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Danksagung

Diese Arbeit wurde in Zusammenarbeit mit der Unternehmung Kendrion N.V am Standort Eibiswald und unter Betreuung des Institutes für Industriebetriebslehre und Innovationsforschung unter der Leitung von Herrn Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer erstellt.

Ich möchte mich bei meinem Betreuer seitens der Universität bedanken, Herrn Dipl.-Ing Mario Kleindienst, der mit sehr viel Engagement, guten Ideen und unermüdlichem Einsatz meine Diplomarbeit betreut hat.

An dieser Stelle möchte ich mich auch bei den Mitarbeitern der Firma Kendrion bedanken, die mit ihrer Arbeit und Geduld zum Gelingen des Projektes beigetragen haben. Mein besonderer Dank gilt meinem Diplomarbeitsbetreuer seitens der Firma, Hr. Gerhard Wagner, welcher es mir ermöglicht hat, ein so interessantes Thema zu behandeln und mit seiner beruflichen Erfahrung und seinem Wissen zum erfolgreichen Abschluss der Arbeit beigetragen hat.

Ein großer Dank gebührt meinen Eltern, deren finanzielle Unterstützung diese Ausbildung erst ermöglichte. Sie begleiteten mich durch alle Höhen und Tiefen und standen mir immer mit bestem Wissen und Gewissen zu Seite.

Ein besonderer Dank gebührt meiner Freundin, die mich immer seelisch unterstütze und während des letzen halben Jahres auf viel gemeinsame Zeit verzichten musste. Sie begleitete mich auf dem Weg durch mein Studium und richtete oft meine Aufmerksamkeit auf die wichtigen Dinge.

Zuletzt ein Dank an meine Freunde, welche ich als wertvolles Gut in die Zukunft mitnehme.

Ohne diese genannten Personen wäre der Abschluss dieses bedeutenden Lebensabschnittes nie möglich gewesen.

DANKE!!!!

Kurzfassung

Diese Arbeit wurde in Kooperation mit Kendrion N.V., genauer mit dem Standort Eibiswald, und mit wissenschaftlicher Unterstützung des Institutes für Industriebetriebslehre und Innovationsforschung der Technischen Universität Graz erstellt. Kendrion N.V ist weltweit einer der führenden Produzenten von hochqualitativen Elektromagneten und gliedert sich in zwei Geschäftsbereiche: Den Sektor Industrial und den Sektor Automotive. Im Standort Eibiswald werden ausschließlich Elektromagnetkomponenten für den Sektor Automotive gefertigt. Diese Komponenten lassen sich in drei Gruppen unterteilen: Druckregelventile, Proportionalventile und Schalt-Hubmagnete. Der ausschlagebene Grund für eine Zusammenarbeit mit der Technischen Universität Graz ist der Erhalt eines Großauftrages und die damit verbundene Erweiterung der Produktion am Standort Eibiswald.

Ziel dieser Arbeit ist es, die Integration der neuen Produktionsanlagen in die bestehende Fabriksumgebung nach ökonomischen Gesichtspunkten zu planen. Dabei wird einerseits besonderer Wert auf ein materialflussoptimiertes Layout der Produktion gelegt. Hierzu wurden zunächst qualitativ mehrere Layoutvarianten entworfen und im Workshops gemeinsam mit dem Unternehmen evaluiert. Des Weiteren wurden unter Anwendung der Andler-Formel die Kostenoptimalen Bestellmengen der einzelnen Zukaufteile eruiert und der daraus resultierende Lagerplatzbedarf ermittelt.

In einem weiteren Schritt wird das gesamte Produktionssystem in Siemens Tecnomatix Plant Simulation modelliert und der Produktionsablauf simuliert. Dadurch können exakte Aussagen über die Mitarbeiter- und Maschinenauslastungen getroffen, Bottlenecks identifiziert bzw. Durchgängigkeit der Produktion überprüft werden.

Die Ergebnisse der Arbeit zeigen unter Anderem, dass die Auslastung der Mitarbeiter in der Produktion deutlich geringer ausfällt, als prognostiziert. Außerdem wird der Waschprozess vor der Vormontage als eindeutiges Bottleneck identifiziert. Durch die Simulation konnte auch gezeigt werden, dass der Aufwand für die interne Bewegung der Bauteile und Baugruppen deutlich unter dem erwarteten Aufwand liegt und durch einen Mitarbeiter innerhalb einer Schicht gut zu bewerkstelligen ist. Auch, dass an der Waschanlage für die Endmontage nur zwei Schichten notwendig sind um die Tagesmenge zu bearbeiten, konnte durch die Simulation gezeigt werden.

Der Produktionsanlauf ist 2015 geplant, bis im Jahr 2017 die volle Jahresproduktionsmenge erreicht wird. Dabei werden die Erkenntnisse welche durch diese Arbeit erlangt werden sind, in die weiteren Überlegung am Standort einfließen und zu einer hohen Planungssicherheit führen.

Abstract

This thesis was developed in cooperation with the company Kendrion N.V, focused on affiliate Eibiswald Austria, and with scientific support from the Institute of industrial management and innovation research of the Graz University of Technology. Kendrion N.V is one of the leading manufacturers of high quality electromagnetic components. Kendrion’s operations are carried out by two divisions: on the one hand division industrial and on the other hand division automotive. The affiliate Eibiswald is only operating in automotive division and the manufactured products can be divided into three main groups: pressure control valves, hydraulic proportional valves and on-off stroke solenoids. The reason for the cooperation with the Graz University of Technology is the acquisition of a major contract.

The aim of this thesis is to integrate new production facilities into the existing layout based on economic aspects. Special emphasis is put on an optimised layout in terms of material flow. Therefore, several layouts were developed and evaluated together with the company during some workshops. Furthermore, the optimum order quantity was calculated based on the strategy to reduce the logistics costs by using the EOQ formula. Afterwards, the required storage space was derived from the order quantity.

In a further step, the entire production system is simulated in Siemens Tecnomatix Plant Simulation. This tool enables to identify bottlenecks and delivers exact data about worker and machine utilizations.
The results from the simulation show that the employee’s utilization is significantly lower as predicted. Furthermore, an unexpected but very important result is that the wash unit which is needed for the pre-assembly is identified as a clear bottleneck. The simulation has also shown that the effort for the internal transportation of the components and assemblies is significantly lower than expected and is well manageable with one employee within a single shift. Another essential result is that the wash unit, which wash all parts for the final assembly, is able to wash the needed amount for three shifts just in two and therefore one employee can be rationalized.
The start of production is planned for 2015 and full annual production volume is reached in 2017. These elaborated results will be included in the further considerations at the affiliate Eibiswald and lead to a higher planning confidence.

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1 Introduction

This chapter explains the company Kendrion, in detail the affiliate located in Eibiswald. Additionally the chapter will describe the aim of the project and the approach within this thesis.

1.1 Kendrion

“Kendrion, a solution provider, develops, manufactures and markets innovative high-quality electromagnetic and mechatronic systems and components for customers all over the world.” [1]

Kendrion’s operations are carried out by two divisions with seven business units focused in specific market segments. The two divisions are the division Industrial on the one hand the division Automotive on the other hand.

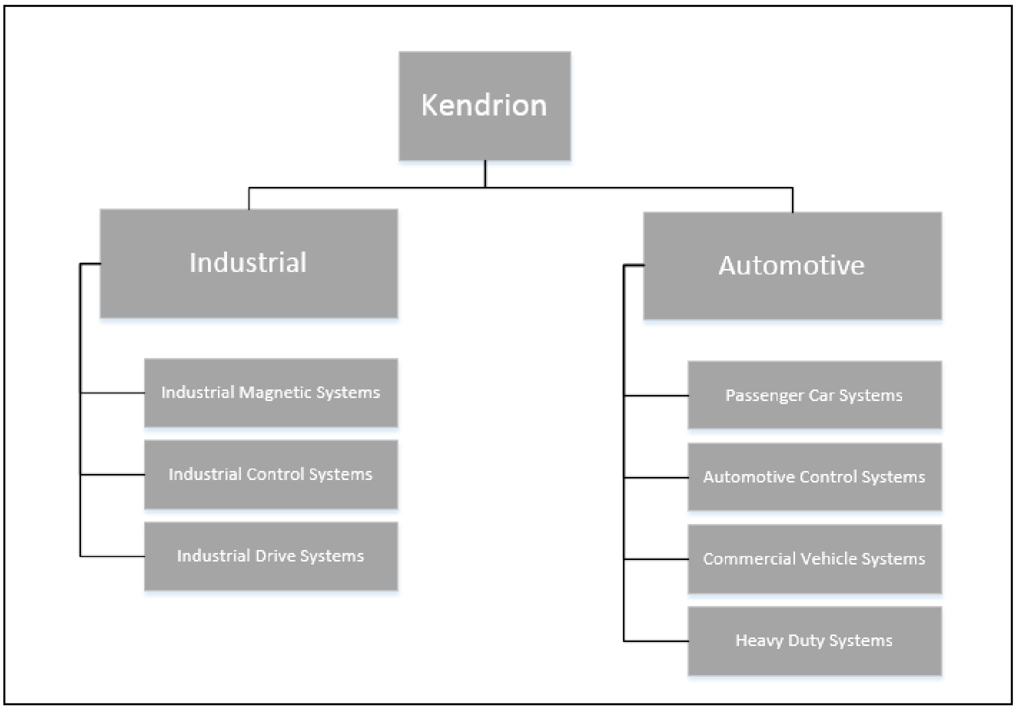


Figure 1-1: Company divisions

Kendrion has a leading position in numerous business-to-business niche markets with revenue from € 354m and with a net profit from €16,7m in year 2013. Germany, on the basis of the automotive industry, is Kendrion’s main market, although other countries are becoming more and more important. [1]

This thesis focuses on affiliate Eibiswald, which is operating in the automotive division. The affiliate Eibiswald exists since 1969 and over the years it has become the developing and manufacturing place for high-quality and innovative electromagnetic components and systems within the group. The affiliate is considered as a first-class innovative partner of the international automobile industry with a high range of products.

1.2 Aim of the project

Due to a major contract, Kendrion now faces the challenge of integrating a new production line into the existing company premises. This project requires extensive changes to the existing layout and in the organization of the material flow, as well as for manufacturing in terms of the huge production volume.
One of the goals was the determination of the required production and storage capacities. In addition, various layouts were created based on these results. The next step was to evaluate these different layouts in terms of the best material flow and other defined criteria. At the same time, the optimal order quantities were calculated at a part number level. After these two steps, it was possible to model, simulate and visualise the final layout in a simulation program and analyse the layouts with regard to bottlenecks, employee and machine utilization.

1.3 Approach

The main concern in the elaboration of the problem was to determine, to analyse, to interpret and to use the relevant data systematically. In accordance with this approach, the process was divided into three phrases. In addition to the approach, a timetable was created which is shown in the following figure 1-2.

1.3.1 Phase I: Analyse

The Phase I contained the analysis of the current situation at the company premises in Eibiswald and the analysis of the future production program.
One of the main tasks in phase I was to understand the setup of the new product and in association with the setup to comprehend the emerging material flow. In order to obtain the right information, an analysis of the company structure and organisation was carried out in the company in Eibiswald. As a result, all necessary information about the working budget, the current and expected material flow, as well as the weak spots was collected. A concrete result of the first phase was a list of all requirements, which served as input for phase II.

1.3.2 Phase II: Layout planning

The material flow and layout planning in Phase II, based on the results from Phase I, was derived in accordance with the existing limiting conditions.
The first step was to calculate the optimum succession of departments to obtain a highly efficient internal transportation. In addition to these results, it was possible to create the first simplified drafts. Concurrently, the optimized ordering cycle, order quantities and the required storage capacity were calculated. Subsequently, different layout variants were developed using the knowledge about the required space and the transport intensity between the departments.

1.3.3 Phase III: Simulation

In Phase III, the main task was to verify the results from the previous phases by modelling and simulating the elaborated layout variants in the simulation program Tecnomatix Plant Simulation 11. In addition to the normal simulation of the production program, various scenarios were developed and tested with the different layout variants. The end of phase III and hence the project was to summarize the results in a final report.

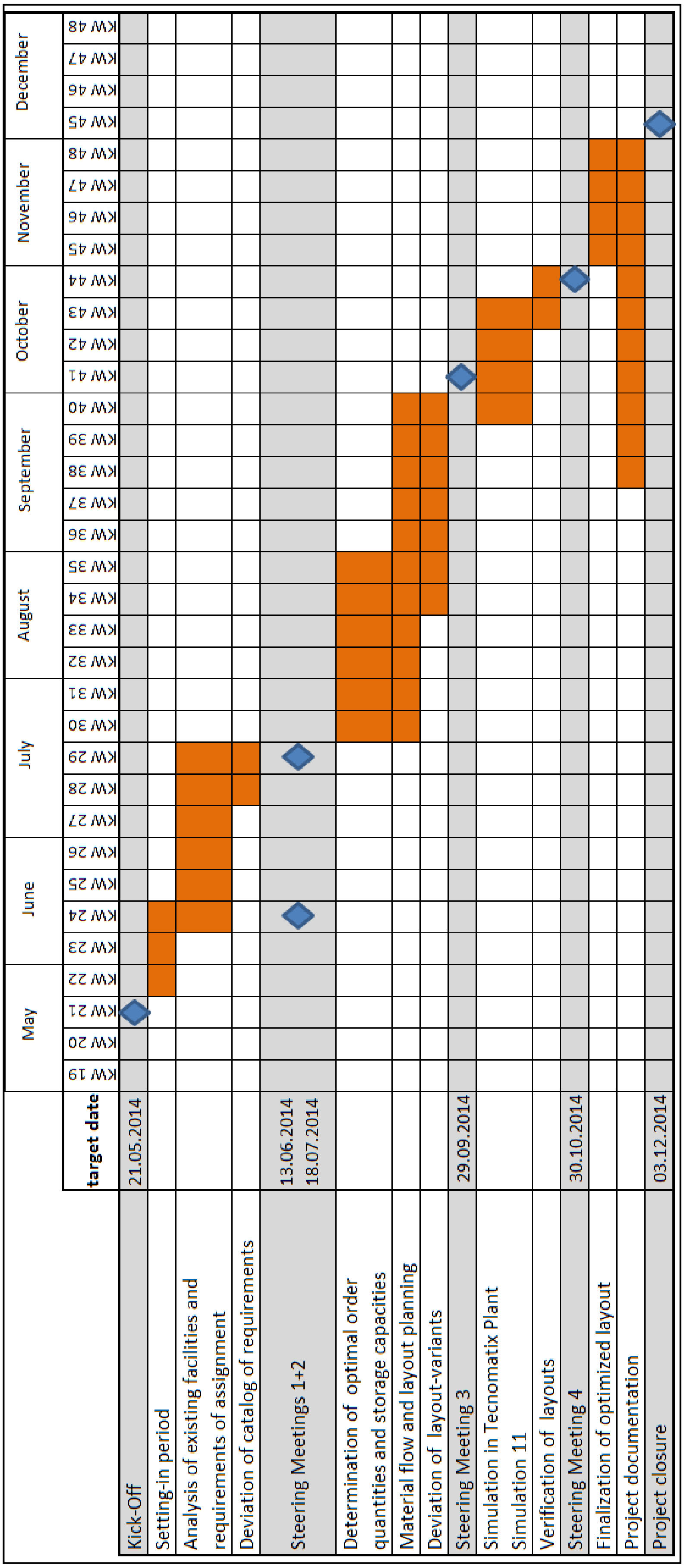


Figure 1-2: Target dates of the project

2 Logistics management

The chapter has been divided into four sections. The first section gives an overview about the development and importance of logistics. Section two defines the term “Logistics”. Afterwards, section three moves on to find out the core processes which play an important role in every logistic task. In the concluding section the different topics of the logistics are defined.

2.1 Development and importance of logistics

Due to the progressive globalisation it is increasingly important for companies to differentiate themselves from the competitors. In order to stand firm to the international competition the companies have extended their assortments and have increased their number of variants.
The increasing customer orientation has a strong impact on the use of the internal logistic system. [2, p. 14] The high amount of variants, the increasing level of products complexity and the higher market segmentation have the effect, that the complexity of logistic systems constantly rising up. Further the globalisation reinforced the effect of increase the complexity level of products and distribution.[3, p. 8] Additional the logistics systems have to be able to accomplish their job although the lead time will be shorter and the adherence to delivery dates will get more important. This result in higher logistic costs compared to the company's costs.[3, p. 46] As can be seen from the bar chart in figure 2-1 that the logistic plays already a not negligibly role in the company. Additionally this it shows the high portion of the costs caused by the logistics.

Therefore, the aim should be to develop new innovative products and bring them in a qualitative and quickly way on the market. To secure the long- term company success it’s necessary to develop sales or to reduce costs. One potential to reduce cost is the optimisation of the material flow and in the efficient use of the available means. Because of this progress the internal and the external logistics are gaining significance.

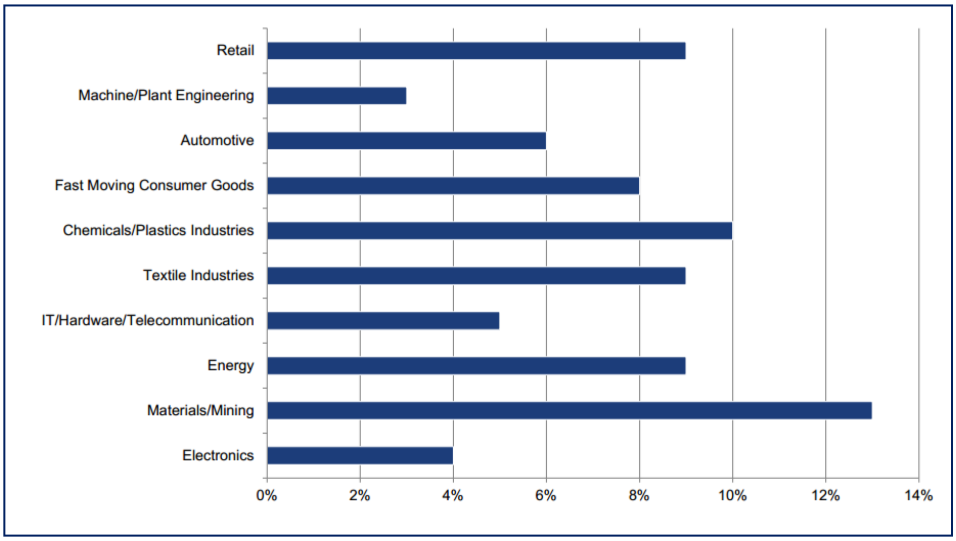


Figure 2-1: Share of logistics costs as percentage of overall revenue in selected industries [2, p. 19]

According to the VDI guidelines 2689 the economic success of the companies is not only depending on their rationalised manufacturing process. One of the main part is to be successful is the fast, smooth and cost-effective material flow in the production and warehouse.

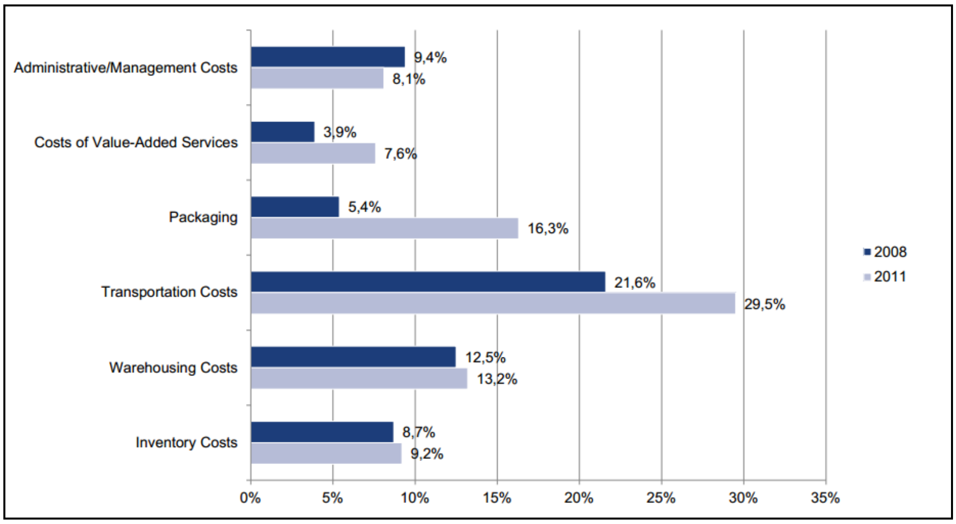


Figure 2-2: Components of total logistics costs for German manufacturing firms [2, p. 29]

Two main points emerge from the bar chart in figure 2-2. First, it shows that almost 30% of the total logistics costs are expended for transport materials and parts and circa 13% cost components for the stock in warehouses. This figure indicates also a gradual increase of most of the costs components over the last years. The cost component Packaging has a steep rise based on the increasing revenue of E-commerce.

