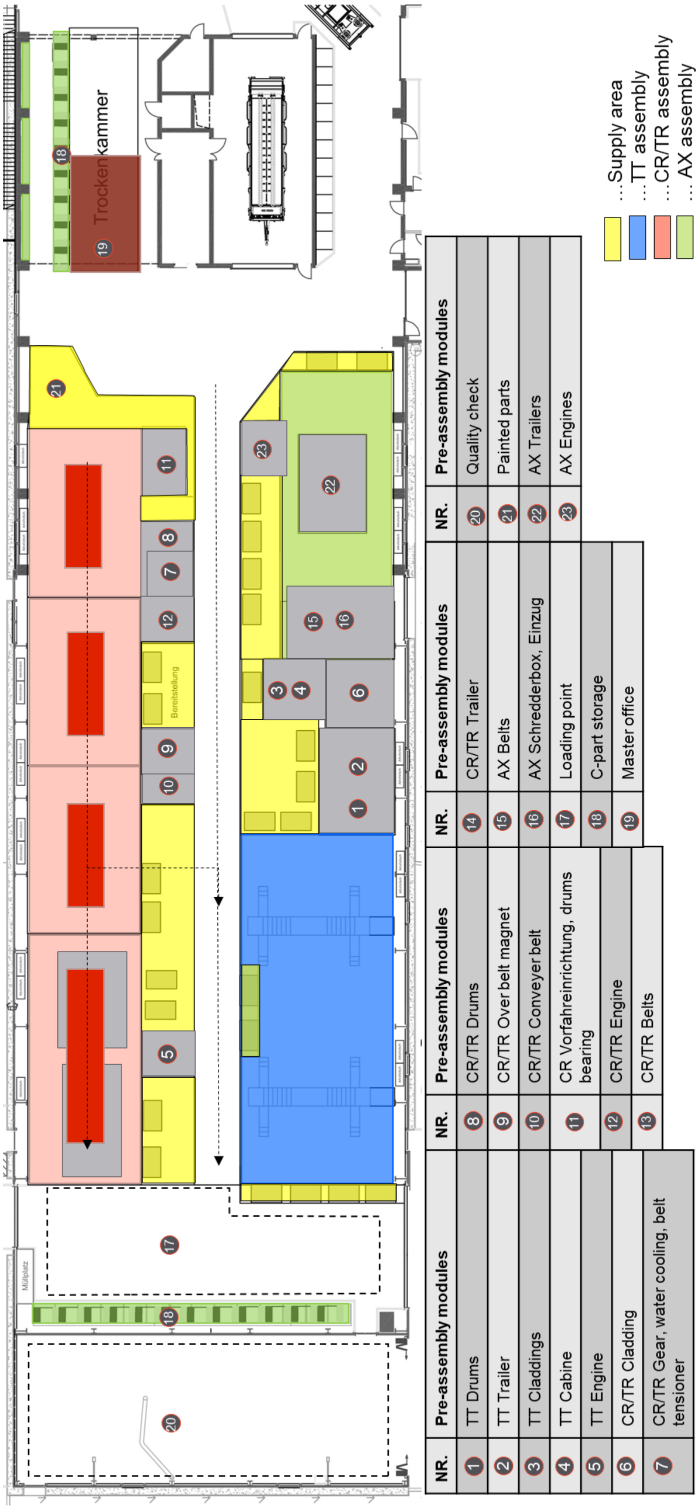


Figure 67: Rough layout variant *Flowing CramTer*

Appendix E

Company/TU Graz	Capacitiy pre-assembly											
Pree-assembly modules	Number of pieces 2018 [#]	Target time [h]	Sum of target time [h]	Employees echt assembly are	Workinghours per year [h]	Capacity/year [#]	Total amoung of assembling hours [h] VM Paket	Required employees	Arbeiter pro AP	Employees per year [h]	Number of shifts	Assembly areas
AX assembly area												
Fahrwerk AX	17	25	425	1	1290	51,6	425,0	0,33	1,0	1290	1,0	1,0
Einzug	17,0	39	663	1	1290	33,1	1513,0	1,2	2,0	1290	1,0	1,0
Schredderbox	17,0	50	850	1	1290	25,8						
								1,50	2,0			
Trailer CR/TR												
Trailer CR	14	12	170	1	1290	107,5	1341,2	1,04	1,0	1290	1,0	1,0
Trailer TR	15	12	180	1	1290	107,5						
Track CR	25	25	616	1	1290	51,6						
Track TR	15	25	375,1	1	1290	51,6						
Vorfahreinrichtung/Drum bearing												
Vorfahreinrichtung CR	19	6	114,6	1	1290	215	497,8	0,39	1,0	1290	1,0	1,0
Vorfahreinrichtung TR	15	6	90,02	1	1290	215						
Walzenlagerung montieren (2Stück)	73	4	293,2	1	1290	322,5						
Gears/Drums CR/TR												
Getriebe + Stirnplatte CR	62	4,5	277,2	1	1290	287	1077	0,83	1	1290	1	1
Wasserkühlung TR	30	2,5	75,02	1	1290	516						
Riemenspannkonsole Cr	33	4	130,6	1	1290	323						
Wasserkühlung CR	47	2,5	118,6	1	1290	516						