By a specific material flow planning, however, not only the transportation costs and the stock lowered, but also a fast and trouble free production process can be achieved. This leads to a higher capacity utilisation and lower capital commitment. Thus the logistics is an important tool for increasing the profitability.

2.2 Definition “Logistics”

Logistics is defined as a holistic, cross- company approach, which has the target to optimize the material flow with the incorporation of the information flow. [4, p. 9]

Schönsleben described logistic: Logistics within and between companies is the organization, planning and the realization of the entire goods, data and control flow along of the product life cycle. And Logistics management is the effective and efficient management of logistics activities to meet the needs of customers. Thus, the goal of logistics is to avoid waste. [5, p. 7]

Further Logistics is the pursuit for the seven right r’s: the **r**ight goods in the **r**ight quantity, with the **r**ight quality, at the **r**ight time, with the **r**ight cost, at the **r**ight place and in cooperation with the **r**ight knowledge.[6, p. 11]

2.3 Core logistics processes

In order to meet the seven right r’s, it requires the implementation of core logistics processes transportation, handling, packing, storage, scheduling and picking. In the following these core logistics processes are explained in this chapter.

- Transportation

Transport processes occur along the whole logistics chain. A distinction is made between internal and external processes. External transport connects departments like the distribution and procurement of two or more companies on the one hand. It refers also to transport between different business locations of a company on the other hand.
Internal transportation is the movement of goods in a company. This includes all different transports like the transport between different departments or storages and the transport to or in the receiving and dispatch storages. [7, p. 9]

- Handling

Handling processes are everywhere, for instance where transport is changing or transferring from the internal to the external transport. Thus, they must be designed in a way that they are able to fulfil their tasks by a minimum of costs and with a minimum of time delay.[7, p. 9]

- Packing

The packing pursues in addition to the protective function for the packaged itself some more important logistical functions: a simple handling during picking and transportation and a good use of space for storage and as well for the movement. Furthermore, the packaging can provide information about the packaged, the receiving location and the transport, especially in electronically readable form. [7, p. 10]

- Storage

Storage can be considered as the planned stock of work objects in the material flow. The storage process is used to bridge timing differences between incoming and outgoing goods. Thus storage is a compensation functions to ensure the production and the delivery. So, for example, safety stock secures the delivery capacity for uncertainties regarding future quantity and times. The amount of inventory depends on the upstream and downstream processes.[7, p. 10]

- Scheduling

Scheduling consist of the quantitative classification of contracts. This classification regards the current service requirements and the scheduled allocation of available resources. In the daily business the tasks are to divide the incoming orders and assign the orders to the departments, as well as to control the material flow and inventories so that all orders are able to be delivered on at the required delivery date. The order of materials is also one of the tasks of a dispatcher.[7, p. 10]

- Picking

Normally there are a lot of changes in terms of order quantity and there are a lot of modifications regarding the composition of an order. In order to meet these requirements it’s necessary to respond flexibly. It should be possible to dissolve loading units and to compile it in terms of the new customer requirement. Thus, the order preparation operation is one of a logistic warehouse's processes. It is made of taking and collecting articles in a specified quantity before shipment to satisfy customers' orders. That means that picking represents a basic warehousing process and has an important influence on supply chain's productivity. [7, p. 9]

2.4 Corporate logistics

Built on information about logistic processes, this chapter discusses the field of cooperate logistics. Further, the different segmentations are explained and considered.

The problem of logistics is closely related to those of the production. The overall function of logistics, as in the production, can be divided into several sub functions. By consideration of the material flow through a company various tasks of logistics can be differentiated.[8, p. 16]

Typical functions of logistics are:

- Delivery of applicable material to a receiving storage or to a workstation. This task is processed from the procurement logistic.
- The transportation from work pieces between different departments. This task is processed from the production logistic.
- Delivery to the customer. This task is processed from the distribution logistic. [4, p. 9]

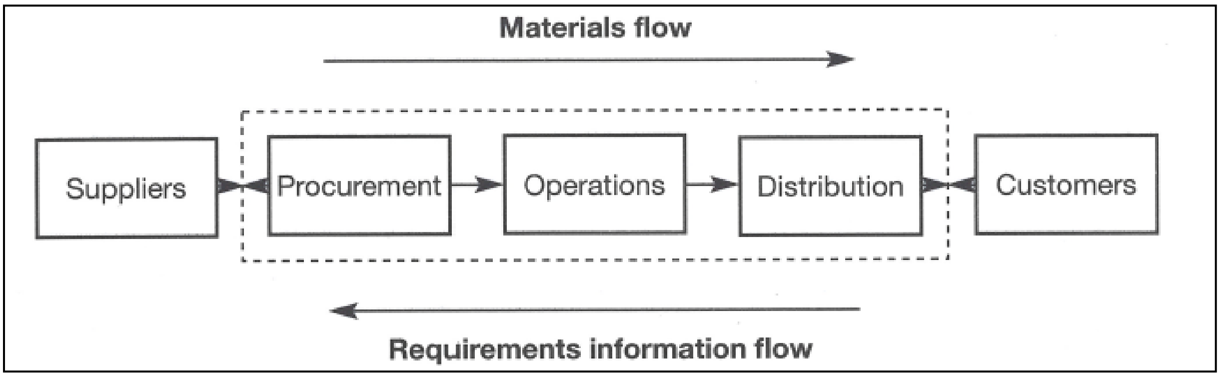


Figure 2-3: Logistic management process [9, p. 13]

The subdivisions of logistic can be seen in figure 2-3, which are procurement, operation and the distribution function. Because of these different functions there exists a very close cooperation with other departments. Especially, there is a high cooperation between production, procurement and operation subdivision. [4, p. 9] Thus, logistics represent an important part in the company organisation and is integrated and supports the main activities. If we take a look on the market and the relationship between the customer, the company and the competitor, we identify that the logistics management can provide a multitude of ways to increase efficiency and productivity and contribute significantly to reduce unit costs. Consequently, logistics is also co-responsible for the company success. [9, p. 7]

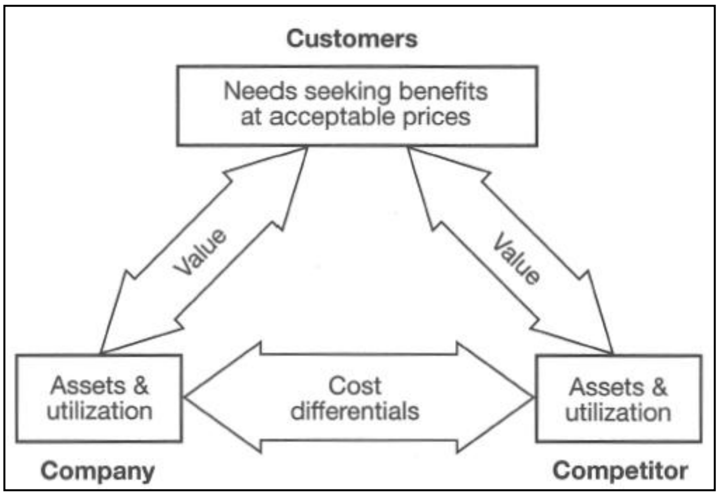


Figure 2-4: The three-way relationship [9, p. 5]

2.4.1 Procurement logistics

Procurement logistics plays an important role in the supply of a company and stays at the beginning of the logistics chain. It can be seen next to the production and sales as one of the basic functions in a company.

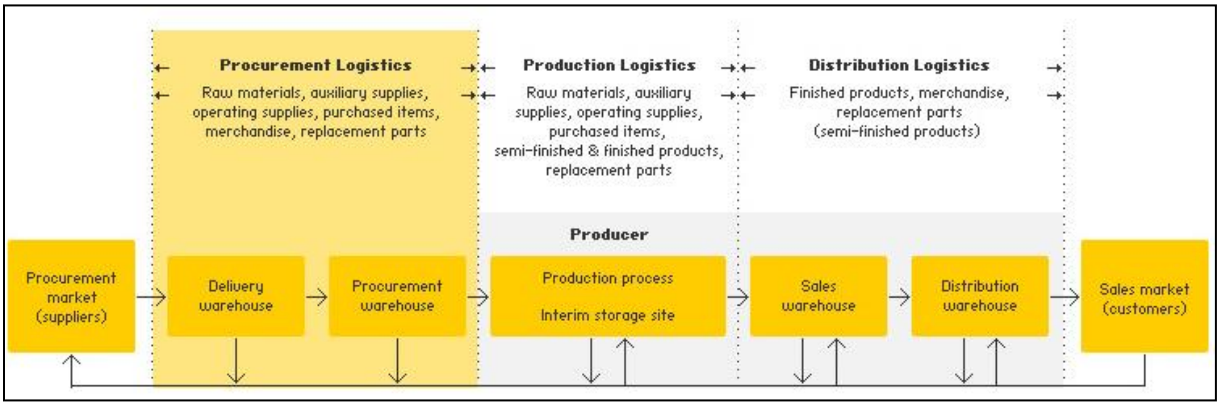


Figure 2-5: Procurement logistics [8, p. 16]

The procurement logistics is responsible for the operational readiness of the production and is also responsible for the availability of the needed materials. It includes all arrangements to supply the company with those factors required by the production that not be made by themselves. Production factors can be either physical goods, for example raw materials, parts and equipment or services or information. The procurement logistics provides therefore an optimal and timely delivery of production factors.[7, p. 13]

The resulting material and information flows go out beyond their own company boundaries. The procurement is therefore an interface to the environment and is also a cross-company part of the value chain. Because of the relationship with the environment and the production the procurement logistics is focused on the analysis and optimise of the external and internal material and information flow. The figure 2-6 represents very clearly the position of the procurement logistics between the company and the market. [10, p. 50]

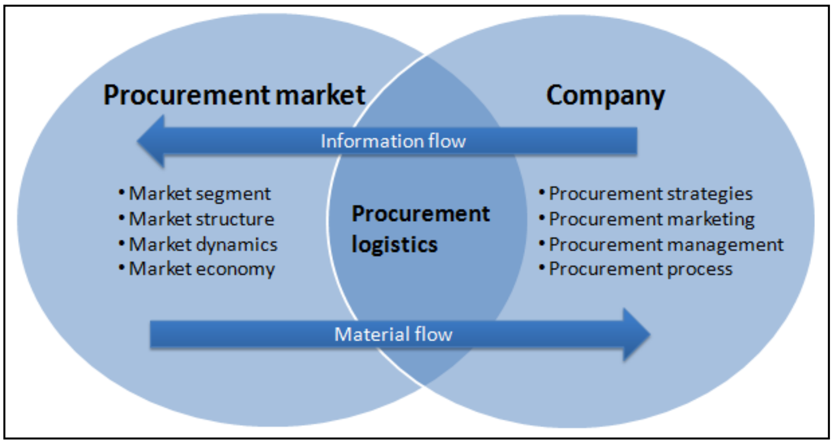


Figure 2-6: Position of the procurement logistics: [10, p. 50]

The main tasks are:

- Determining of the demand quantity based on a production program
- Determining of the order point and quantity
- Make or Buy decision
- Supplier management
- Analyse and determination of the stocks
- Purchase of the required production factors

Procurement logistics fulfils a number of important requirements. Furthermore, it is responsible that the optimal supply is given with all necessary materials at the appropriate time. It also promotes the economical use of resources and guarantees that low inventories prevail and therefore a reduction of storage costs is possible. Among other things, it provides optimal utilization of capacity and enables a quick response to customer requests. [10, p. 52]

2.4.2 Operations logistics

The main tasks of the production logistics are the planning, management and control of the production, internal transport, handling and warehouse processes. It involves the steady and sufficient supply of the individual manufacturing departments with the necessary materials. The optimization of the material flow between the stages and the storage is also a matter of this subdivision. [7, p. 14] The position of the production logistics in the value chain is illustrated in figure 2-7.

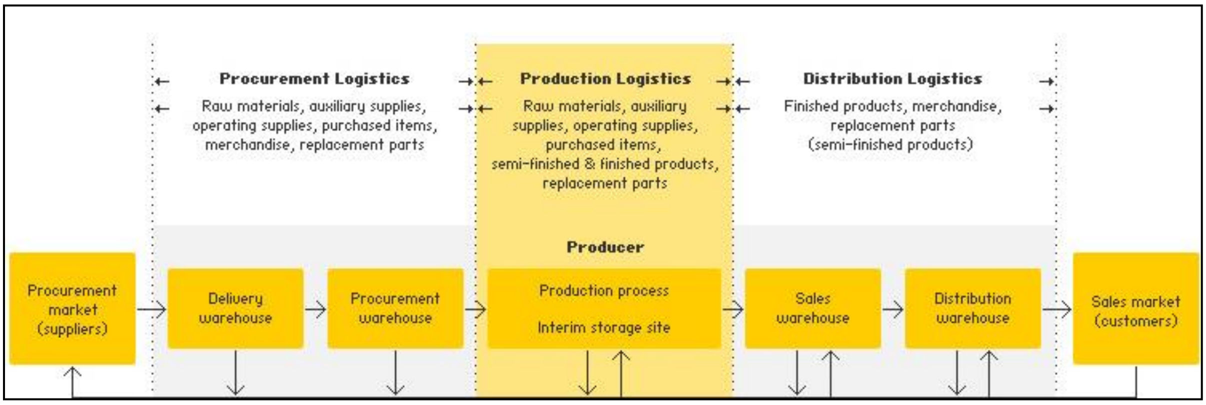


Figure 2-7: Production logistics [8, p. 18]

The main tasks of production logistics can be divided in program planning, material planning, scheduling and capacity planning. The production program planning calculates the required amounts based on the actual production range. The next task, the material planning plans the storage and ensures the provision of needed material. The scheduling defines the delivery and manufacturing dates. Finally, the capacity planning manages the coordination of capacity allocation of resources. [11, p. T1]

Furthermore the production logistics is a very important prerequisite for the business success. From the financial perspective of the company the production logistics sustains some very important success factors like the company profit, the return on investment and the liquidity. From the perspective of a customer these part of logistics have an influence on the costumer connectivity, customer satisfaction and winning new clients.[11, p. T1]

2.4.3 Distribution logistics

Distribution logistics covers all necessary activities to transfer the goods from industry to the customer. The basic task of distribution logistics is the efficient provision of goods for downstream companies in compliance with specified quality criteria, for example delivery performance, product and service quality. Thus the distribution logistics represents a link between production and the market, which is represented the figure 2-8. [7, p. 13]

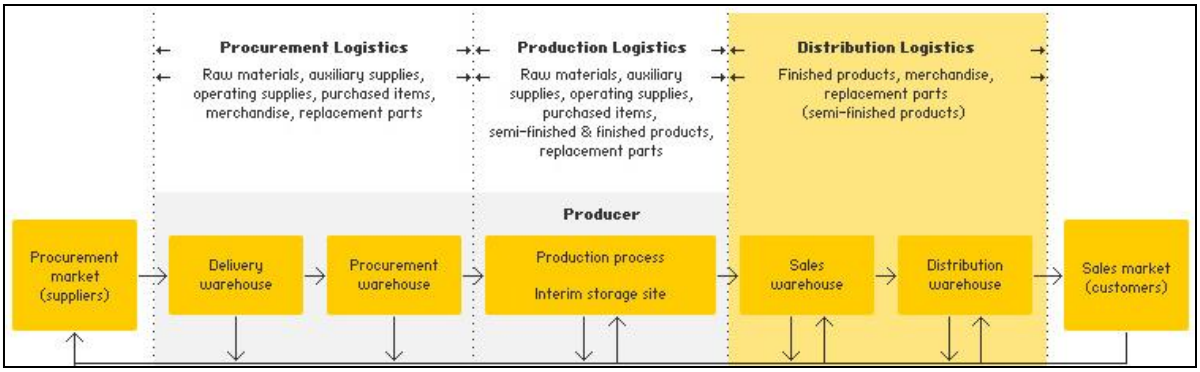


Figure 2-8: Distribution logistics [8, p. 18]

Distribution logistics includes all logistics activities that act with the storage, picking and packing the products, as well as the transportation to the customer Therefore, it is characterized by a high customer orientation. The maintenance and improvement of delivery reliability, delivery capacity and delivery service is very important to convince the customer of company's the logistics performance.[12, p. 99]

In addition to these core processes, the logistic distribution also includes planning activities, such as the design of optimal distribution networks and storage locations as well as administrative tasks and order processing. [7, p. 13]

3 Material requirement planning

This chapter is divided into five main parts. At the beginning of the chapter is tried to be answered the question “Why is it so important to have a correct assessment about the needed materials and goods”. Section two moves on to consider the different types of material requirements. The following part covers all information about different methods for the right determination of material requirements. Section four goes on to discuss the order point technique which includes how to determine the appropriate safety stock. The concluding section gives information about the resulting logistics costs and explains how to calculate the optimum batch size to keep the costs low.

Stocks are necessary for balancing fluctuations between consumption and production. Stocks are also able to secure production and supply interruptions. They are needed to meet the performance or service requirements and are suitable for optimize the operating costs. Stocks of goods require internal storage bins, cause capital commitment and they are associated with risk. These are some reasons why the stock of goods is tried to be reduced without considering increasing costs and degradation of their performance. Too high and too low stocks are results of a lack of knowledge and of other facts, for example:

- Shared responsibility for stocks and inventory costs
- Lack of criteria for selection of stocked items
- Excessive requirement on the delivery capacity
- Wrong or a insufficient assessment of demand [13, p. 356]

The first three facts are easily to correct with strategic arrangements:

- Transfer of responsibility for stocks and inventory costs to one office
- Targeted selection of the stocked items
- Accurate determination of the delivery capacity [13, p. 356]

3.1 The different types of material requirement

The material requirement planning is principally involved in the decision, which materials are ordered. It is also responsible to decide the amount and the delivery time. It is necessary to order the right materials in order to meet requirements for a given production program or to fulfil a customer’s order. The material requirement characterizes the type and amount of material, which is needed for the production or to supply the sales market.

In general, there are three main types, which is shown in figure 3-1: [14]

- **Primary requirements**: They are products or parts and they are finished for shipping. The primary requirement is commonly called market demand.
- **Secondary requirements**: These are materials and they are needed to produce the primary requirements.
- **Tertiary requirements**: These are auxiliary and operating materials and they are needed to produce the primary requirements.

Furthermore the requirement is divided in consideration of the warehouse stocks into:

- **Gross requirements:** These are material requirements without consideration of the warehouse stock.
- **Net requirements:** These are material requirements in consideration of the warehouse stock. [14]

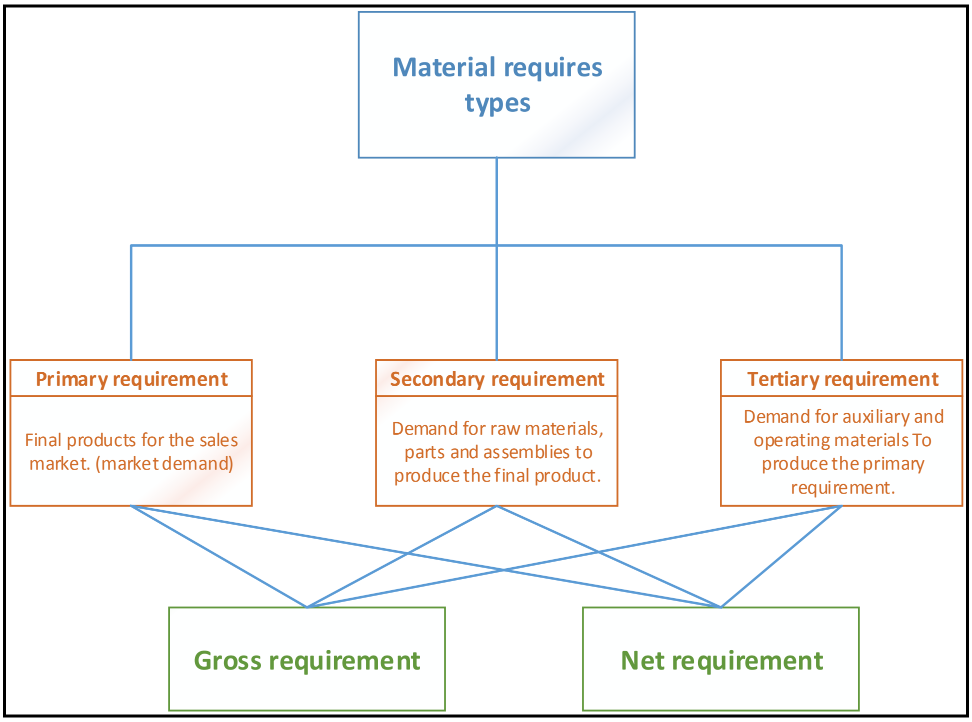


Figure 3-1: Three main types of material requirements

3.2 Methods of material requirements determination

There are basically three different methods to plan the material requirement. All of them are valid for the primary as well as for the secondary requirements. They are called deterministic, stochastic and heuristic needs assessment. [14]

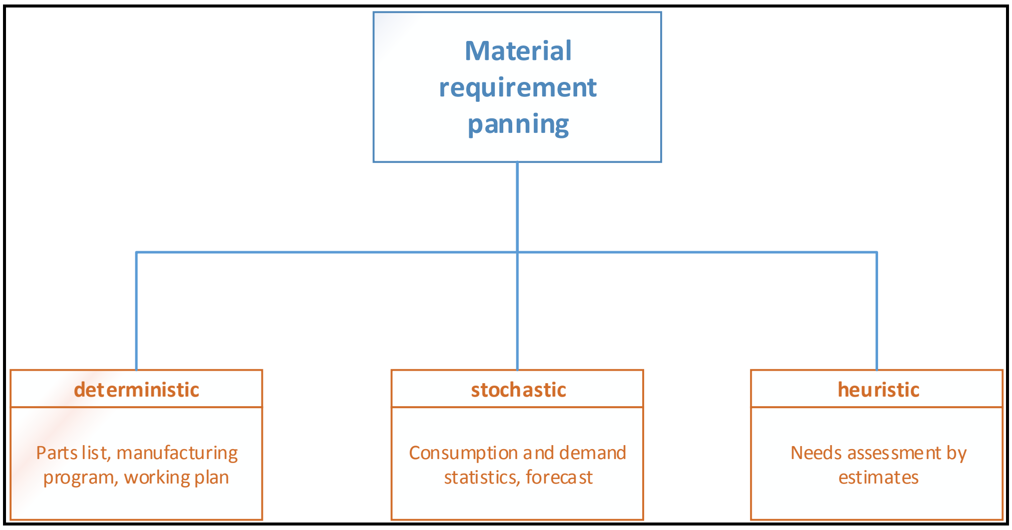


Figure 3-2: Different methods of material requirement planning

3.2.1 Deterministic approach

The deterministic method calculates the secondary needs on the basis of part lists, manufacturing programs and working plans derived from the primary requirements. The deterministic method is used for quality or customer-specific goods, some of them may have a long lead time. In principle, the deterministic identification of needs is desirable. Because the secondary requirement can be exactly determined and so it's possible to keep the stock low and material shortages can be avoided.[14]

Information needed for a determining assessment:

- The knowledge of the primary products for a certain period of time
- Part lists, to calculate the secondary requirement
- To know the lead time in every manufacturing level and the replenishment lead time[14]

3.2.2 Stochastic approach

The fundamental for the stochastic method are the consumption values of the past. These values are statistically evaluated and updated in the form of predictions about the future. Sufficient data are the precondition for the application of the stochastic method. It must have sufficient information on the consumption in the past.

Stochastic methods are not suitable for new products, and premium high-tech parts.[14]

3.2.3 Heuristic approach

In the heuristic method, an experienced employee or experts determines the requirements with subjective estimates. This method is suitable for products, assemblies or parts with no existing sufficient data from the past. For example the method is appropriate for new products. Or maybe data of a similar part can be used. The disadvantage is that each article must be individually considered. With a large number of products or parts an individual assessment is very costly. Hence it is only estimates. The resulting inaccuracies can be compensated by safety stocks to ensure stock availability.[14]

But it is necessary to focus on groups of materials that require special treatment in the procurement process. There are a lot of various types of tools and in this thesis the differentiation in diverse groups is made with the ABC- analysis which is explained in the next section.

ABC- analysis

The ABC analysis is an important tool for the material requirements analysis. ABC analysis illustrates the materials according to their value and amount and defines three different types of materials. [15, p. 277]

The usual division divide A-, B- and C-Classes, where the method gets its name. However, the division into three classes is not mandatory. The number of classes depends on the following different treatment of each group. The ideal type applies the 80-20 rule. For example in the case of the customer reviews, with only 20 percent of the customers are achieved already 80% of its revenues (A customers = high importance), 30% of customers buy 15% (B customers = medium importance) and 50% of customers cover only 5% of turnover (C customers = low importance).
In the procurement of the A-goods are especially reasonable rates and to ensure delivery and terms of payment. The B group are goods with a share of the total value of more than 15 percent and the other goods belong to the C group. [16, p. 76]

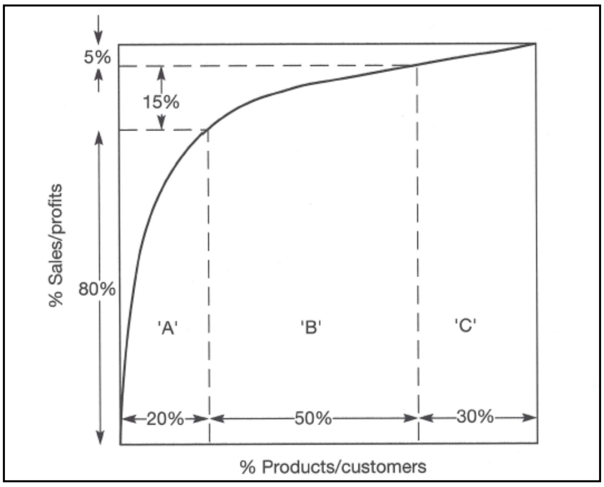


Figure 3-3: ABC analysis [9, p. 57]

The XYZ analysis is carried out in addition to the ABC analysis. The classification into A, B and C parts alone is not a sufficient method to choose the disposition strategy. In addition, a classification according to the predictability of the part requirement is necessary to meet the customer's demand. Because of that there is a division into X, Y and Z-products (XYZ-analysis). Products that are sold very regularly and in reasonably constant quantities are referred to as X-items, while the Z-class contains such items which sale very irregular. [16, p. 77] For the definition of the XYZ borders often the following values of the coefficient of variation can be used: X- items VK < 25%, Y-items VK between 25% and 50% and Z- items VK > 50%. [15, p. 278] The XYZ- analysis is often combined with the ABC analysis. This combination is referred to as the ABC / XYZ analysis and further procurement strategies are derived from.

3.3 Order point technique

"The order point technique is used for items with a deterministic or stochastic demand which occurs relatively continuously along the time axis. The characteristic inventory curve is the saw-tooth curve." [5, p. 532]

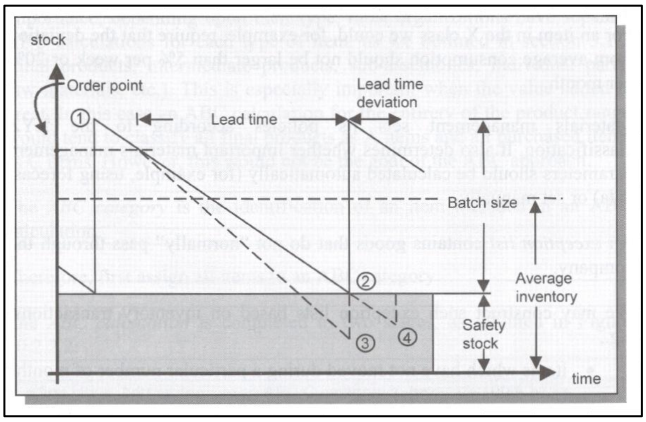


Figure 3-4: The saw tooth curve [5, p. 532]

As shown in figure 3-4 the stock falls gradually until it is below a minimum quantity that is called the order point. At this point, a production or procurement order is generated. The inventory level sinks continually until it gets to point two. After the stock entry the consumption/order cycle begins anew. The line between the point's one and two conforms the demand during the replenishment lead time. If is the demand is a stochastic value, it's possible that the consumption is larger than the excepted consumption. This is shown in the figure with the dash line between the point's one and three. If the replenishment lead time is longer as the excepted one, the inventory line corresponds to the dashed line that leads to point four. For these two Situations, if we do not maintain a safety stock, there will be a stock out.

The actual "x_A (t)"stock fluctuates between the safety stock and the maximum stock after stock entry.

$$x_s \leq \ x_A\,(t) \leq x_{max} \tag{3.1}$$

The maximum stock is the sum of the safety stock "x_S" and the procurement or production quantity "x_p".

$$x_{max} = x_s + x_P \tag{3.2}$$

After the calculation of the maximum and the safety stock it's possible to calculate the average stock, which is defined by:

$$x_A = x_s + x_P/2 \tag{3.3}$$

3.3.1 Safety stock calculation

Safety stock serves to cushion deviations in the lead time as well as in the demand during the replenishment lead time. [5, p. 533]

If the replenishment quantity consumed evenly until reaching a minimum stock and delivered at regular intervals then describes the temporal profile of the stock a step function. Because of this temporal profile the minimum stock fluctuates about the prior defined safety stock.
The safety stock prevents the inability to deliver. Because of stochastic demand or uncertain delivery times it is possible that the stock drops to zero before the replenishment quantity arrives. [13, p. 347]

Therefore safety stock is required if there are

- Delays in production or procurement (external or internal)
- Fluctuations in demand.

By the determination of the safety quantity it can be distinguished between the interruption reserve and the safety stock. The interruption reserve is a stock to ensure the supply of the production and consumer for a duration of an irregularly interruption in terms of the supplier. An irregularly Interruption describes for example a transport loss, equipment breakdown, repair or a shortage by the supplier. The safety stock is a reserve to ensure the delivery capacity during the stochastic fluctuating replenishment lead time. [13, p. 347]

Thus there are some different techniques to determine the safety stock depending on the type of the product.

Technique	Safety stock calculation	Typical application
fix size	Defined quantity	new or cheap products, infrequent demand
time periods based	Calculated by forecast	Critical components , new products, infrequent demand
statistical derivation	Calculated by statistical methods	Products with a lot experience, Frequent demand, minimal deviations in the predicted range

Table 3-1: Different techniques to determine the safety stock [5, p. 538]

While the safety stock for the first two techniques is determined intuitively, there exists a technique for the statistical derivation. After the explanation of the various techniques, it’s important to consider the two different types of fluctuations more in detail.

a) Statistical fluctuations of procurement or production

Fluctuations during the lead time, for example unplanned delays in the production or procurement, are ensured with a safety period.
The safety period is a scheduled time to protect against temporal variations in the cycle time in addition to the normal lead time. The order release and the order finish dates are scheduled earlier. [5, p. 538]

b) Statistical fluctuations of demand

To handle the fluctuations in demand a safety period, like the safety period at fluctuations in procurement and production, is not enough.

The figure 3-5 shows the behaviour of the demand for two articles with the same demand forecast, but different demand variability.

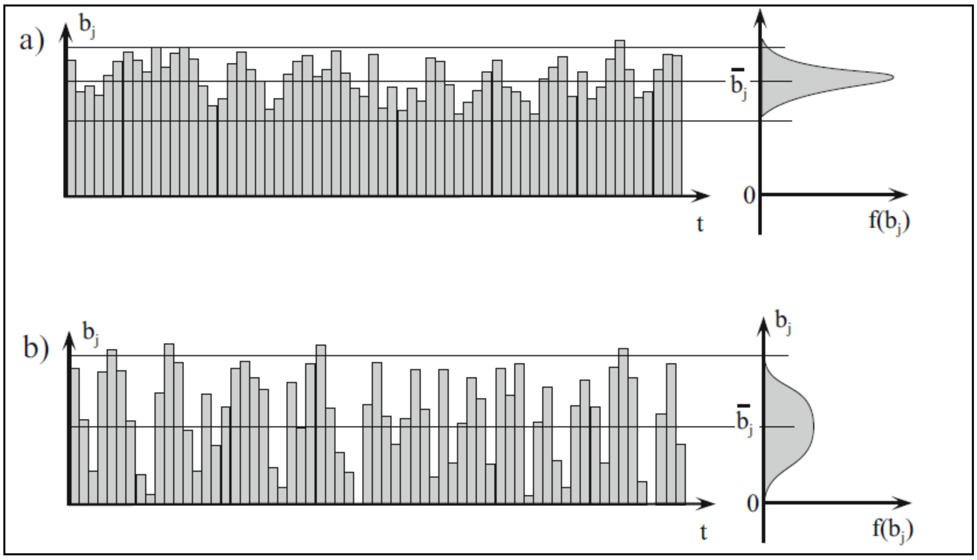


Figure 3-5: Different patterns of the deviation of demand; a) demand with low variation b) demand with high variation [17, p. 179]

The safety lead time is not a sufficient basis for the calculation to absorb the fluctuations in the demand. The safety stock level for the item in situation B must be larger than the one for the item in situation A. A pattern of demand which has only a small dispersion around the demand forecast will bring a smaller safety stock level, one with bigger variation will require a large safety stock. [5, p. 538] Additionally the service level has also an influence on the safety stock calculation.

3.3.2 Service level

The determination of the delivery capacity is a very difficult and significant decision for the company. This decision depends on the actual market situation, the needs for security on and other risks that are very hard to define. [13, p. 382]
By definition, the service level represents the percentage of demand which can be covered by the available stocks. [5, p. 539] It follows that both, the safety stock and the inventory costs increase along with the service level. This dependence between the stock and the investments in safety stock is shown in figure 3-6.

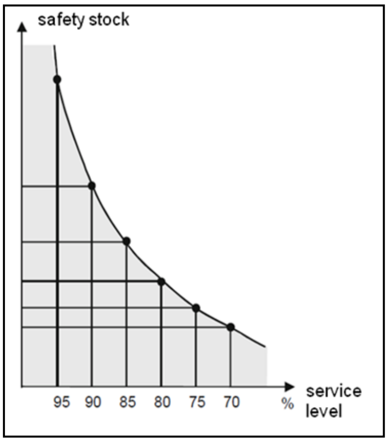


Figure 3-6: The dependence between safety stock and service level [5, p. 540]

The service level corresponds to an integral distribution function. This function is the integral under the distribution curve for consumption up to particular value “s”. [5, p. 541]

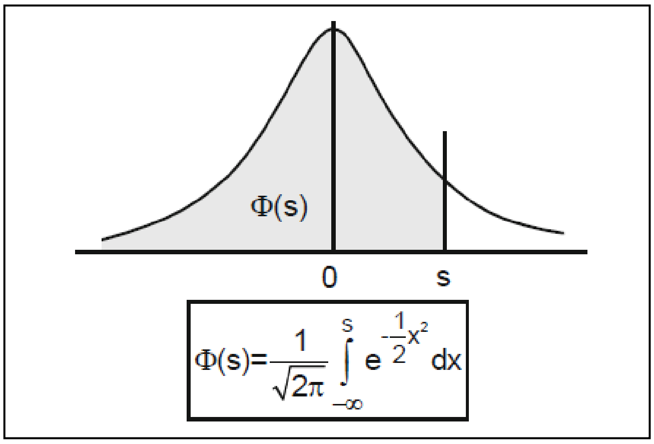


Figure 3-7: The integral distribution function [5, p. 541]

The value “s” represents at the same time a multiplier for the standard deviation called safety factor. The safety factor is the inverse function of the integral distribution function. The multiplier factor for the standard deviation which belongs to a particular service level can be read from the tables.

Service level %	Safety factor
50	0
80	0,842
95	1,645
98	2,054
99	2,326
99,9	3,09

Safety factor	Service level %
0	50
1	84,13
2	97,73
2,5	99,38
3	99,86
4	99,997

Table 3-2: Service level and safety factor [5, p. 541]

Now all factors are defined and the resulting formula for safety stock is shown in formula 4.3. The safety stock is defined as a multiplication between the safety factor “s” ,the standard deviation during the lead time “σ“ normalization factor, “T” the uncertainty period and “t” represents a factor with the aim to standardise for example on a unit like a week or a month.

$$x_S = \sigma * \sqrt{\frac{T}{t}} * s \tag{3.4}$$

The standard deviation during the lead time “σ“ is defined with the variables “n” for the length of the statistic period and “x_i” the consumption in one particular period

$$\sigma = \sqrt{\frac{1}{n-1} * \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{3.5}$$

and the variable ”$\bar{x}$ “

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3.6}$$

3.4 Logistic costs

This chapter describes the various cost components and defines the optimal order batch size. Material procurement costs often account for a large portion of the total operating costs faced by most manufacturing companies. It's possible to decrease these costs via optimizing the material procurement planning.

The core task of procurement planning is to ensure the reliable supply of a business, or an institution or department with the needed goods at minimum costs. The potential for optimization of the procurement resulting from the choice of delivery dates and quantity delivered. [18, p. 303]

The total costs consist of two components: the procurement cost/transportation costs and the inventory costs. Figure 3-8 shows the two components and the different costs they consist of. But the two components are working in opposite direction. By higher quantity delivered the ordering costs are going down and at the same time the storage costs up. [16, p. 94] The total costs are reduced by a specific calculation of the quantity delivered. In determining the optimal order quantity is to clarify whether it is cheaper to order a large amount at the beginning of the period or smaller amounts during the ordering period.