Walze bestückt (2 Paar) CR	61,6	3	184,8	1	1290	430						
Walze bestücken TR	48,4	6	290,4	1	1290	215						
Discharge conveyer CR/TR												
Motorverkleidung TR	18,9	17	320,9	1	1290	75,9	1127,2	0,9	1,0	1290	1,0	1,0
Motorverkleidung	47,4	17	806,3	1	1290	75,9						
Belts												
Überbandmagnet Cr	29	9	260,6	1	1290	143	1885,7	1,46	2,0	1290	1,0	1
Überbandmagnet Ax	33	9	297	1	1290	143						
Überbandmagnet TR	20	9	178,6	1	1290	143						
Austragsband Cr	47,4	5		1	1290	258						
Austragsband TR	30	5	150	1	1290	258						
Abwurfband AX	11,9	12	142,8	1	1290	108						
Abwurfband Cr	47,4	8	379,5	1	1290	161						
Abwurfband TR	30	8	240,1	1	1290	161						
Engines CR/TR/AX												
Motor CR	61,6	16	985,6	1	1290	80,625	1879	1,46	2	1290	1	1
Motor TR	48,4	16	774,4	1	1290	80,625						
Motor Ax	17	7	119	1	1290	184,285714						
								6,05	6	210	1	1
CladdingCR/TR												
Verkleidung	43	18,2	782,6	1	1290	70,88	792,92	0,61	1	1290	1	1
Bewässerung	43	0,24	10,32	2	1290	10750,00						
Engnies TT												
Motor Topturn	43	10,5	451,5	1	1290	122,857143	679,4	0,5267	1	1290	1	1
Trailer/Drums/Cabine												
Fahrwerk VM	43	1,6	68,8	1	1290	806,25	1152,4	0,8933	1	1290	1	1
Track VM	43	7,2	309,6	1	1290	179,17						
Walzen	43	12,7	546,1	1	1290	101,57						
Kabine	43	5,3	227,9	1	1290	243,40						
								2	2			
Total number of required employees [#] (Calculated/Rounded)								9,59	10			