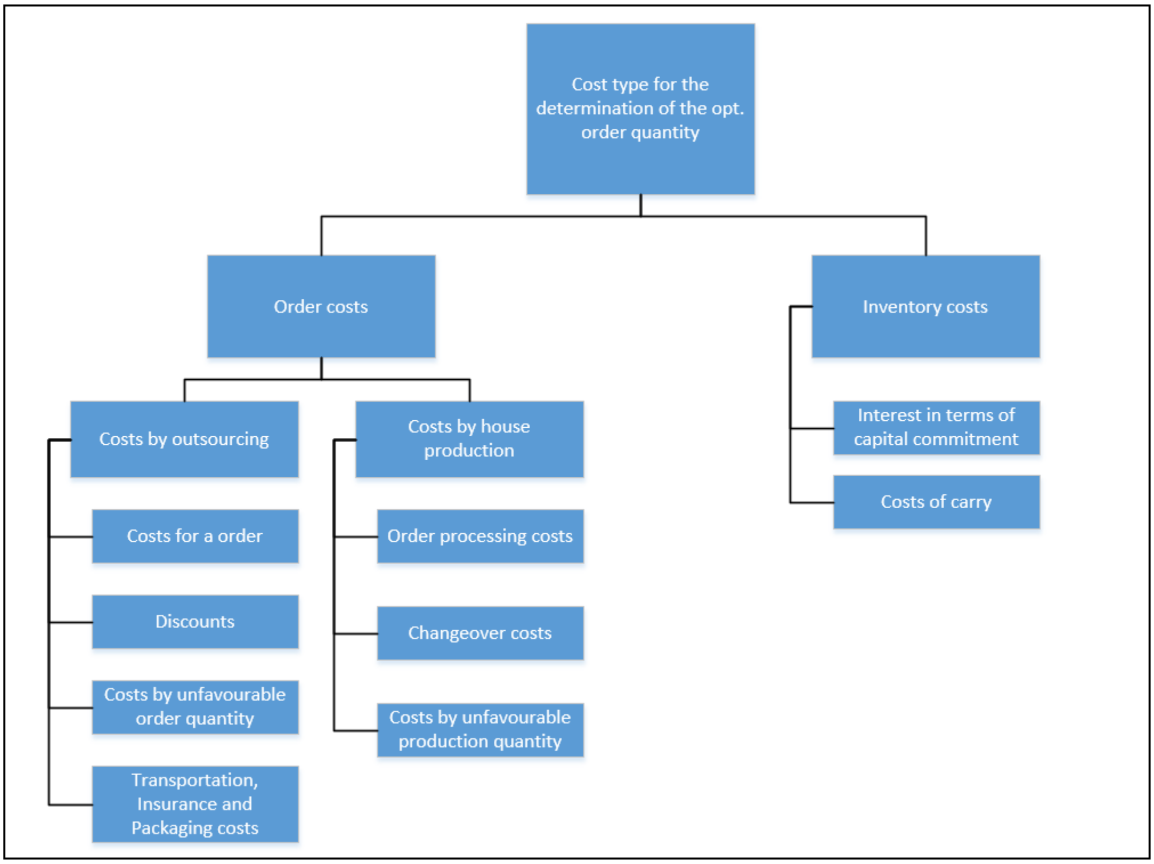


Figure 3-8: Different types of costs [14]

The logistic $C_L(q_D)$ costs consist of two different kinds of costs. On the one hand the order costs $C_O(q_D)$ and on the other hand the inventory costs $C_I(q_D)$.

$$C_L(q_D) = C_O(q_D) + C_I(q_D) \quad (4.5)$$

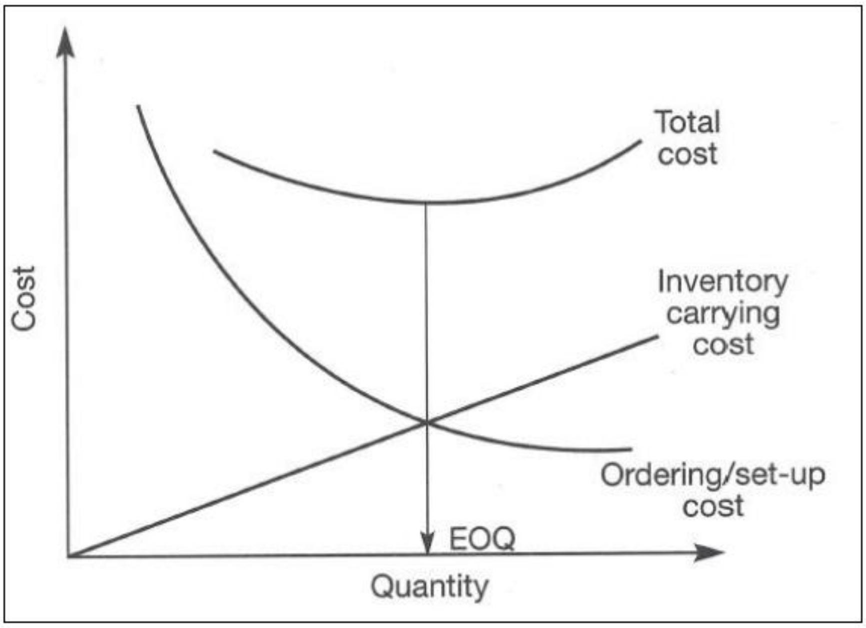


Figure 3-9: The economic order quantity [9, p. 261]

The economic order quantity model is based on the minimization of the order and inventory costs. The EOQ model reaches the optimum order quantity by balancing the inventory carry cost against the cost of issuing replenishment orders and/or the cost of production set ups. [9, p. 183] The figure 3-9 shows that the behaviour of the two types of costs depending on the procurement quantity, takes place in opposite directions: while the order costs decrease because of the overheads and the possibility to get a better price with increasing the procurement amount, inventory costs increase linearly because of the larger storage quantity.[7, p. 105] An important property of the EOQ model is their low sensitivity and their flat profile of the total cost curve near at the minimum. This gives that model, despite the high number of premises, a high level of functionality for the practical work. Thus, a deviation from the calculated result by up to 30% down causes the increase of flexibility and the reduction of the needed storage space and the lead time. On the other hand a correction of the result by up to 50%, has the effect to get lower prices and a higher utilization of all means of transportation.[7, p. 106]

3.4.1 The order costs $C_O(q_D)$

The order costs correspond essentially to the ordering costs which are the administrative costs of purchasing. Administrative costs also include costs of receiving stock and stock control. This procurement costs also include all costs per order that are independent of quantity, such as shipping, handling costs, etc. In the extreme case, they depend on the suppliers and the delivered items. [5, p. 409]

$$C_O(q_D) = \left(\frac{\lambda}{q_D}\right) * (c_{Pcon} + \{(c_{Te} + c_{Ti}) * \left(\frac{q_D}{C}\right)\}) \quad (3.7)$$

The procurement costs incurred with a consumption λ, certain batch size q_D, the transportation capacity C and costs like:

Procurement contract costs c_{Pcon} [€/Pcon]
The procurement contract costs consist of the internal contract cost including placing the order, the information transfer with the supplier, costs of receiving stock and external costs for example the costs for the order acceptance, picking, packing and shipping. [13, p. 338]

External transport costs c_{Te} [€/tu]
The external transport costs per delivery unit are costs for the transportation between the supplier and the company and they depend on the kind of shipping, on the capacity of the transportation unit and on the distance between supplier and company. [13, p. 339]

Internal transport costs c_{Ti} [€/tu]
The internal transport costs per delivery unit are costs for transportation between the receiving and the storage place. [13, p. 339]

3.4.2 The inventory costs $C_I(q_D)$

Inventory costs are all costs incurring in connection with the stocking of goods. The inventory costs include the costs of financing or capital costs, because inventory stocks tie up financial resources. Calculation using an interest rate yields the costs of immobilising money in inventory. The storage infrastructure costs, incur for the infrastructure necessary to related to the stock of goods for example buildings, installations, warehouse employees, insurance, etc. And the logistic costs include cost for the risk of depreciation and the risk for damage or destruction. [5, p. 418]

$$C_I(q_D) = P_{ma} * i_L * \left(q_S + \frac{q_D}{2}\right) + c_{SP} * \{(q_S + q_D * f_S)/C\} \tag{3.8}$$

The inventory costs incur with safety stock q_S, certain batch size q_D, the transportation capacity C and costs like:

Price per unit P_{ma} [€]
The acquisition value for external procurement is the current net purchase price per consumption unit net of all rebates and discounts. By in-house production the acquisition value is equal to the manufacturing cost without set-up costs and overheads.[13, p. 339]

Storage interest rate i_L [%/pe]
The warehouse interest rate is the sum of the interest rate on capital and the interest rate for the risk. The interest rate on capital describes the capital commitment and the interest rate for risk represents the risk for shrinkage, aging, unsaleability. [13, p. 339]

Storage infrastructure costs c_{SP} [€/pallet*pe]
The storage infrastructure costs are costs for buildings, installations, employees and insurance which are necessary to store products. The infrastructure costs like the internal transportation costs depend on the type of the loading unit and the used warehouse equipment, but are irrespective of the value of the goods.[13, p. 340]

Storage organisation f_S
The storage organisation factor describes the exit of a assigned storage place for all the goods.

$$f_S = \begin{cases} \frac{1}{2} & fixed\ warehouse\ layout \\ 1 & free\ warehouse\ layout \end{cases}$$

Fixed warehouse layout: the fixed warehouse layout there a fixed place reserved for every article, for the maximum expected inventory, a fixed place reserved that may not be occupied by other articles. [13, p. 336]

Free warehouse layout: a free storage place to be used for the next article, no matter which article it is. [13, p. 336]

3.4.3 The optimum batch size

The inventory costs consist of the interest costs and of the stockholding costs and usually rise linearly with the procurement quantity. The optimum batch size or the optimum lot size is the batch amount with the minimum of total costs, and it results from deriving the total logistic costs and setting it to zero. The formula is also called the Andler formula. [5, p. 409]

$$q_{Dopt} = \sqrt{2 * \lambda * \frac{c_{Pcon} + (c_{Te} + c_{Ti}) * \frac{C-1}{2 * C}}{P_{ma} * i_L + 2 * f_S * \frac{c_{SP}}{C}}} \tag{3.9}$$

Because of flat characteristic in area about the minimum, the minimal total costs do not depend very sensitively on the exact value of the optimal procurement quantity. This has consequences for the calculation for example:

- The calculation for the optimal procurement quantity does not need to be particularly accurate.
- It's not necessary to observe the optimal calculated procurement quantity, for example to round up or down to get a full ordering or transportation amount.
- The inaccuracies of some costs do not have a big impact on the calculation to get the optimal procurement quantity.

4 Factory design

This chapter contains the planning of material flow and layout design. In addition this chapter also explain all theoretical approaches and tools that are applied in this thesis.

Material handling can account for 30-75% of the total cost, and efficient material handling can be primarily responsible for reducing a plant´s operating cost by 15-30%.[19, p. 279] The material flow determine the inventory and building requirements, department arrangement, lead time and time needed to produce a product. It’s important to plan the material flow, material handling, storage and transportation, because they are directly associated with costs. The purpose of the chapter is to give the reader a better understanding about material flow and how to plan the material handling.

Material flow is also a result of production and distribution activities. Thus the planning of material flow has a direct relation to the strategic objectives of the company. In this way the material flow planning is linked directly to the strategic planning. [17, p. 233]

Basically the design of the material flow can be divided into two component parts. The first part deals with the analysis of the actual situation and is called material flow analysis. Based on this knowledge, in a second step, the material flow planning is carried out. As part of a new or change planning of a material handling system, the knowledge of the existing or intended throughput is required. Furthermore it should develop several alternatives in early stages of planning and the best solution should be determined on the basis of a technical and economic evaluation.[14]

4.1 Definition of material flow

The guideline VDI 2689 defined the material flow such a concatenation of all processes by winning, processing and distribution from goods in a defined area. Generally this includes editing, handling, transporting, testing and storage. Is the area the whole company then the material flow comprises all proceedings from the supplier to the customer.
Jünemann considers that the material flow consists of a quantity of different objects: goods, people, information, energy and infrastructure.[15, p. 371]

The guideline VDI 2411 segmented the material flows into six main processes which are shown in figure 4-1:

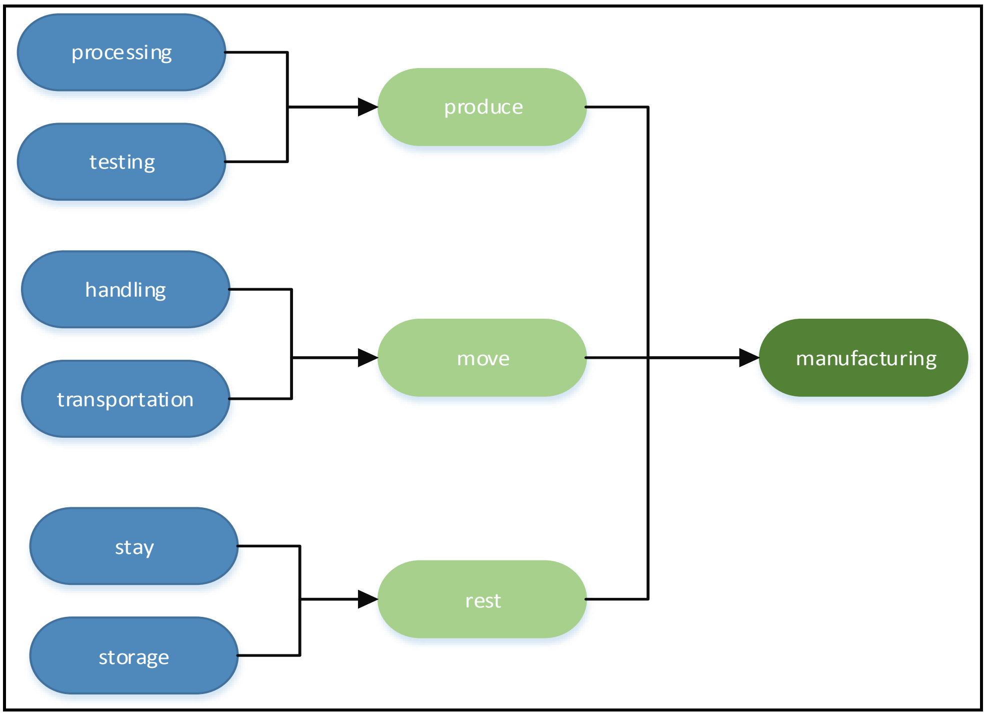


Figure 4-1: The six main processes

- ***Processing*** is an operation in which a work object is moved closer to the final state in which the product will leave the company
- ***Testing*** is every control process during the material flow
- ***Handling*** is the manual movement which are needed by starting or ending a processing, testing, warehousing, transportation and storage.
- ***Transportation*** is the movement from work objects and people in the system.
- ***Stay*** is the unplanned dwell time from work objects in the material flow.
- ***Storage*** is the planned dwell time from work objects in the material flow.

4.2 Actual state analysis

The actual state analysis is the basis of the material flow and layout planning. It is the systematic screening of a company in terms of moving goods and materials from a technical and business perspective. The material flow analysis is used not only for the design and planning of a new facility, it is used also for a rationalization, modernization and expansion of existing businesses. It will be helpfully for the further planning steps.

This analysis pursues two goals. On the one hand to collect those data and information, which are necessary to realize the design or reorganisation of a plant.

On the other hand the collect data are also starting points for technical and operational improvements and cost reduction.[14]

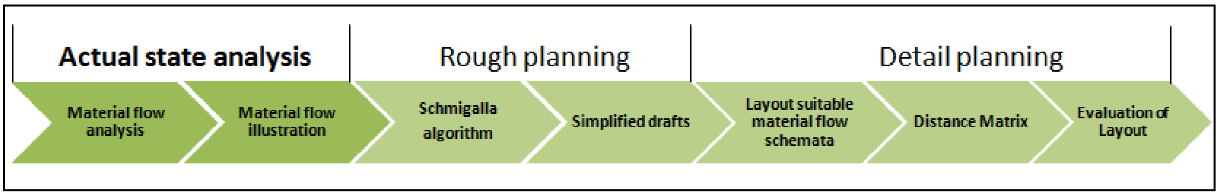


Figure 4-2: Actual state analysis

4.2.1 Scanning area

Before it’s possible to start with the material flow analysis we should determine the considered scanning area. It is very important that already in the early stages of analysis, the boundaries of the viewing area are marked out very precisely, on that one wants to concentrate subsequently. The object of an investigation can be divided into some general areas, sub-areas or individual sections.

Possible scanning areas are:

- The environment of a company
- The internal material flow in a company and the flow between different buildings in the company area
- The internal material flow between departments
- The material flow on a workstation

The environment of a company means external transportation between companies with their environment. In this consideration material flows are viewed from and of the premises of a company. In the analysis of the internal material movement it will be subjected the material flow which flows between the buildings of a company premise. The next step is to analyze the relationship between departments. And the last level of detail is the material flow on a workstation.

Data sources

For the initiation of an actual situation analysis, the required data for this analysis must be collected. The relevant internal documents for the planning are: [17, p. 84]

- Organization chart
- Location and development plans
- Construction drawing
- Production program

- Parts list
- Working and manufacturing plans
- Capacity plans
- Bills of delivery
- Inventory card
- Inventory stock lists
- Pay slips
- Cost distribution sheet

In addition to the previously listed data sources, there are a number of providers of business software solutions, such as the company SAP AG. In such ERP systems (Enterprise Resource Planning) is in practice stored and collected much of the data. So they can be accessed anytime.[20, p. 103]

4.2.2 Methods of data collection

The data collection for the material flow analysis can be divided into three groups. These three groups are: Collection of data by operational documents, by interview and by observation.

Material flow analysis by operational documents

Most documents that are located in the departments such as work plans, parts list and manufacturing plans are very useful for the actual situation analysis. They can provide important information for example quantities, work sequences, material properties and so on. Other possible data sources were listed already in the chapter 4.2.2 "Data sources". Here is a distinction between the target figures (Work plan, transportation plan) and the actual figures (bills of delivery, material reference data)

Material flow analysis by interviewing

Often a data collection is not sufficient by operational documents. Interviewing additional can be obtained important information. Moreover, this type of investigation brings more numerous other benefits. It can be won different data by interviewing several people on the same subject. The findings are comparable and can facilitate the analysis of problems. In addition this kind of data collection can be performed in a short time. Additionally it’s possible to increase the quality of the information from the operating documentation with the data from the employee survey. Although one must not ignore the danger of unconscious or conscious concealment or manipulation by making wrong statements. Another way to obtain information is the output of self made formulas. The employee should note the required data by himself. The employee should take down the required data independently. Important data to be written are for example the time of day, activity, quantities and processing times over a period of time. This kind of investigation is suitable for bigger, not ever changing material flows. However, it can arise some problems such as the psychological stress of the employees on the basis of a monitoring feeling which arises from the necessary inspection walkways.

Material flow analysis by observation

Influencing factors might also be detected and evaluated based on observations over a longer period. In this way, representative average data can be determined. It is possible that the collection and subsequent evaluation of complex processes are very time consuming and intensive. So here is often limited to a short-term observation.

4.2.3 Identification of relevant data

The existing data sources usually contain a large amount of information; normally they cannot be used to solve the given problem. It is therefore important to ensure that the existing data for the future representative and interpreted appropriately within the meaning of the task. In determining the data material, the planner should focus on the following factors: [14]

- typical time periods
- Representative products
- Dominant operating ranges

Often they many selected data have different characteristics and meanings, they must be further processed, analyzed and interpreted. For this task, various analysis tools are available. One of them is the ABC analyse, with or without cooperation with the XYZ analysis.

4.2.4 Illustration methods of material flow

This chapter discusses the illustration facilities of a material flow and material flow relationships between departments.

An important preliminary planning work for layout planning is determining and quantifying the transport relations and their graphical representation. It cans the internal transport relations as well as inter-company and external transport relations considered. The differentiation of the scanning areas is in the chapter 4.2.1 already treated.[21, p. 542]

Meanings of the transport relations for the layout planning: [14]

- It is important to detect the transport relations between different departments and also between which departments the transport intensity has a really high value. Because of that really high intensity some areas should be arranged as close as possible to each other.
- Other important factors that should be included in a consideration are the handling of the products and the minimization of the number on the cumbersome and complicated steps.

It was previously already mentioned that the selection of data should be forward-looking. There are two ways to determine the transport relations, as well as a combination of both, if required by the complexity of the material flow. These can be divided into the analytical approach, the extrapolation and a combination of both.[21, p. 544]

The analytical procedure for determining the transport relationship assumes the quantities of the target figures. Here, the mass flows are based on a period of time and measured on pieces, weight or on volume. We obtain, for example, as a unit pieces per day, a further investigation of transport relationship is possible with the extrapolation procedure. This option is only useful if it is a new or redesigns of an existing establishment. In this investigation variant, which aims to obtain target data, the actual data are collected and then extrapolated to a given day in advance. The combination of the two methods is used, if the application of the analytical method encounters difficulties and the actual data can be extrapolated but only to a limit. [21, p. 544]

The transport relationships can be represented in tabular form. This style is often referred differently in the literature, for example, as "From-To charts", "Material flow matrix", "transport intensity matrix" or "transport matrix". In figure 4-3 , the considered departments are in a column (vertical) and in a row (horizontal). The table is separated into two parts by a diagonal from top left to bottom right. So you can see that a relationship between the same departments is not possible. Furthermore on the basis of the diagonal it’s possible to measure the two transport directions separately. Now it can map all possible relationships over a certain period of time between the individual departments in this matrix. For example, it is possible to determine the products to be manufactured per day, passing through the considered manufacturing areas. In addition to the relations between the individual departments it’s also possible to determine the total amounts which accrue or drain off from one department. With the usage of the “from to chart” it’s also possible to illustrate for example different kinds of information or to the energy consumption of the different departments.

from \ to	1	2	3	4	5	6	7	8	9
1		1.760	149.354	43.504	0	0	0	0	0
2	0		0	0	0	1.760	0	0	0
3	0	0		147.303	0	2.051	0	0	0
4	0	0	0		137.619	0	149.738	0	0
5	0	0	0	48.275		0	0	0	0
6	0	0	0	0	0		0	0	38.620
7	0	0	0	0	0	0		96.550	0
8	0	0	0	0	0	0	0		96.550
9	0	0	0	0	0	0	0	0	

Figure 4-3: Transport intensity matrix

The distance between the different departments, which is a relevant factor for a layout planning, cannot be found here. This must be considered in a separate analysis and can combine later with the transport intensity. It's possible to create the same matrix as before, but instead of the transport intensity the distance between the departments will be considered like in chapter 0.

But to get a feeling about the importance of the different departments and to show somebody the actual or future material flow, the transport intensity should be also represented graphically. Such a graphically presentation allows to realize the situation at one glance. Possible display variations are the Sankey diagram, the triangle diagram and the circle scheme.

The circuit diagram represents the different departments in points, which are arranged to each other in a circular which is illustrated in the figure 4-4. The lines from one point to another point with their different line thicknesses represent the intensity of the transport relations between the individual departments.

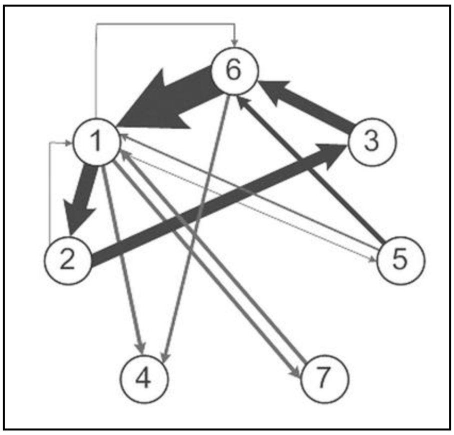


Figure 4-4: Circle scheme

In the triangle scheme the nodal points represent the individual departments and as in the circuit diagram, the thickness represents again the intensity of the transport relations.

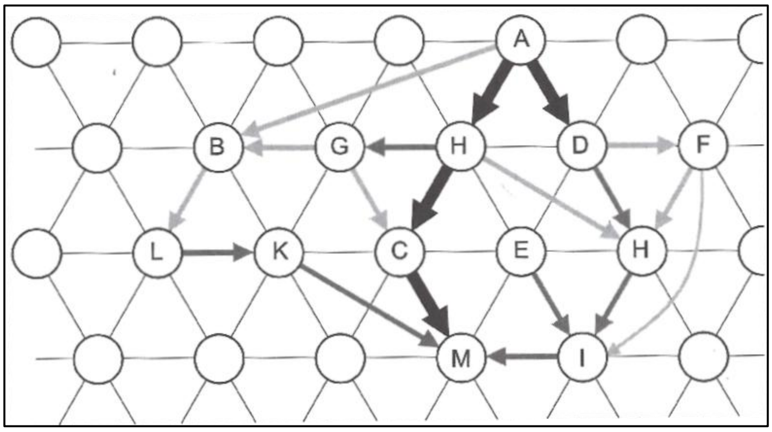


Figure 4-5: triangle scheme [22, p. 129]

One advantage of this display variation against the circle diagram is the ability to consider the spatial arrangement of the individual departments. In the next step it's possible to include in addition to the transport relations the distance of the different departments in the analysis.[20, p. 161]

To improve the illustration, you can display the results in a transportation lane scheme as shown in figure 4-6. Figure 4-6 is shown a Sankey diagram of a material flow from a plant layout. In this representation the real plans of the operating ranges are used and the intensities between the departments registered directional. Here applies the same rules that had been valid in the pre-considered display variations. Here the same rules that have been valid in the pre considered display variations apply. It can be made visible crossing streams, shown the burden of transport routes and optimizing the layout plans with the knowledge of the material flow.

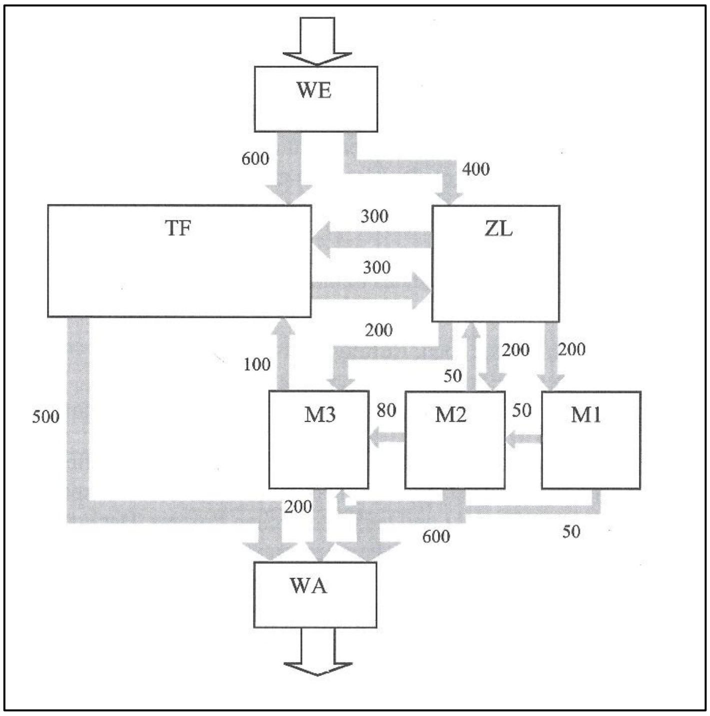


Figure 4-6: Sankey diagram [22, p. 128]

4.3 Material flow and layout planning

As described in chapter 4.2, after the material flow analysis and the representation follows the material flow planning. This chapter will now explain the contents of the individual planning steps to achieve an optimized layout.

Medium and long term business goals are the direction for the material flow planning. They can be divided into costs and operational goals. Cost targets can be for example the reduction of capital commitment costs, equipment costs or personnel costs. Operational targets can be for example, the reduction of transport routes, increasing of the flexibility of the production, the increase in the availability of products and the improvement of material flow. From these priorities goals can be derived different material flow targets. These can be, for example, the reduction of the waiting time or lead time, adjusting the buffer areas, as well as a faster internal and external information flow. Planning a material flow takes place under a variety of constraints. These can be, for example time pressure, lack of capacity, a tight budget and various social aspects. Therefore, it is important to divide the planning into meaningful steps.[17, p. 269]

For planning, the following steps have established:

- Rough planning
- Detail planning

In practise a blur of the boundaries cannot be avoided. That's the reason why a separation of the individual planning steps from each other is not always possible. In no case should be making important fundamental decisions in a early planning step, as a result of this expiration scheme. There should be performed some different expiration schemes and definitions, such as the planning steps. More important than the choice of which of these suggestions will be followed, is that the steps are carried out conscientiously. Inside the layout types can be divided into rough and real layout. [17, p. 271]

4.3.1 Rough layout planning

This chapter discusses a way to transfer the knowledge about the existing material flow from a company to a rough layout which is illustrated in the figure 4-7.

The aim of the rough planning is to create a material flow concept and develop a wide variety of alternatives, which are evaluated in the following sequence. In addition, it's important to work out fundamental decision parameters for the evaluation.
In this phase it is the purpose to bring the departments in a favourable arrangement in terms of the material flow. The goal is to optimize the material flow by changing the array of the operation ranges and may in cooperation by changing the operation processes.

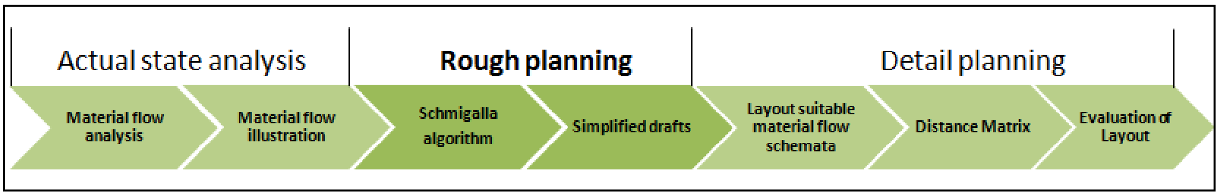


Figure 4-7: Rough planning

4.3.1.1 Object allocation

To generate new layouts it's helpfully to know the succession of the different departments to get a low transport coefficient of performance as possible. A very simply but useful tool is the Schmigalla algorithm.

At first for the better understanding about the following procedure description it's shown the ready reckoner in figure 4-8.

		1	2	3	4	5	6	7	8	9
1			1.760	149.354	43.504	0	0	0	0	0
2		0		0	0	0	1.760	0	0	0
3		0	0		147.303	0	2.051	0	0	0
4		0	0	0		137.619	0	149.738	0	0
5		0	0	0	48.275		0	0	0	0
6		0	0	0	0	0		0	0	38.620
7		0	0	0	0	0	0		96.550	0
8		0	0	0	0	0	0	0		96.550
9		0	0	0	0	0	0	0	0	
4	1	43.504	0	147.303	0	137.619	0	0	0	0
7	2	0	0	0	0	0	0	0	96.550	0
sum		43.504	0	147.303	0	137.619	0	0	96.550	0
3	3	149.354	0	0	0	0	2.051	0	0	0
sum		192.858	0	0	0	137.619	2.051	0	96.550	0
1	4	0	1.760	0	0	0	0	0	0	0
sum		0	1.760	0	0	137.619	2.051	0	96.550	0
5	5	0	0	0	0	0	0	0	0	0
sum		0	1.760	0	0	0	2.051	0	96.550	0
8	6	0	0	0	0	0	0	0	0	96.550
sum		0	1.760	0	0	0	2.051	0	0	96.550
9	7	0	0	0	0	0	38.620	0	0	0
sum		0	1.760	0	0	0	40.671	0	0	0
6	8	0	1.760	0	0	0	0	0	0	0
sum		0	3.520	0	0	0	0	0	0	0
2	9	0	0	0	0	0	0	0	0	0

Figure 4-8: Ready reckoner for to "Schmigalla" algorithm

The approach to calculate the optimum succession of the different departments with the ready reckoner work as follows:[23, p. 119]

1. The first step is to create a transport intensity matrix which is explained in chapter 4.2.4. This matrix is located at the top of the ready reckoner and centrepiece of the calculation. Because of this it is very important that the matrix is prepared on a high quality level.
2. The following step converts the transport matrix from a direction dependent matrix in a non direction dependent matrix. To convert the matrix we have to mirror every figure symmetric over the diagonal from the left bottom corner under the diagonal into the right top corner. It's displayed in figure 4-8 with the grey figure in column four and row five and this figure has been added up with the figure in column five and row four.
3. The first selection is the department with the highest value in the matrix. In figure 4-8 is that the department number four in connection with number

seven. Subsequently these departments are entered in the first columns down the transport matrix left from the blue box with the one inside and the two inside. The first selection represents the departments with the highest frequency of transportation in the considered area.

4. Every intensity in connection with these departments are written down in the row left of them. But with the exception of the previous highest value. Moreover these values are added up in the next row called sum. This is displayed in the third row down the transport intensity matrix.
5. Now has that column, which has the highest entry in the sum row, the highest material relationship with the already listed departments. This is in figure 4-8 the department number three.

   Afterwards all transport intensity in connection with this department number there are written down in the row similar like in step number 4. After that this row is summed with the previous sum row. It is Important to ensure that only this material flow relations, which are not already transferred in the lower chart, are considered. Another important point is that the last highest value will not consider anymore. In this example is that the yellow box in the first sum row with the value of 147.303.
6. This procedure, from step number 5, will repeats so many as that all transport intensities are considered and when all departments have been assigned.
7. In case that there are two equal maximum subtotals, than the following department is chosen arbitrarily.

   After finishing these steps it's necessary for a better understanding to illustrate the different department in a graphic like in figure 4-9. Each department occupies only one intersection point. This simplified draft is useful to illustrate first ideas or different material flow strategies. Additionally, the several elaborated layouts can evaluate or compare with other different layout possibilities.

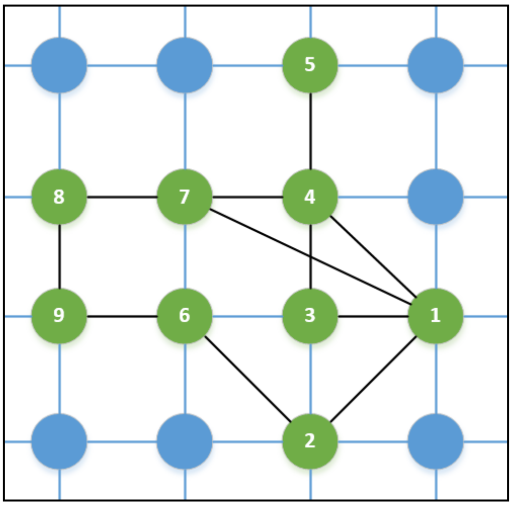


Figure 4-9: Object allocation

Figure 4-9 shows a typical simplified draft with the different departments which are illustrated with those green points. The aim of this method is to create different arrays on that grid and to develop some material flow strategies. The assumptions that are made are the required space of each department; the transport direction and the real distance between them are not considered. It has to mentioned that every intersection point can occupies just from one department. Finally, the transport effort is calculated with the intention to compare and evaluate the different several simplified layouts. The transport effort is defined as the product from the transport intensity times the distance from the grid. The transport intensity is already calculated and can be seen in the “from to chart” and the distance is defined as one between two departments which have the shortest possible distance like the department five and four. The other needed distances like the black line between the department seven and one can calculate like the diagonal from a rectangle with the Pythagoras Theorem. The simplified drafts should provide a first demonstration of how it can be and should give a first direction of thought and interceded the knowledge about which relationships are important and which material flows are negligibly.

4.3.1.2 Ideal layout planning

As part of the ideal planning is to develop the best technical and organizational solutions and considered without any economic, geographical or other restrictions.[17, p. 273] Thus the ideal planning creates a layout only under the aspect of the material flow. It takes place without an orientation on needed space, existing resources or building infrastructure and is a part of the rough planning. Mostly it’s more an unrealistic layout with the task to evaluate other layouts and to know it what would be possible.[22, p. 159]

The determination of the functionally correct arrangement of the departments plays an essential role and became also a core part of layout planning. The assignment of work stations to obtain a layout can be done by trial or by empirical approach. This method based on no systematic procedure and it is sometimes very inaccessible and limited in their capabilities. Therefore, a variety of mathematical methods have been developed. These can basically be divided into analytical and heuristic methods. The analytical methods include, for example, methods of linear programming, branch and bound method and the method of enumeration. In these methods, an optimal solution for a given target criterion by an exact calculation can be determined. But this leads already for a small number of objects to a high computational complexity. This disadvantage is counteracted with the heuristic method by the use of simple arithmetic rules. Heuristic methods can be divided basically in the setup process, the exchange method and into a combination of the two.

During the setup process, is the first step to place the departments with the largest transport intensity at first on the grid. This method creates a graphic like in figure 4-9 is shown. In subsequent steps are placed successively the departments with the highest transport intensities in connection with the already arranged departments like it already discussed in chapter 4.3.1.1.
In this thesis a combination of methods is chosen. So the first layout is created with the method from Schmigalla. Subsequently, several rough layout variants are developed and demonstrated by a wide variety of arrangements of the individual departments the possible potential of rationalization. The goal is to achieve a lowest possible Transport coefficient of performance.

4.3.2 Detail planning

This part of planning transfers the previously developed ideal solutions in real layouts with the inclusion of company specific boundary conditions. By consideration of the chronological order the detail planning is placed after the actual state analysis and the rough planning as can be seen in the following Figure 4-10.

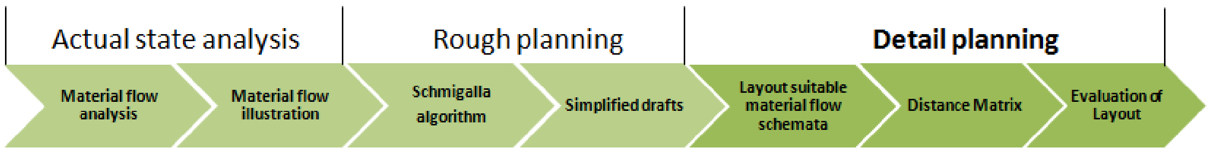


Figure 4-10: Detail planning

Now all remaining degrees of freedom and constraints are taken into account. This refers most of the time to realizable object allocation and facts like:[17, p. 274]

- The appropriate conveyor (crane, fork lift truck,..)
- The storage inventory
- Fix points (That is for example, product machines that are on basis of fundaments or other fittings are not available to shift on a other location)
- Working funds which are integrated in the material flow
- Organisation (specifications from higher authorities)
- Good manufacturing practice
- Different kinds of resources
- Legal circumstances

One of the main distinctions to the previous rough planning is the consideration of the required space which is explained in the chapter 0 and the real distances between the departments. Typical evaluation parameters for the rough planning are the transport intensity matrices and as a result of them by a combination with the distances the transport coefficient of performance which is explained in the section 0.

Determination of the required space

As part of the rough planning it will also determine the capacity of the necessary storage and staging areas, for example like in figure 4-11. However, it should be taken at this stage no decision about some construction methods and technical execution.

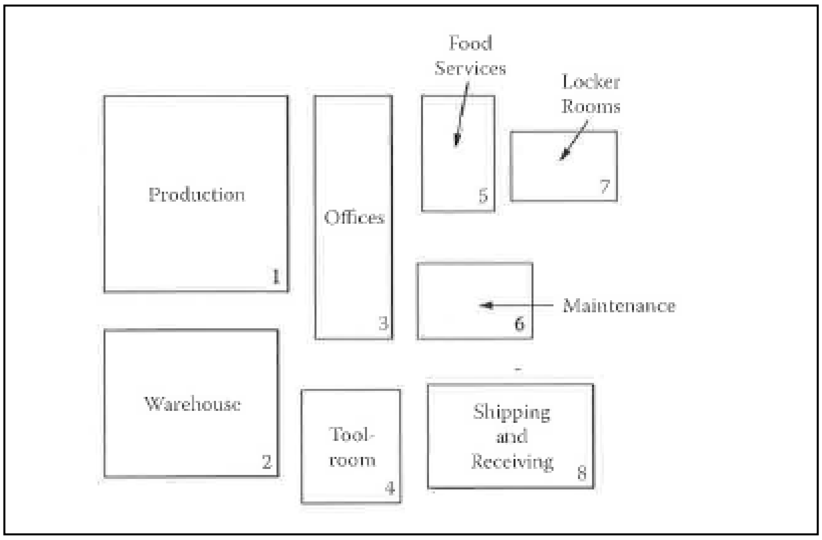


Figure 4-11: Necessary staging areas [19, p. 509]

Transport coefficient of performance

The transport coefficient of performance is calculated with the consideration of the spatial arrangement and the resulting routes and quantities of materials between the departments. In the following formula the transport coefficient of performance is illustrated mathematically. [20, p. 161]

$$T = \sum_{i=1}^{n}\sum_{j=1}^{n} T_{ij} = \sum_{i=1}^{n}\sum_{j=1, j\neq i}^{n} \lambda_{ij} * d_{ij} \tag{4.1}$$

In this formula the “λ_{ij}” represent the amount of transport goods between the different departments, which is also illustrated in the material flow matrix and the “d_{ij}” stands for the distance or transport way between them. To get the various transportation efforts “T_{ij}” it’s also possible to multiply the material flow matrix with the distance matrix which is shown in figure 4-12.

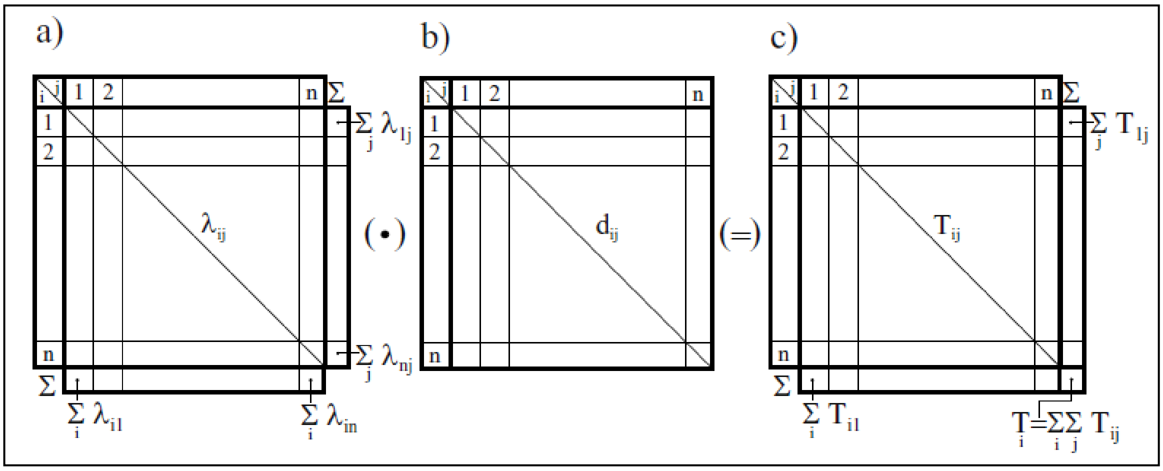


Figure 4-12: a) material flow matrix b) distance matrix c) matrix with the transport coefficient of performance

[17, p. 272]

The quantity of the transport coefficient of performance influences the material flow cost and should therefore be minimized. By their reduction, productivity can be increased. This is achieved by shorter transport distances, decrease lead times, and better organization of the material flow. The difference of a current transport coefficient of performance between an alternative material flow layout represent a measure of the possible potential of rationalization that can be achieved by a new arrangement of the departments. [14]

Thus the real layout represents solutions which are realizable with all necessary framework conditions. The final result of the detail planning is finally the planning variant which has the best assessment and fulfilled all relevant criteria as a solution of the original planning task. In addition the assessment is equally important as the developing.