Figure 68: Capacity calculation for pre-assembling modules *Company/TU Graz*

Variant Flowing CramTer	Capacitiy pre-assembly											
Pree-assembly modules	Number of pieces 2018 [#]	Target time [h]	Sum of target time [h]	Employees echt assembly area	Workinghours per year [h]	Capacity/year [#]	Total amoung of assembling hours [h] VM Paket	Required employees	Arbeiter pro AP	Employees per year [h]	Number of shifts	Assembly areas
AX assembling area												
TrailerAX	17,0	25,0	425,0	1,0	1290	51,6	425,0	0,3	1,0	1290,0	1,0	1,0
Einzugsrahmen	17,0	39,0	663,0	1,0	1290	33,1	1655,8	1,3	2,0	1290,0	1,0	1,0
Schredderbox	17,0	50,0	850,0	1,0	1290	25,8						
Discharge conveyer d AX	11,9	12,0	142,8	1,0	1290	107,5						
Engine Ax	17,0	7,0	119,0	1,0	1290	184,3	119,0	0,1	1,0	1290,0	1,0	1,0
								1,7	2,0			
Trailer CR/TR												
Trailer CR	14,2	12,0	170,0	1,0	1290	107,5	1341,2	1,0	1,0	1290,0	1,0	1,0
Trailer TR	15,0	12,0	180,0	1,0	1290	107,5						
Track CR	24,6	25,0	616,0	1,0	1290	51,6						
Track TR	15,0	25,0	375,1	1,0	1290	51,6						
Vorfahreinrichtung/Drum bearing												
Vorfahreinrichtung CR	19,1	6,0	114,6	1,0	1290	215,0	497,8	0,4	1,0	1290,0	1,0	1,0
Vorfahreinrichtung TR	15,0	6,0	90,0	1,0	1290	215,0						
Drum bearing	73,3	4,0	293,2	1,0	1290	322,5						
Gears/Drums CR/TR												
Gears CR	61,6	4,5	277,2	1,0	1290	286,7	1076,6	0,8	1,0	1290,0	1,0	1,0
Water cooling TR	30,0	2,5	75,0	1,0	1290	516,0						
Belt tensioner Cr	32,6	4,0	130,6	1,0	1290	322,5						
Water cooling CR	47,4	2,5	118,6	1,0	1290	516,0						
Drums CR	61,6	3,0	184,8	1,0	1290	430,0						
DrumsTR	48,4	6,0	290,4	1,0	1290	215,0						
Discharge conveyer CR/TR												
Discharge conveyer Cr	47,4	8,0	379,5	1,0	1290	161,3	619,5	0,5	1,0	1290,0	1,0	1,0
Discharge conveyer TR	30,0	8,0	240,1	1,0	1290	161,3						
CladdingCR/TR												
Cladding TR	18,9	17,0	320,9	1,0	1290	75,9	1127,2	0,9	1,0	1290,0	1,0	1,0
Cladding CR	47,4	17,0	806,3	1,0	1290	75,9						
Overband magnet/belt												
Overband magnet CR	29,0	9,0	260,6	1,0	1290	143,3	957,3	0,7	1,0	1290,0	1,0	1,0
Overband magnet AX	5,1	9,0	45,9	1,0	1290	143,3						
Overband magnet TR	19,8	9,0	178,6	1,0	1290	143,3						
Belt CR	47,4	5,0		1,0	1290	258,0						
Belt TR	30,0	5,0	150,0	1,0	1290	258,0						
Belt Ax	17,0	5,0	85,0									
Engines CR/TR												
Engine CR	61,6	16,0	985,6	1,0	1290	80,6	1760,0	1,4	2,0	1290,0	1,0	1,0
Engine Tr	48,4	16,0	774,4	1,0	1290	80,6						
								5,7	6,0	210,0	1,0	1,0
TT												
Cladding	43,0	18,2	782,6	1,0	1290,0	70,9	792,9	0,6	1,0	1290,0	1,0	1,0
Bewässerung	43,0	0,2	10,3	2,0	1290,0	10750,0						
Engnies TT												
Engine TT	43,0	10,5	451,5	1,0	1290,0	122,9	451,5	0,4	1,0	1290,0	1,0	1,0
Trailer/Drums/Cabine												
Trailer pre-asembly	43,0	1,6	68,8	1,0	1290,0	806,3	1152,4	0,9	1,0	1290,0	1,0	1,0
Track pre-assembly	43,0	7,2	309,6	1,0	1290,0	179,2						
Drums	43,0	12,7	546,1	1,0	1290,0	101,6						
Cabine	43,0	5,3	227,9	1,0	1290,0	243,4						
								1,86	2			
Total number of required employees [#] (Calculated/Rounded)								9,28	10			