4.4 Simulation

Simulation is an important useful tool to support the planning, realization and the operations of very complex systems.

Various trends in the economy are:

- Increasing the product complexity
- Increasing quality requirements with increasing cost pressure
- Increasing demands for flexibility
- Declining product lifetimes
- Falling lot sizes
- Increasing competitive pressure

These trends have the impact that planning cycles are becoming increasingly shorter and at the same time system complexity is significantly increasing. The simulation tool is used where simpler normal methods cannot provide a useful result. By using simulation software, different changes in terms of the product segment or productions volume can already be estimated in an early phase of planning.[24, p. 9]

4.4.1 Definitions

The following chapter define the terms Simulation, System, Model and Experiment.

Simulation

Simulation is the imitation of the operation of processor system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviours/functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time. According to VDI 3633 a simulation is the preparation, implementation and evaluation of targeted experiments with a simulation model.[24, p. 10]

System

A system is defined as a marked out arrangement of components that are interrelated. The system boundaries need to be defined in advance. Thus, a system can be an entire company, including supplier factories or only a part of this factory. [24, p. 10]

Model

The next level of detail is the model. The model is defined as a simplified replica of a planned or actually existing system which consist all defined departments, operations and processes. Thus, the model is a abstract image of a system. [24, p. 10]

Experiment

According to the VDI 3633 an experiment is a testing of the behaviour of the system in a defined model over a certain period of time. Additionally, the aim of an experiment is to get more information and knowledge about the system behaviour. To reach these goals, the model is examined by systematic variation of the parameters and these results are analyzed and used as a basis for further experiments. [24, p. 10]

4.4.2 Aim of the simulation:

Producing and selling more products does not lead to more profit if you cannot extract maximum production efficiency from your manufacturing operations. Building products with inefficient manufacturing operations and capacity utilization can quickly erode your bottom line. Numerous factors affect the operational efficiency and throughput of manufacturing operations, and they are difficult to manage. These factors include:

- Determining the optimal configuration for new production systems
- Establishing proper levels of work-in-process inventory
- Setting appropriate production schedules
- Establishing the correct production throughput-to-resource utilization ratio

Benefits:

- Improve productivity of existing facilities
- Reduce Investment in planning new facilities
- Reduce material handling costs by analysis distances and cost time
- Reduce inventories and safety stocks by evaluating different line control strategies [25]

4.4.3 Simulation program: Tecnomatix Plant Simulation

Plant Simulation is used in almost all industries, especially in the automotive industry, plant engineering, mechanical engineering, the steel industry in the semiconductor industry, the food industry, the pharmaceutical industry to banks and insurance companies, as well as in research and teaching.
Plant Simulation is used for strategic decision support in planning complex production and logistics systems. This simulation program can be used for virtual commissioning of production systems and can be used in the tactical and operational planning to optimize outcomes and to support decisions in terms of delivery dates, batch sizes, order quantity and scheduling. [25]

4.4.4 Performance Characteristics

Simulation and optimization

This program is able to create high complex manufacturing and logistics processes to analysis the behaviour and the characteristics with the result to optimize the performance of the system. Numerous analysis tools allow an assessment of different scenarios. The system also provides tools for automated optimization of system parameters.[26]

Visualisation

The processes can be visualized in a 2D view, or in a 3D model. The 2D view gives an overview with the aim that processes and dependencies can be quickly oversee and simulation experiments are carried out particularly efficient. 3D models are particularly suitable for management presentations, to support the sales or for presentation at fairs.[26]

Library

Plant Simulation delivers a huge of standard objects to illustrate processes and material flows. Additionally there is the opportunity to develop custom simulation and they can store in a library. The object-oriented architecture provides an excellent reusability and maintainability of the components.[26]

5 Factory design of the Kendrion plant

The Empirical work has been divided into three main sections. Section one explains the motivation for this thesis and the future development of the company. Section two represents the actual state analysis which delivers the fundamental information and knowledge for the further work. The purpose of following section three is to create based on the elaborated knowledge some layouts. This section three consist of two parts which is the rough planning on the one hand and the detail planning on the other hand.

5.1 The reason for this thesis

The chapter gives an overview about the motivation to work on a project in cooperation with the university. Later in the chapter, we discuss issues associated with the company progression.

Based on the aspects we discussed in the chapter 2.1 and because of the receiving of a major contract, the company Kendrion faces now the challenge to integrate a new production line at the existing company premises. The following part is to focus on the existing material flow and on its growth due to the integration of the new assignment.

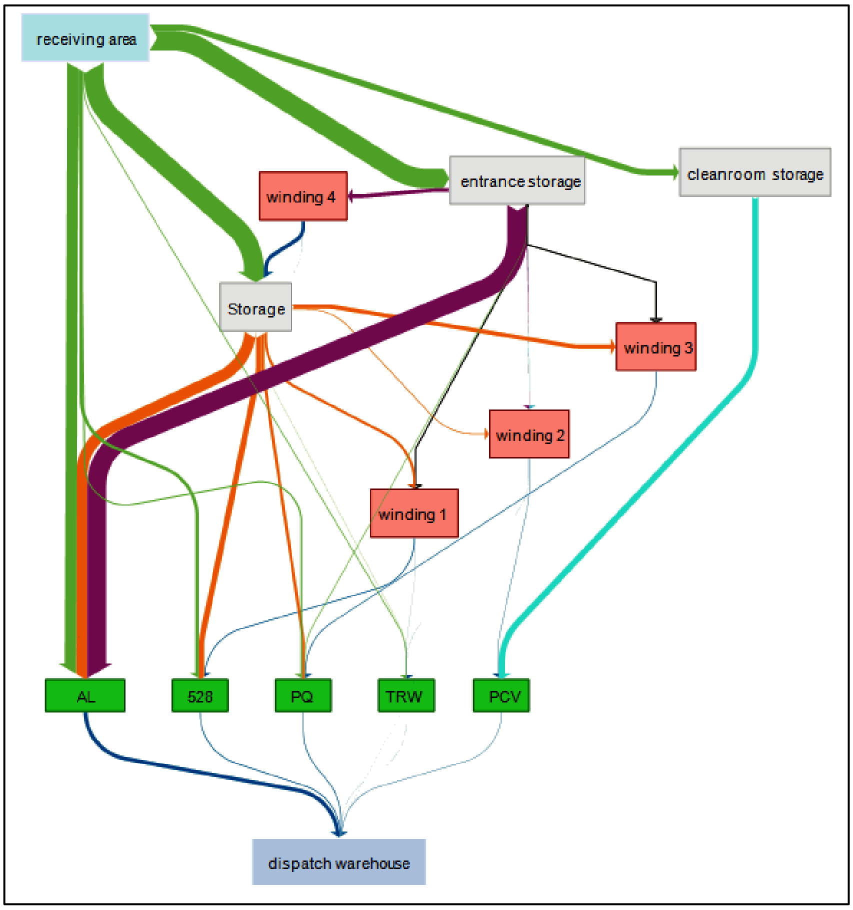


Figure 5-1: The material flow through the company in 2013

This figure 5-1 illustrates the company in a very simplified way, which consists of four winding machines, some different storages, the five prime manufacturing lines and one dispatch warehouse. In reality the company layout is more complex than this figure, but the task of this Sankey diagram is to show the existing material flow. The growth of the development of the material flow will be illustrated in a following figure. It is just a simple qualitative representation but it shows already the material flow through the company and that the material flow is dominated by a small number of products. Considering the material flow more in detail it shows that the manufacturing line AL (Automotive Lighting) is the biggest part. Figure 5-2 shows additionally to figure 5-1 the progression of the material flow in the company in 2017. This illustration affords a clearer understanding about the modification of the company structures because of the integration of the new assignment and the importance to consider the flow through the plant. It shows that the main material flow, about more than 80%, is dominated by only two manufacturing lines. These two products are the already existing Automotive Lighting product on the one hand and the new assignment Bilstein on the other hand.

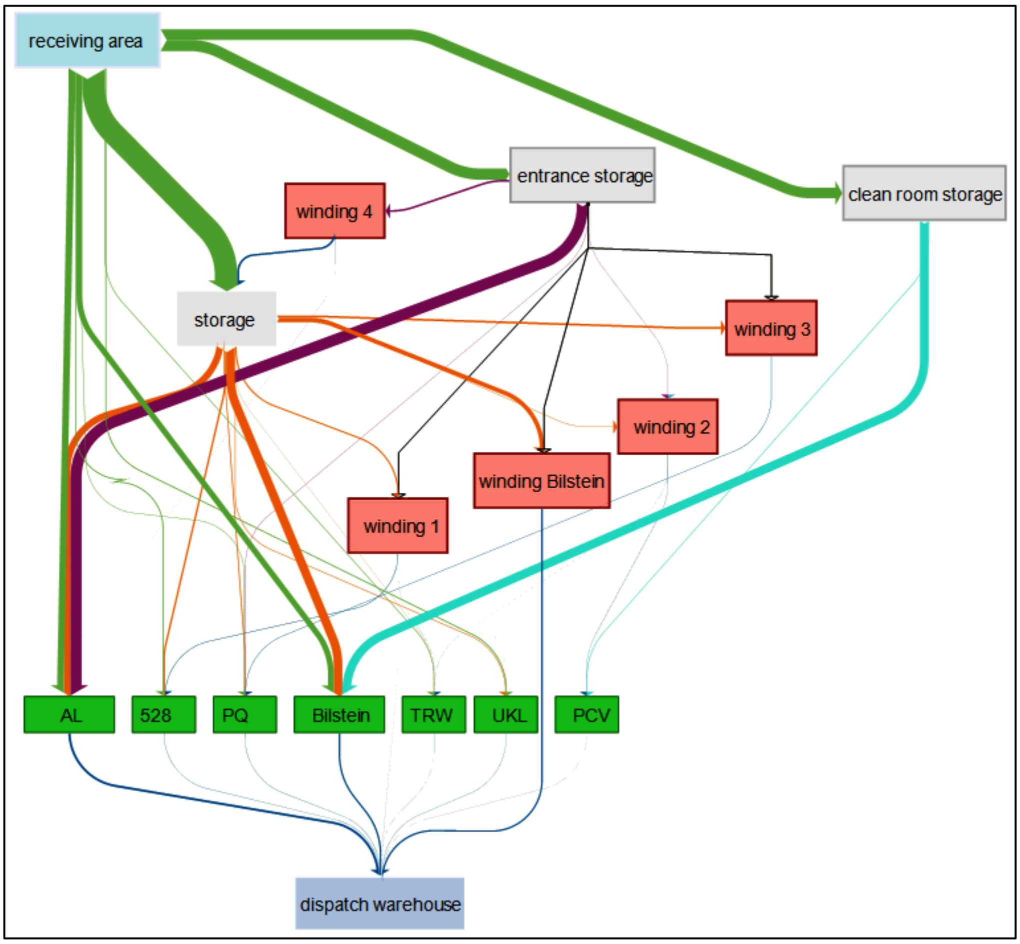


Figure 5-2: The material flow through the company in 2017

In preparation for this project, a layout plan including material flow and bottleneck analysis and a stock quantity determination will be created as a basis for the specific implementation of the new production line.

5.2 Actual state analysis

The actual state analysis is carried out in three separated analysis. The first section gives more details about the new assignment that means more information about the new product, the quantity deliver and the suppliers for the bought-in parts. Following, the second section discuss issues associated with the manufacturing process. Finally, the last section analyzes the actual layout, which includes the whole inventory with the different departments, product lines, storages and production capacity.

5.2.1 Product

In this chapter, we discuss issues associated with the product. The first two sections give an overview about the scale of the production order and about the design. Furthermore it illustrates more details of the different parts in terms of special features, suppliers and functionality.

The function of the product

Generally, the product is a proportional valve to adjust or modify the characteristic of a shock absorber from a car. By a consideration of the functionality more in detail, the product is able to adjust the rebound and compression phases during the drive on a very fast way. The advantage of an adjustable shock absorber is that the car is able to react on the actual quality of the street. For example the product can used in combination with a camera which takes a look on the street and with this information the proportional valve modify the shock absorber. With this feature it’s possible to drive very comfortable and efficient.

“With the new generation of the DampTronic® sky, the damping force is adjusted by two infinitely variable adjustment valves on each shock absorber. One valve controls the alternating rebound and compression stages. Using the data from the acceleration and wheel speed sensors, the suspension control unit can individually adjust the damping forces for each wheel in a matter of only a few milliseconds, thus compensating the road influences which spoil driving comfort.

Thanks to the adjustment valves, the shock absorbers are also able to ensure damping force adjustment in the high-frequency range of wheel vibration. With its independent adjustment of the rebound and compression forces, the new BILSTEIN

DampTronic® sky is the high-end system of semi-active damping force adjustment. “ [27]

As figure 5-3 illustrates, the whole design of one shock absorber unit in cooperation with new proportional valve. As can be seen from the figure, that the shock absorber unit consists of two valves, which are located on the side at the damping rod. At the moment there are so designed that one of the proportional valve controls alternating the rebound phase or the compression phase.

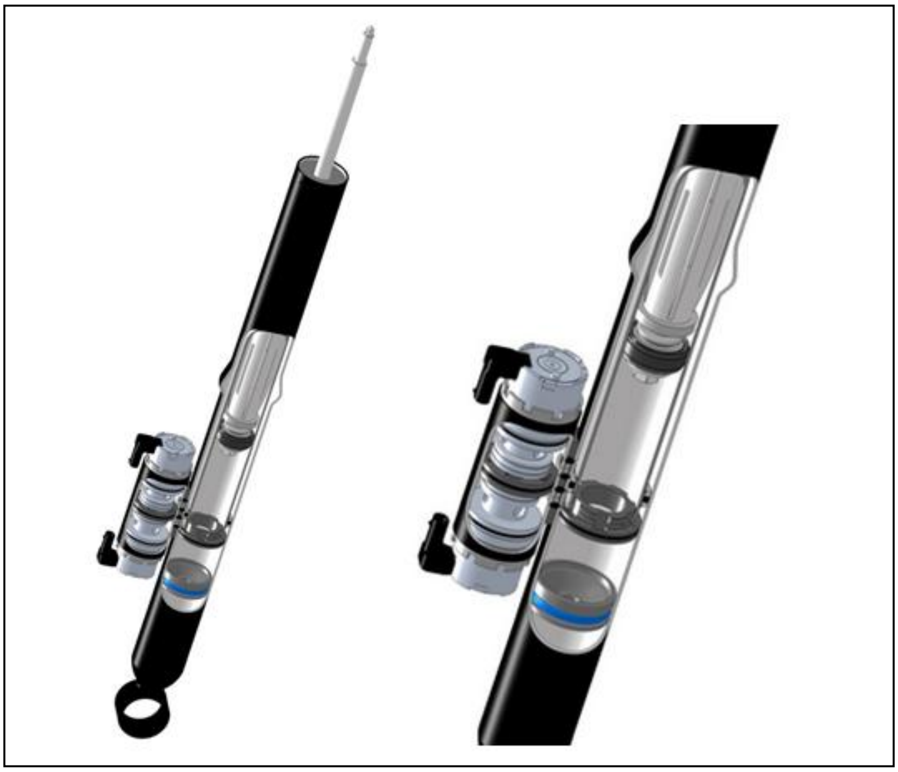


Figure 5-3: Shock absorber [27]

5.2.1.1 Assignment

This section explores the information’s which are needed for a clearer understanding about the importance of this new assignment. Table 5-1 illustrates the production volume for the next ten years. It shows a sharp increase in the first four years and after a constant period around 2018 it falls slightly. The first two years represents the seed stage to become more details, experiences and information’s about possibly or resulting bottle necks or problems with the process. It serves also the propose to optimize the process which is developed just on the white paper. It is to mention that the production volume has to be produced just on one manufacturing line that means that a simultaneously production is not possible. It follows that the cycle time has to be very fast and the process has to run trouble-free to mange this huge production volume per year. These aspects show that the seed stage is necessary to optimize the procedure and the organisation. Table 3-1 indicates also the period of investigation to serve as the basis for the following layout planning and material requirement calculation. Finally it shows in the right column the quantity of variants which has to produce. In the seed stage it starts with two different pin diameters and increase to six variants in the year 2017.

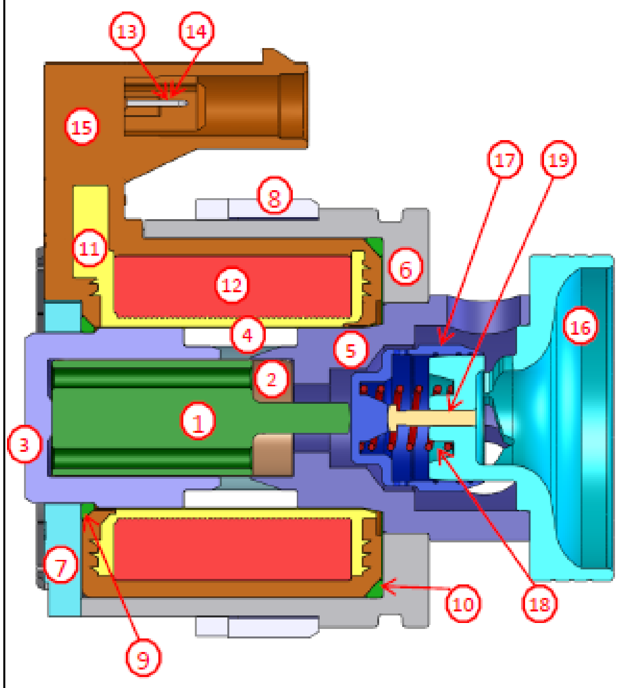
Manufacturing Program - Project P111292 Kendrion		
Period	Quantity	Variants
2015	55.000 #	2
2016	1.344.000 #	2
2017	3.053.000 #	6
2018	3.862.000 #	6
2019	3.740.000 #	6
2020	2.952.000 #	6
2021	2.539.000 #	6
2022	2.160.000 #	6
2023	1.131.000 #	6
2024	587.000 #	6
2025	200.000 #	6
sum	**21.623.000 #**	

Period of investigation (2017–2019, marked)

Table 5-1: Manufacturing Program [28]

5.2.1.2 Design

This section will provide some general data about the proportional valve. The product consists of nineteen parts with a weight of 380g and dimensions of 64 x 57, 5 x 44 mm. The following figure 5-4 shows a sectional drawing of the valve with a parts list on the right. The list illustrates the designation, the position number and the assembled amount of every part.



Pos.	pcs.	Designation
1	1	amarture
2	1	PTFE-film
3	1	cover
4	1	tube
5	1	pole core
6	1	housing
7	1	plate
8	1	threaded ring
9	1	o- ring outside
10	1	o- ring inside
11	1	bobbin
12	1	winding
13	1	plug pin left
14	1	plug pin right
15	1	coil complete
16	1	valve body
17	1	slider
18	1	pressure spring
19	1	pin

Figure 5-4: Proportional valve [28]

5.2.2 Supplier

Eleven different suppliers deliver these nineteen parts. One common factor shared by the suppliers is that they are all situated in Europe, as can be seen in the table 5-2. Another common factor is that every part is produced only from one supplier. The advantages from that procurement strategy are:

- to get a lower price on grounds of the delivery amount
- the complexity for the communication, logistic and procurement process decrease
- to build up a long-dated relationship business connection to the supplier and
- to involve the supplier more in the development to increase the quality of the product. [29, p. 211]

These are the reasons for the single source procurement strategy. Additionally, to get a better understanding about the importance of the several suppliers, they are listed in terms of the piece prices of the parts which they are deliver.

	Supplier	# of Parts delivered	Material costs (based on the total costs included transportation and contract costs)	Location
1	Mesa	6	52,38%	Germany
2	Frank &Pignard	1	15,90%	France
3	Synflex	1	10,52%	Austria
4	Vegu	1	6,83%	Austria
5	Hiebler	2	5,52%	Austria
6	Saxonia Franke	1	2,52%	Switzerland
7	Microdeco	1	2,02%	Spain
8	Freudenberg	2	1,79%	Germany
9	Kernliebers	1	1,31%	Germany
10	Unimet	2	0,73%	Germany
11	Salix	1	0,45%	Czech Republic

Table 5-2: Supplier

Packaging strategy

Before we explain the several suppliers more in detail, it has to be mentioned that most of the parts can divided into bulk materials and work pieces, which are delivered in individual blister packaging. Parts with critical tolerances, or for example with seal faces, are laid in this blister packaging. The idea behind the special packaging is to ensure that the fragile parts arrive undamaged. Other parts that do not need any special treatment during transportation are bulk materials and these are packed into special transport containers, cartons or plastic bags. Figure 5-5 illustrates an individual blister package.

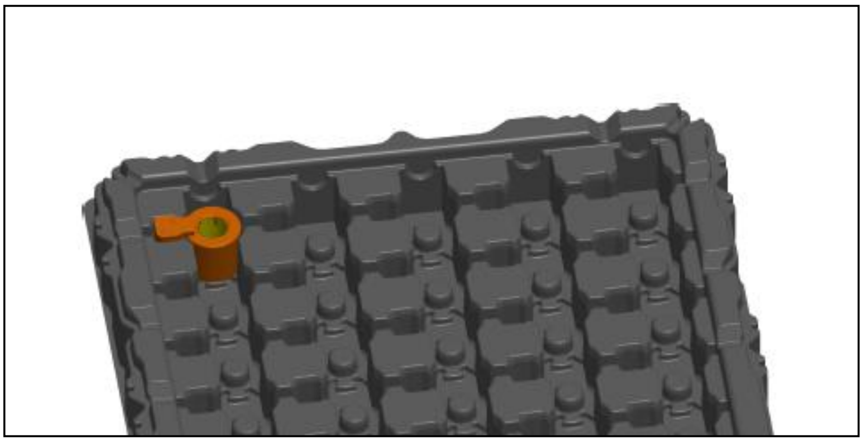


Figure 5-5: Blister packaging [28]

MESA

The supplier Mesa is situated close to the Swiss frontier in lower Germany. Due to the huge manufacturing competence for turned parts, Mesa is responsible for the delivery of six highly complex turned parts. These six parts are: the armature, the cover, the tube, the pole core, the valve body and the slider. Most of them are packaged in these special blisters; only the tube is classed as bulk material.

Most of the parts exist in just one variant; only the valve body exists in six different variants. Figure 5-4 shows that the valve body is assembled with the pin. The pin also exists in six variants and these several variants vary in terms of diameter. This diameter significantly influences the characteristics of the proportional valve. The diameter is selected according to the weight and the type of the car. Finally, for every pin diameter, there exists one valve body with the right hole to assemble these two parts.

The information needed for the material requirement planning is shown in table 5-3. We propose the following definition for the replenishment lead-time, which is illustrated in table 5-3: it is the time needed between the procurement order and the time of arrival. TU (transport unit) is defined as the standardized transport container, which is used by the company. The possible loading of the pallet in the last column of the table is dependent on the height of the transport container to ensure pallet stability. Every transport container has the same footprint, but they are available in different heights.

MESA		Replenishment lead time		48hrs.
pos.	Designation	pcs./blister	pcs./TU	TU/pallet
1	armature	228	456	28
3	cover	135	270	24
4	tube	bulk mat.	1000	16
5	pole core	135	270	28
16	valve body	60	120	28
17	slider	187	374	24

Table 5-3: Supplier: Mesa

Frank&Pignard

Frank & Pignard is also, just like Mesa, a high performance manufacturing company with a high level of practical experience. The company is located in France near to Swiss and Italy. Because of this, replenishment lead times increase by a factor of two to 96hrs. Frank&Pignard is responsible for the housing with the position number six. A special feature of this supplier is the cardboard packages that make it possible to deliver 3,120 parts per pallet. The disadvantage of this packaging is that every part has to be repacked on a special tray. This special tray is necessary for the downstream processes within the company. This particular case will explain in the following chapter.

Frank&Pignard		Replenishment lead time		96hrs.
pos.	Designation	pcs./blister	pcs./TU	pcs./pallet
6	housing	-	-	3120

Table 5-4: Supplier: Frank&Pignard

Synflex

The supplier Synflex, which also has a location in Austria near Vienna, delivers copper wire. The copper wire is wound and packaged in a huge basket with an overall weight from 180kg. The replenishment lead-time is zero. This seemingly impossible replenishment lead-time is not defined with regard to their location, but on the grounds of their shared use of the receiving storage space at Kendrion. At this point, it is useful to consider the shared use of the receiving storage more in detail. The company Synflex is allowed to store the required goods in the receiving area at company. At the moment, when Kendrion take the goods out of the storage, they enter the fact directly into the accounting and pay for the item. That means that the availability for the cooper wire is one hundred per cent and hence the replenishment lead-time is zero.

Synflex		Replenishment lead time		0hrs.
pos.	Designation	pcs./blister	pcs./TU	kg/basket
12	winding	-	-	180

Table 5-5: Supplier: Synflex

Vegu

Similar to Synflex is the supplier Vegu also placed in Austria. Exactly, Kendrion and Vegu are immediate neighbour. By an investigation of the history of the company Vegu, it salient that they has arose from Kendrion. Kendrion sourced out their manufacturing twenty years ago with the intention to be focused on their core competence to develop and assemble high–quality electromagnetic components in a much optimized way.

Vegu		Replenishment lead time		72hrs.
pos.	Designation	pcs./blister	pcs./TU	TU/pallet
8	threaded ring	bulk mat.	500	16

Table 5-6: Supplier: Vegu

Hiebler

Hiebler is also very close to Kendrion. That closeness has the advantage to deliver very frequently on the one hand and it accrues the possibility to over moulding the final coil in Hiebler´s factory. More details will be given below in the following chapter.

Hiebler		Replenishment lead time		24hrs.
pos.	Designation	pcs./blister	pcs./TU	TU/pallet
11	bobbing	bulk mat.	2000	16
pos.	Designation	pcs./blister	blister/pallet	pcs/pallet
15	Coil complete	50	20	4000

Table 5-7: Supplier: Hiebler

Saxonia Franke

The following supplier is located in our bordering country Switzerland. Saxonia Franke is in the leading position about stamping and forming technologies and delivers one part with a replenishment lead time about 96 hours.

Saxonia Franke		Replenishment lead time		96hrs.
pos.	Designation	pcs./blister	pcs./carton	pcs./pallet
7	plate	bulk mat.	500	24000

Table 5-8: Supplier: Saxonia Franke

Microdeco

Microdeco based in Spain and is responsible for the smallest part in the product. But is also a part which takes a special treatment in the manufacturing. The really high tolerances in combination with that size require a lot of experience in the turning manufacturing processes. That part, which is already discussed in the section Mesa, exists in six variants with a distinction in the diameter.

Microdeco		Replenishment lead time		96hrs.
pos.	Designation	pcs./blister	pcs./carton	pcs./pallet
19	pin	bulk mat.	70000	-

Table 5-9: Supplier: Microdeco

Freudenberg

The German company Freudenberg operates in the division seals and sealing materials and produce the needed o-rings in two different sizes.

Freudenberg		Replenishment lead time		48hrs.
pos.	Designation	pcs./blister	pcs./plastic bag	pcs./pallet
9	o- ring outside	bulk mat.	2000	-
10	o- ring inside	bulk mat.	2000	-

Table 5-10: Supplier: Freudenberg

Kernliebers

As can be seen in figure 5-4 that the proportional valve consist of a pressure spring which is manufactured by the company Kernliebers. Based on the magnet attraction of the coil, this depends on the wire quality and diameter, an appertaining pressure spring with a defined spring force is assembled. Furthermore, the achieving spring force is defined as the product of the length times the spring rate. Additionally, the spring rate depends also of the material diameter and quality. That demonstrates the complexity of the manufacturing process to produce pressure springs with a high tolerance in terms of the force. Thus, the company are not able to define how many spring pressures they will produce from each variant.

Kernliebers		Replenishment lead time		48hrs.
pos.	Designation	pcs./blister	pcs./carton	pcs./pallet
18	pressure spring	bulk mat.	4000	-

Table 5-11: Supplier: Kernliebers

Unimet

The proportional valve is assembled with two plug pins on the top of the coil to trigger the valve. That pins are wound on a reel with a load of 65.000 pieces per reel. The coil consists of two plug pins, they are located directly side by side, and there is a distinction between the right one and the left one. Thus, it exists two variants of plug pins left and right. It is the only part which has a termination date and need a special treatment in the storage. If the pins store longer than three months the surface that shine normally silver discolour to black and the functionality is not guaranteed. That means, that the pins which already discoloured are not allowed to assemble.

Unimet		Replenishment lead time		48hrs.
pos.	Designation	pcs./blister	pcs./reel	TU/pallet
13	plug pin left	-	65000	-
14	plug pin right	-	65000	-

Table 5-12 Suplier: Unimet

5.2.2.1 Salix

Finally, the last supplier is based in the Czech Republic and is responsible for the PTFE film. The film is wound around the armature with the aim to ensure the mobility.

Salix			Replenishment lead time	48hrs.
pos.	Designation	pcs./blister	pcs./TU	TU/pallet
2	PTFE- film	-	30000	16

Table 5-13: Supplier: Salix

5.2.3 Process

The aim of this chapter is to describe the assembly process in more detail. The following section describes the several assemblies. The second section discusses issues associated with details about the manufacturing process.

Assemblies

The intention of this section is to describe the construction of the product. The product, as can be seen from the sectional drawing in chapter 5.2.1, consists of three main assemblies. These three assemblies are fitted in three separate manufacturing lines. Figure 5-6 gives an overview of the construction and of the assemblies of the proportional valve. At the beginning, the two assemblies, the actuating system and the coil, can manufacture at the same time. In the following figure, these two assemblies are illustrated in blue, the actuating system, which consists of six parts and the coil, which consists of four parts. The “Coil compl.” in green represents the over-moulding process by the factory Hiebler. With these two finished pre-assemblies and with the last eight parts, which are shown on the right side of the figure, the proportional valve can be assembled. Figure 5-6 shows some more information about the product for example the quantity of possible variants. The six different pin diameters on the one hand and two polarizing keys on the other. This means that there is a right proportional valve and a left one. These two proportional valves have two different polarizing keys to ensure that the cable harnesses between them is not twisted.

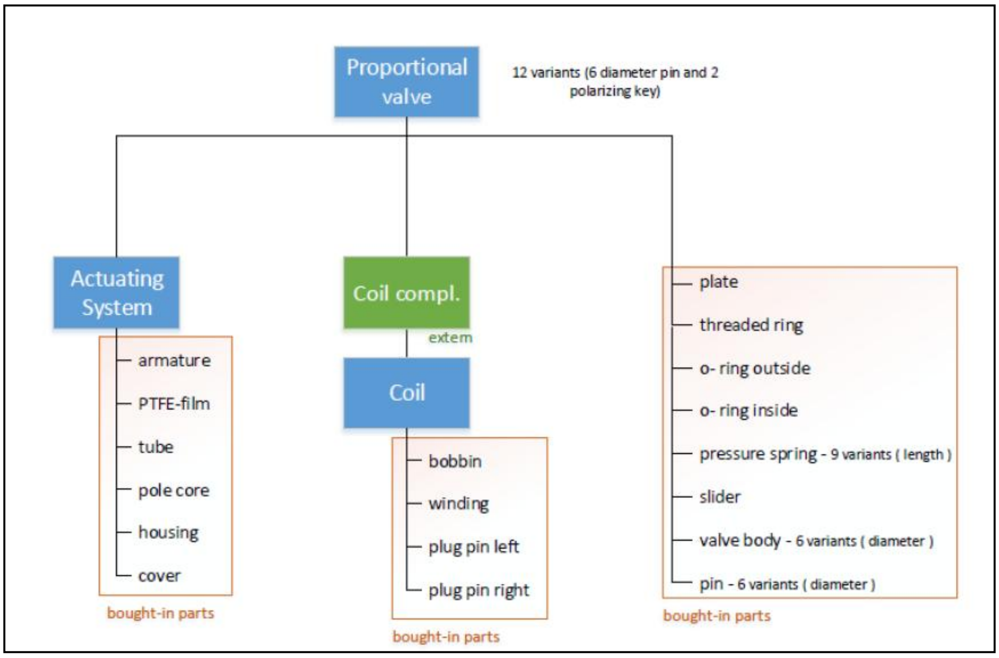


Figure 5-6: Assemblies

5.2.4 Assembly process

The second section of this chapter shows the manufacturing process. It starts with the pre-assembly and with the necessary preliminary work. Afterwards, it will give more details about the winding process with the over-moulding by Hiebler. The third section will explain the assembly from the actuating system with the coil and the last eight parts to the final product, and finally it will describe the hydraulic test.

Figure 5-7 represents the business process modelling (bpm) from the whole manufacturing process and this chart will be explained more in detail in the following sections. In this bpm, the blue parallelograms represent the several needed parts, the blue rectangles are the production/washing/testing processes and the green parallelograms are examples of finished assemblies. The black arrows represent the internal connection between the processes or machines and the orange arrows represent the external connection with Hiebler.

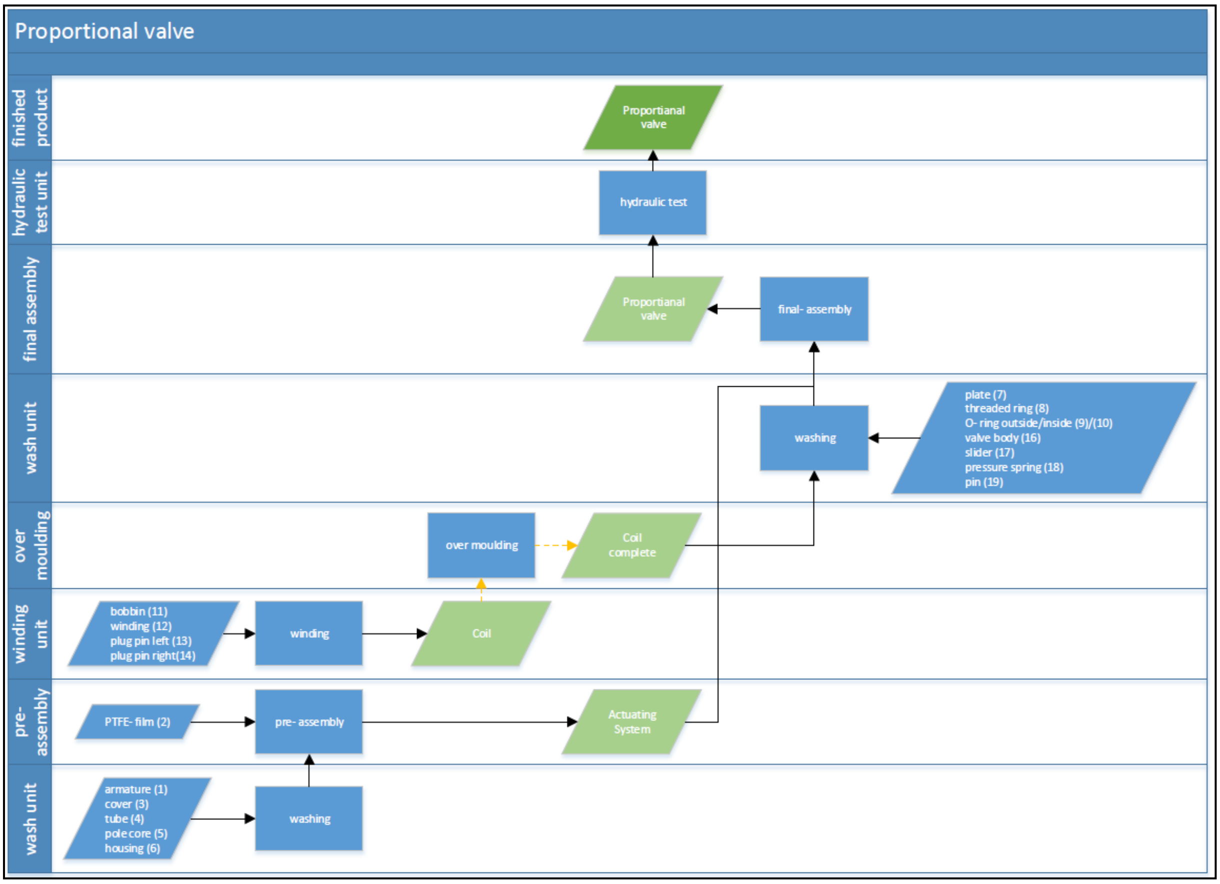


Figure 5-7: Manufacturing process

Pre-assembly

The pre-assembly, which assembles the actuating system, consists of the parts with the position numbers one to six. Because of the welding process during pre-assembly, it is necessary to clean most of the parts. Figure 5-8 shows a larger illustration of the pre-assembly and it can be seen that all parts without the PTFE-film (2) have to be washed to remove the oil layer and all operation materials residues from the manufacturing.

The first step is to wash the needed parts. The washing machine resembles a belt conveyor and special washing baskets made of stainless steel with a defined load for every part. Chapter 5.2.2 explains the generally used packaging. On the one hand there are simply parts without any special feature like a seal face and they are packaged in transport containers. The other parts with some tolerances are packed into individual plastic blister packs and these are transported into these transport containers. The worker who operates the washing machine and loads up the wash baskets has to upend the parts from the plastic blister into a tray made of steel. These trays have the same load as the blister and have the same pattern. The result is that the upending movement can be done in one work step. Afterwards, the worker loads the wash basket with these trays. All bulk materials are packed in these wash baskets without any trays.

The washing machine for the pre-assembly has a possible capacity of three baskets at the same time and needs an average operation time from fourteen minutes for the washing program. After the washing, they have to be stored in a buffer for not less than four hours. That time is necessary to ensure that all parts are cooled off and that the original dimensions with the scheduled tolerances are as at the beginning.
After the cooling off process, they are ready for the pre-manufacturing line. This manufacturing line has buffers for trays or buffers for bulk materials. This means that the parts, which are placed on trays, can be left on them. Generally, the pre-manufacturing work is completely automatic. The only support the machine needs is to fill up the buffer and to unload the buffer with the finished products and pile them on a pallet. Finally, some facts about the manufacturing line: the production machine assembles one actuating system every five seconds with an availability of eighty-five per cent, from this it follows that the pre-assembly produces approximately 4,712 pieces in one work shift defined by 7,7 hours and with a required space of 50m².