Figure 69: Capacity calculation for pre-assembling modules *Flowing CramTer*

Flowing CramTer Implementation	Capacitiy pre-assembly											
Pree-assembly modules	Number of pieces 2018 [#]	Target time [h]	Sum of target time [h]	Employees echt assembly area	Workinghours per year [h]	Capacity/year [#]	Total amoung of assembling hours [h] VM Paket	Required employees	Arbeiter pro AP	Employees per year [h]	Number of shifts	Assembly areas
AX assembly area												
TrailerAX	7,0	25,0	174,3	1,0	1290	51,6	174,3	0,1	1,0	1290,0	1,0	1,0
Einzugsrahmen	17,0	39,0	663,0	1,0	1290	33,1	1655,8	1,3	2,0	1290,0	1,0	1,0
Schredderbox	17,0	50,0	850,0	1,0	1290	25,8						
Discharge conveyer d AX	11,9	12,0	142,8	1,0	1290	107,5						
Engine Ax	17,0	7,0	119,0	1,0	1290	184,3	119,0	0,1	1,0	1290,0	1,0	1,0
								1,5	2,0			
Trailer CR/TR												
Trailer CR	11,6	12,0	139,1	1,0	1290	107,5	1097,3	0,9	1,0	1290,0	1,0	1,0
Trailer TR	12,3	12,0	147,3	1,0	1290	107,5						
Track CR	20,2	25,0	504,0	1,0	1290	51,6						
Track TR	12,3	25,0	306,9	1,0	1290	51,6						
Vorfahreinrichtung/Drum bearing												
Vorfahreinrichtung CR	15,6	6,0	93,7	1,0	1290	215,0	407,3	0,3	1,0	1290,0	1,0	1,0
Vorfahreinrichtung TR	12,3	6,0	73,7	1,0	1290	215,0						
Drum bearing	60,0	4,0	239,9	1,0	1290	322,5						
Gears/Drums CR/TR												
Gears CR	50,4	4,5	226,8	1,0	1290	286,7	880,8	0,7	1,0	1290,0	1,0	1,0
Water cooling TR	24,6	2,5	61,4	1,0	1290	516,0						
Belt tensioner Cr	26,7	4,0	106,8	1,0	1290	322,5						
Water cooling CR	38,8	2,5	97,0	1,0	1290	516,0						
Drums CR	50,4	3,0	151,2	1,0	1290	430,0						
DrumsTR	39,6	6,0	237,6	1,0	1290	215,0						
Discharge conveyer CR/TR												
Discharge conveyer Cr	38,8	8,0	310,5	1,0	1290	161,3	506,9	0,4	1,0	1290,0	1,0	1,0
Discharge conveyer TR	24,6	8,0	196,4	1,0	1290	161,3						
CladdingCR/TR												
Motorverkleidung TR	15,4	17,0	262,5	1,0	1290	75,9	922,3	0,7	1,0	1290,0	1,0	1,0
Motorverkleidung	38,8	17,0	659,7	1,0	1290	75,9						
Overband magnet/belt												
Overband magnet CR	23,7	9,0	213,2	1,0	1290	143,3	807,0	0,6	1,0	1290,0	1,0	1,0
Overband magnet AX	5,1	9,0	45,9	1,0	1290	143,3						
Overband magnet TR	16,2	9,0	146,1	1,0	1290	143,3						
Belt CR	38,8	5,0		1,0	1290	258,0						
Belt TR	24,6	5,0	122,8	1,0	1290	258,0						
Belt Ax	17,0	5,0	85,0									
Engines CR/TR												
Engine CR	50,4	16,0	806,4	1,0	1290	80,6	1440,0	1,1	2,0	1290,0	1,0	1,0
Engine Tr	39,6	16,0	633,6	1,0	1290	80,6						
							6061,6	4,7	6,0	210,0	1,0	1,0
TT												
Cladding	43,0	18,2	782,6	1,0	1290,0	70,9	792,9	0,6	1,0	1290,0	1,0	1,0
Bewässerung	43,0	0,2	10,3	2,0	1290,0	10750,0						
Engines TT												
Engine TT	43,0	10,5	451,5	1,0	1290,0	122,9	451,5	0,4	1,0	1290,0	1,0	1,0
Trailer/Drums/Cabine												
Trailer pre-assembly	43,0	1,6	68,8	1,0	1290,0	806,3	1152,4	0,9	1,0	1290,0	1,0	1,0
Track pre-assembly	43,0	7,2	309,6	1,0	1290,0	179,2						
Drums	43,0	12,7	546,1	1,0	1290,0	101,6						
Cabine	43,0	5,3	227,9	1,0	1290,0	243,4						
								1,86	2			
Total number of required employees [#] (Calculated/Rounded)								8,07	10			

Figure 70: Capacity calculation for pre-assembling modules *Flowing CramTer Implementation*

Appendix F

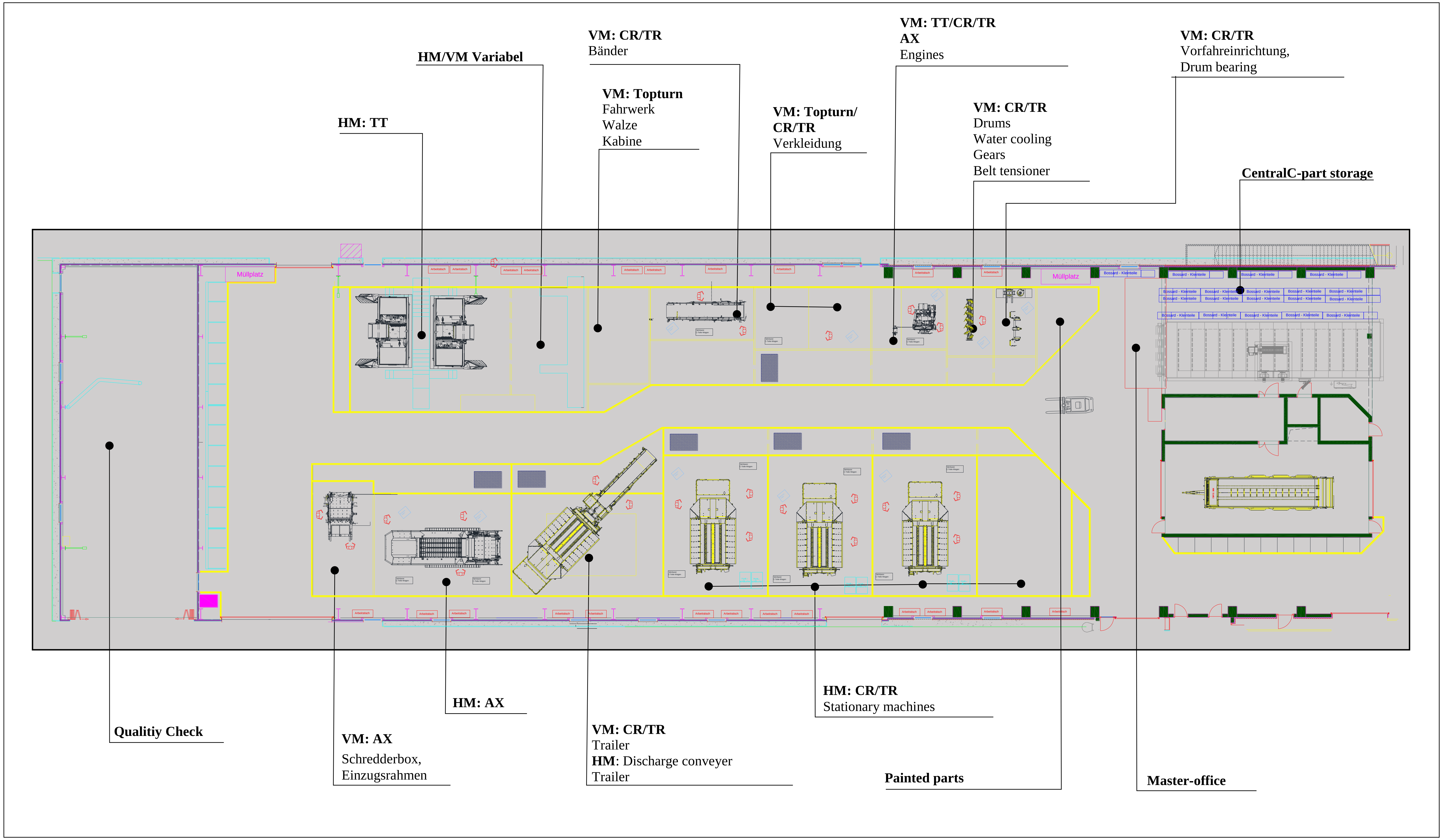


Figure 71: Fine-layout *Company/TU Graz*

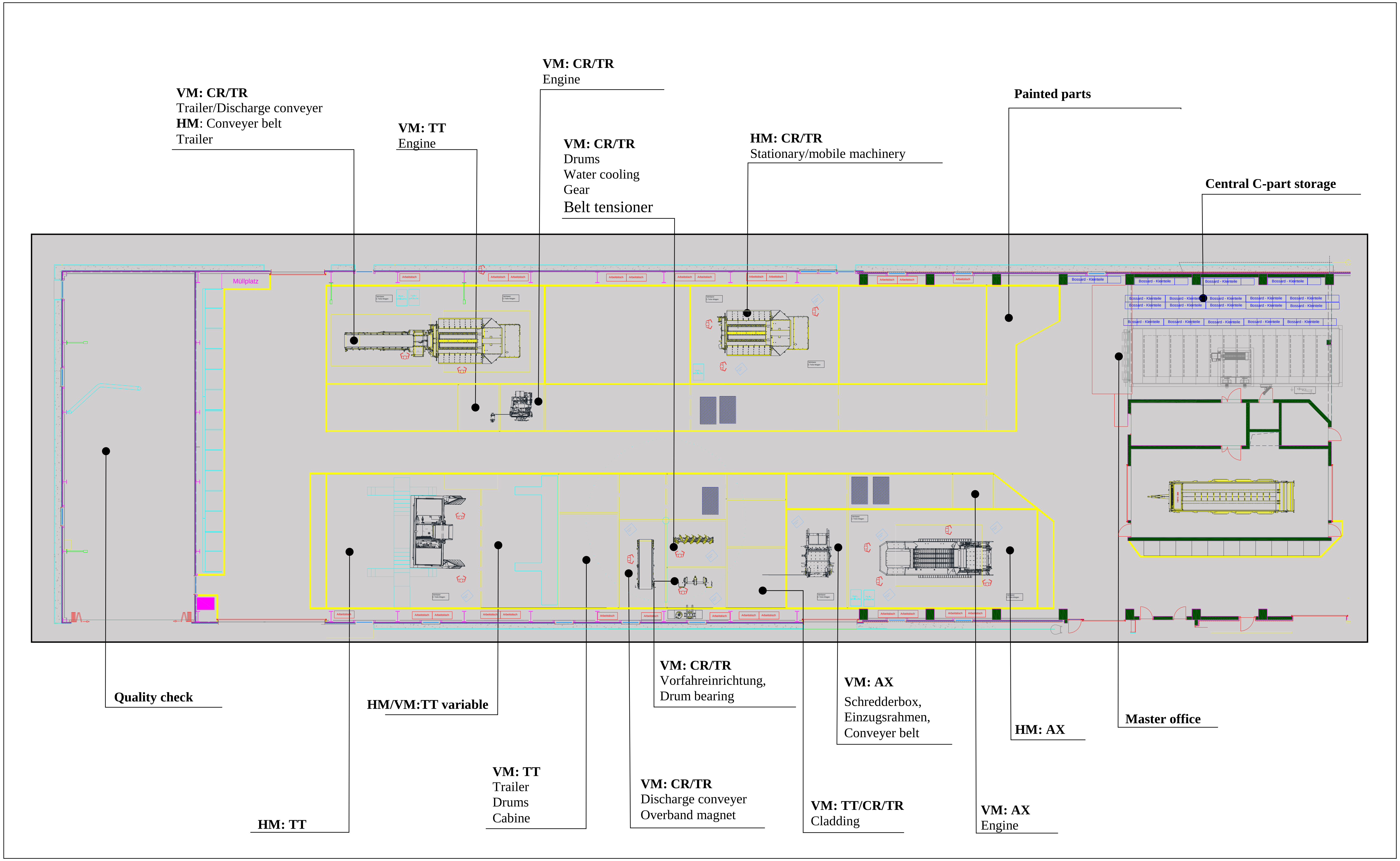


Figure 72: Fine-layout *Flowing CramTer Implementation*

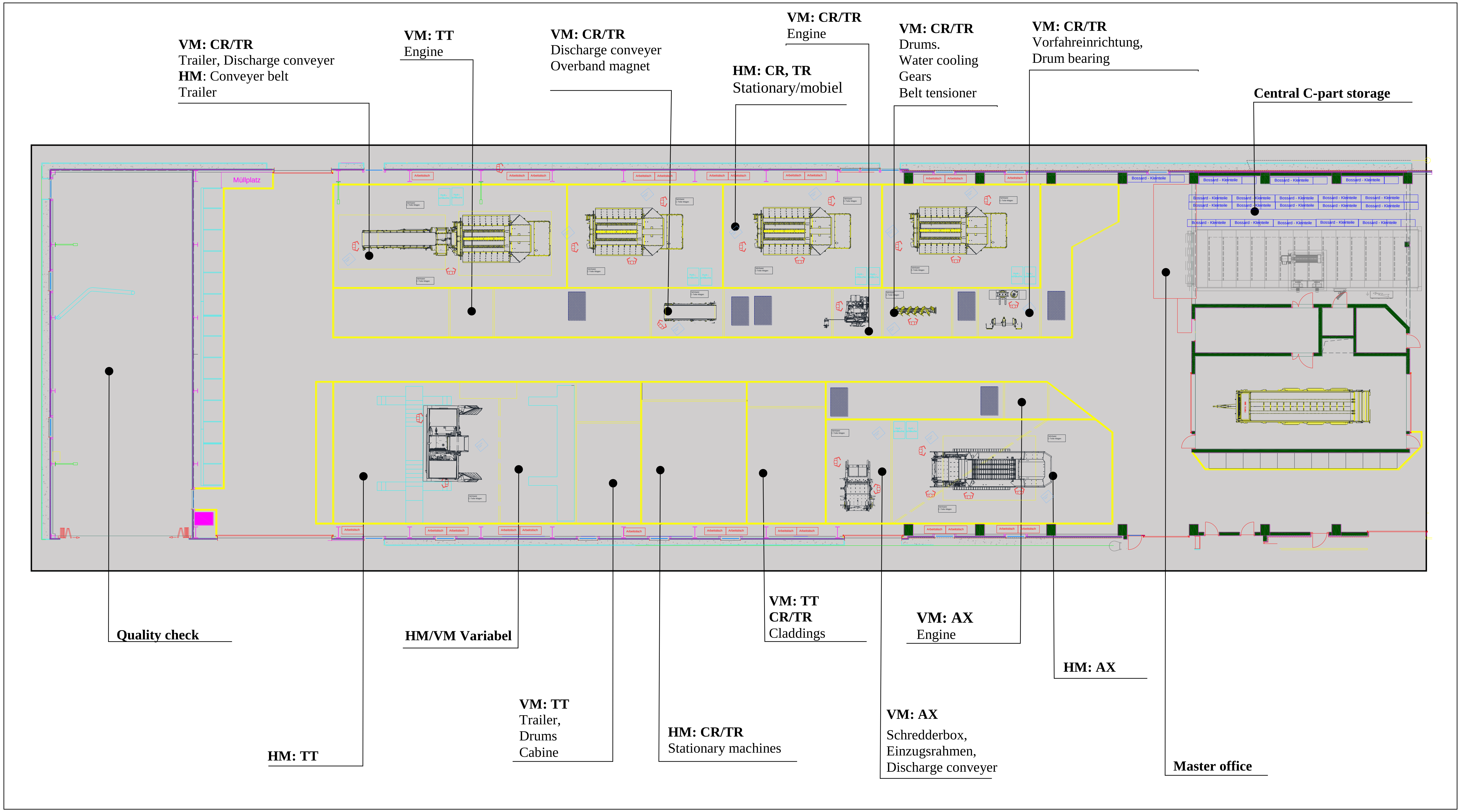


Figure 73: Fine-layout *Flowing CramTer*