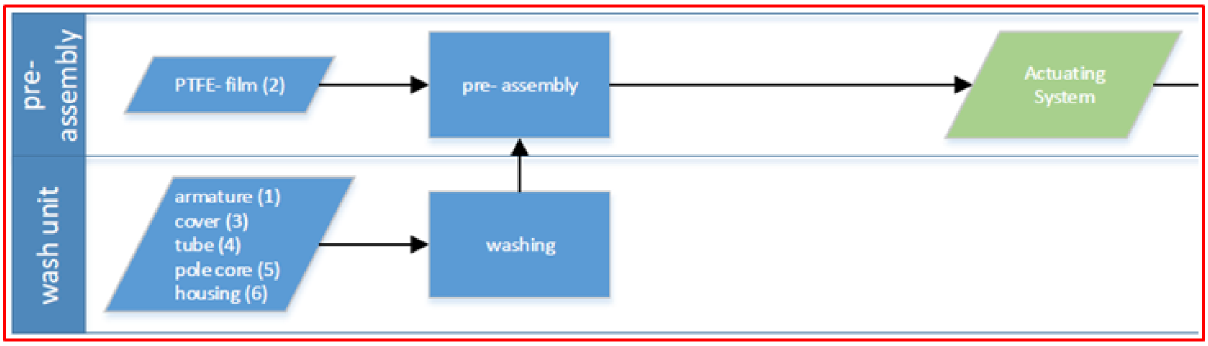


Figure 5-8: Pre-assembly

Winding machine

The winding machine simultaneously assembles or produces the coils for the proportional valve. The winding process consists of five main work steps. At first it is made up of a slot that is able to wind six bobbins at the same time. After the winding, the plug pins, one for each side, are inserted and the third work step is to bend the plug pins. Now the coil is finished and has to pass two more quality assessments, the surge test and afterwards, a dimension test carried out by a camera to check the angle of the bent pins. Finally, the finished coils are packed into a plastic blister and are ready for shipping to Hiebler.
Similar to pre-assembly, the winding machine works completely automatically, without any worker. The winding manufacturing line is able to assembly a coil every five seconds with an availability of ninety per cent resulting in a production volume of 654 pieces per hour and with a required space of 38m². It can be seen from the figure 5-9 that the coils after the winding process are over-moulded by the company

Hiebler. This means that every day the finished coils leave the factory and that Hiebler delivers the daily consumption.

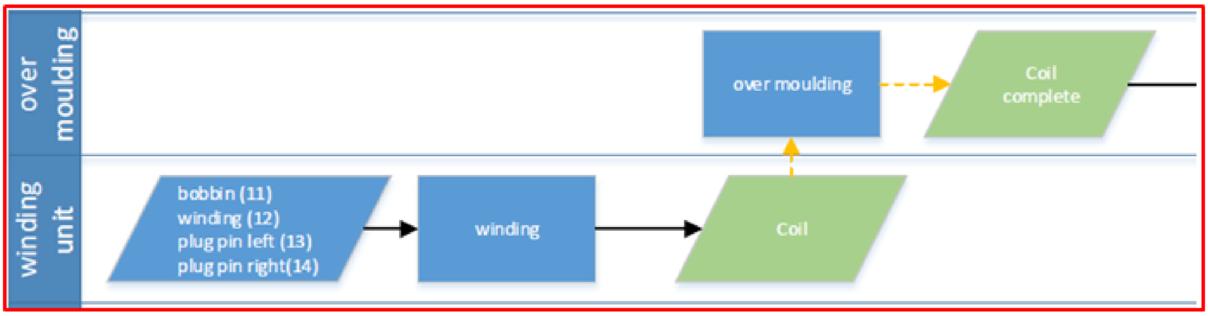


Figure 5-9: Winding

Final assembly

The final assembly represents the last manufacturing process. After the completed actuating system and the over-moulded coil, the proportional valve is ready to be assembled. The procedure takes a similar approach to the pre-assembly. First of all, most of the bought-in parts have to be washed to remove the oil layer for the welding process. The washing approach and the capacity of the washing unit is just the same as the one used by the pre-assembly with the distinction that parts for another product also have to be washed by the same wash unit. Another significant distinction is that the washing unit feeding the final assembly is separated into a blow down unit and a washing machine. Figure 5-10 shows that two arrows go directly to the wash unit. The arrow from the right represents the bought-in parts and the other symbolizes the coil compl.. The other arrow coming from the bottom of the diagram and going directly to the final-assembly and represents the material flow starting from the pre manufacturing line.

The blow down unit is used for parts that have not had any “cutting manufacturing” and without any residues from the operation materials. Those are the coil compl., the o-ring outside/inside and the pressure spring. Special ionized air removes dust and other particles from the parts with an average operating time of 30s per tray or bag.

To ensure the high quality standard, the final manufacturing line is placed in a clean room, which can be seen in the figure 5-17 and a manual workstation for a quality check is located on the manufacturing line. This basically means that an employee check the finished assembled part in terms of functionality and for external damage. Afterwards, the worker places it on a belt conveyor that transports the product to the hydraulic test unit outside the clean room.

Some production facts about the final-assembly: the production machine assembles one product by an availability from eighty-five per cent every 5.25 seconds; from this it follows that the final-assembly produces about 4,488 pieces in one work shift defined by 7,7 hours and with a required space of 50m².

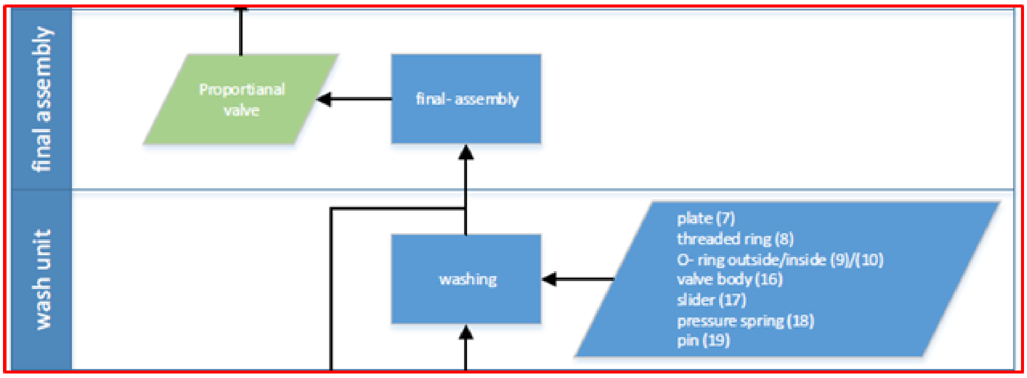


Figure 5-10: Final-assembly

Hydraulic test

Finally, every product has to pass the hydraulic test to ensure the functionality. The hydraulic test unit consists of six test stations that enable six products to be tested at the same time. The test cycle consists of two different characteristics curves and requires about 30 seconds per product and the machine need a space about 40m². After that, the tested proportional valves are blister packed completely automatically. Additionally, another employee is necessary to put two blisters into one transport container and put it on a pallet.

Figure 5-11: Hydraulic test unit

5.2.5 Actual state analysis

This chapter primarily analyses the actual layout and with all parameters that are required for the integration of the new manufacturing lines. At the beginning, more details are given in terms of the current production. This chapter also gives an overview of the support processes, for example the different storages. Finally, it defines all free available spaces that we can use for the installation and integration of the new production line. All this information is based on internal documents.

Current Production

The current manufacturing facilities in the company consist of eleven departments. These different production machines manufacture various products for the automotive industry. The products can be clustered into three main types. The three types are the Pressure Control Valves, Hydraulic Proportional Valve and On-Off Stroke Solenoids. [1] The various production machines and their locations can be seen in figure 5-12. To improve clarity, the three types have been allocated different colours. The yellow one is a production machine that produces Hydraulic Proportional Valves, the blue one assembles Pressure Control Valves and finally the green ones produce On-Off Stroke Solenoids.

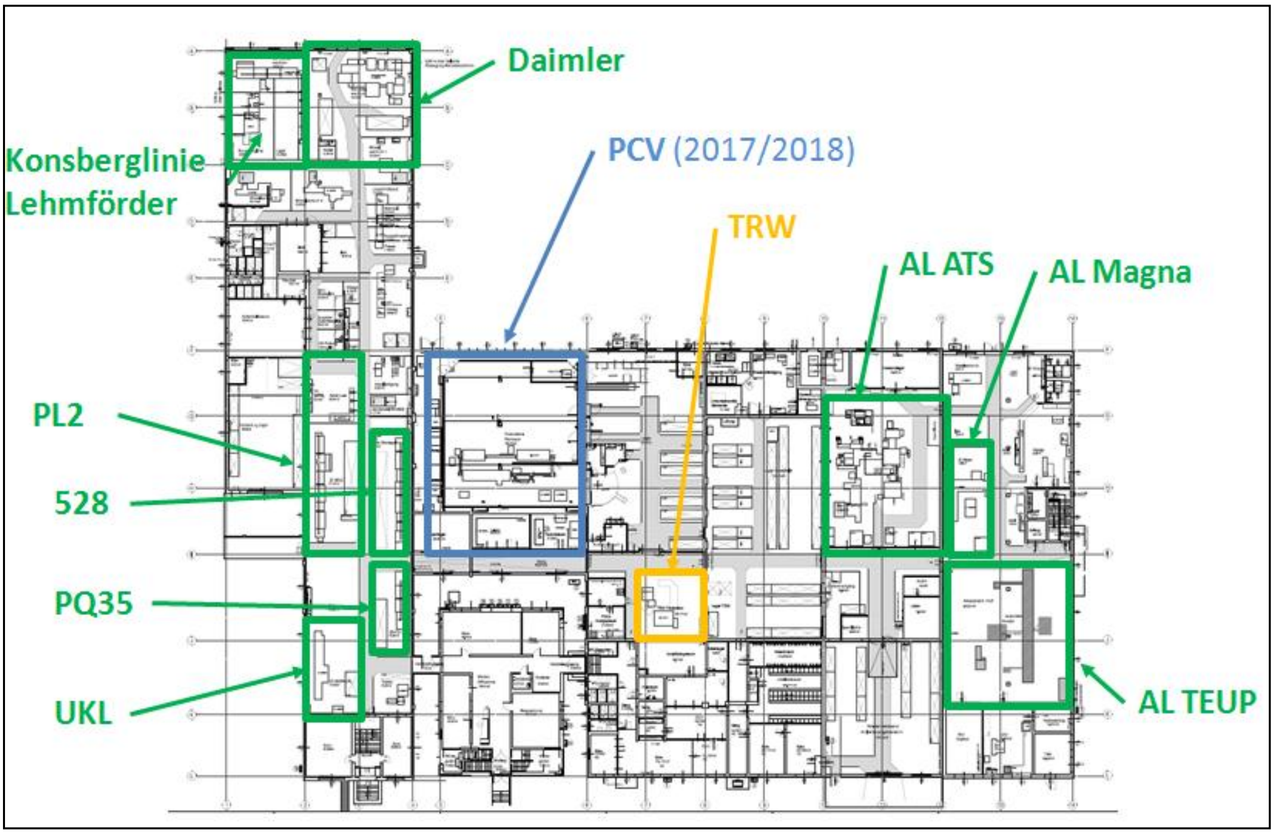


Figure 5-12: The actual manufacturing

Apart from identifying the different types of production lines and their locations, it is also necessary to know the manufacturing volume. It is helpful to know which of these existing products sell well and which of them sell badly.

The aim of this analysis is to focus on the best selling products and thus to be able to reduce the effect of the integration of the new production machines on existing manufacturing. The analysis indicates that there are significant distinctions in terms of the manufacturing volume of these different departments. Figure 5-13 shows the relationship between the departments and the dispatch warehouse in a simplified qualitative illustration. It can be seen that the department AL has the biggest part of these five material flows. It has to be mentioned that the other production machines illustrated in figure 5-12 only produce spare parts and because of this they do not have a huge production volume and are not illustrated in figure 5-13. To substantiate the size of the material flow between the AL and the dispatch warehouse, it is possible to say that this flow is about 66% of all flows between the production machines and the dispatch warehouse. Furthermore, this means that the unit Automotive Lighting constitutes more than the half of the whole annual output and, because of this, all input material flows are also larger than the others.

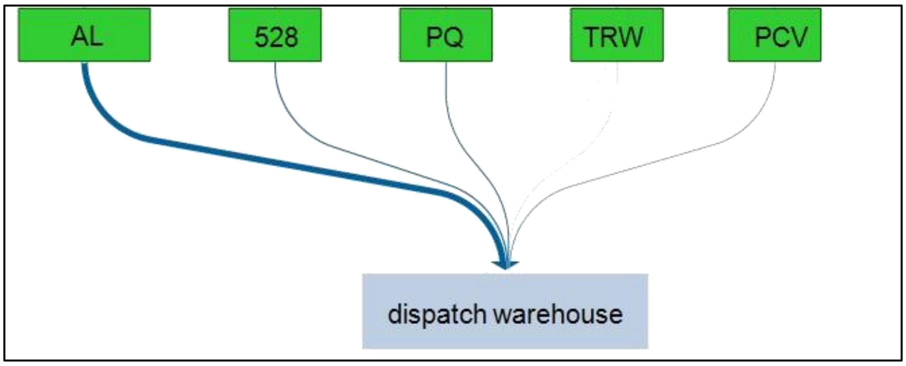


Figure 5-13: Production volume

Coiling machines

One of the essential part of every product is the coil. Doesn´t matter which kind of product we consider, all produced article contains a coil, which is wound on one of the automatic coiling machines. That coil plays an important part in terms of the utilization of every product. Furthermore the design and winding of these coils is one of the core competences of the company. Figure 5-14 shows, in brown marked the locations of the winding machines. The bracketed information in figure 5-14 represents the production machine which assembles the produced coils. As can be seen from this picture that the closeness between the winding machines and the appertaining assembly machines are already low.

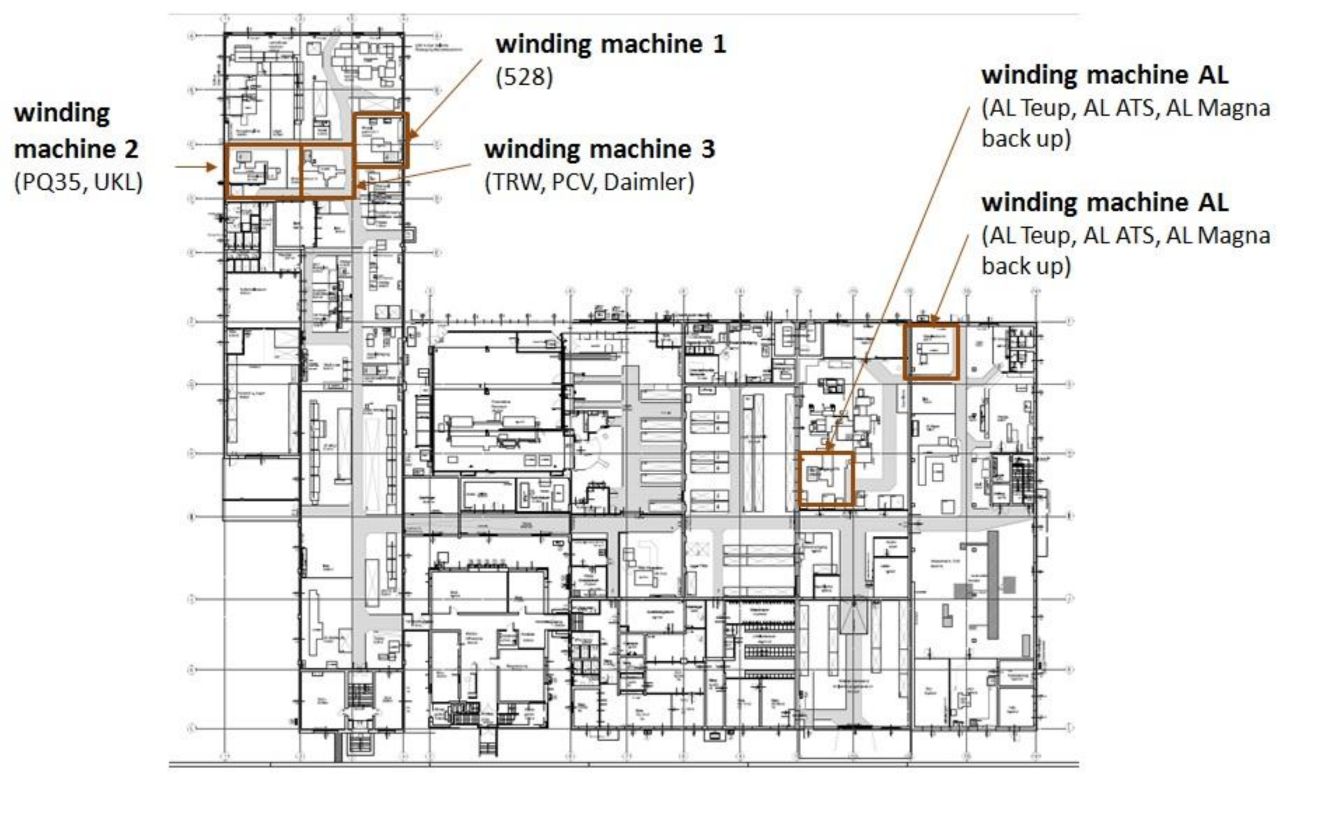


Figure 5-14: Winding machines

Storages

Storage is necessary to establish a buffer consisting of materials, parts or finished articles to be able to deliver the contracted quantity. There are different storage areas in the company to store the required parts and materials for the assemblies as well as a dispatch warehouse for outgoing goods. In addition, it should be noted that the company stores tiny parts directly at the production machine. Thus not all required parts have a storage place in the defined areas. Figure 5-15 shows the position of different storage areas in the company. The receiving area, marked with a green arrow, is located at the right corner and the shipping area, marked with a red arrow, is located on the left. To reduce the distance between the receiving area and the storage and between the shipping area and the dispatch warehouse, they are located next to each other. Figure 5-15 shows another storage area called the clean room storage, which contains only parts for PCV manufacturing, which is located in the clean room opposite this storage area.

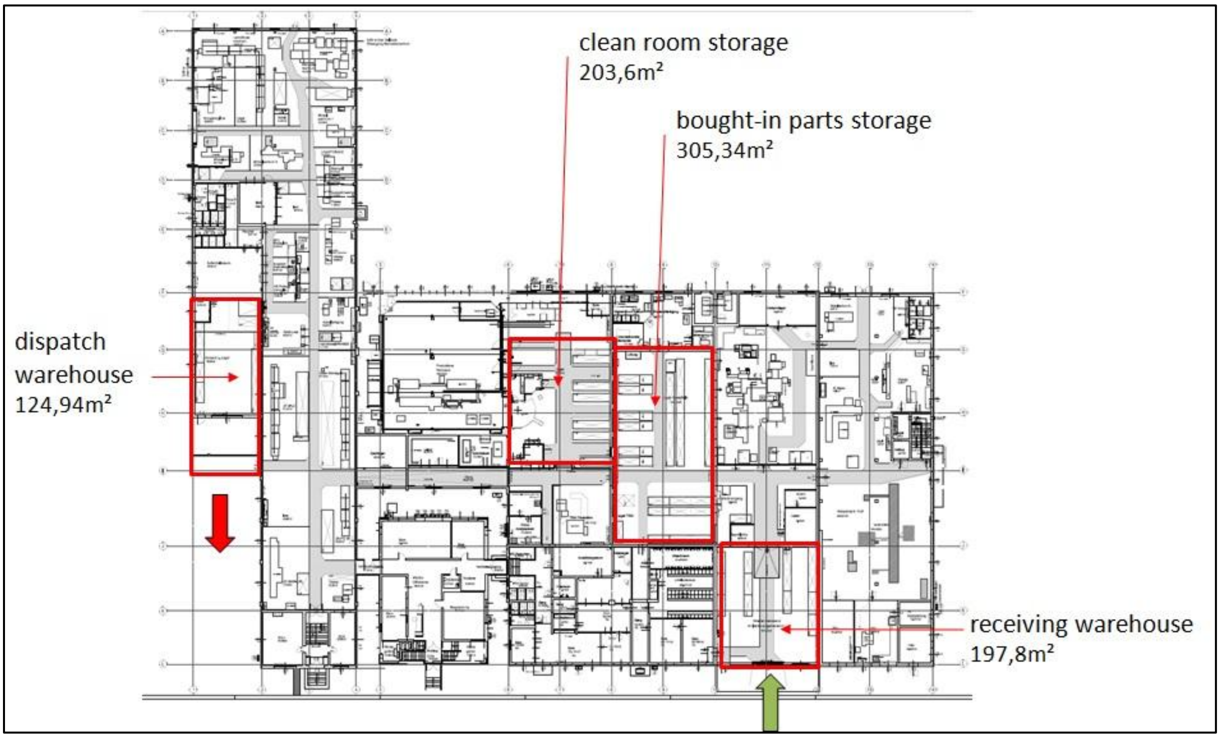


Figure 5-15: Storages

When considering the huge production volume of AL articles and the significantly large material flow between the storage and the receiving area and simultaneously between the storage and AL production, it can be seen that the straight path that connects these three departments must exhibit intensive transportation traffic. This path is shown in figure 5-16 and should be considered with a higher attention in the layout planning.

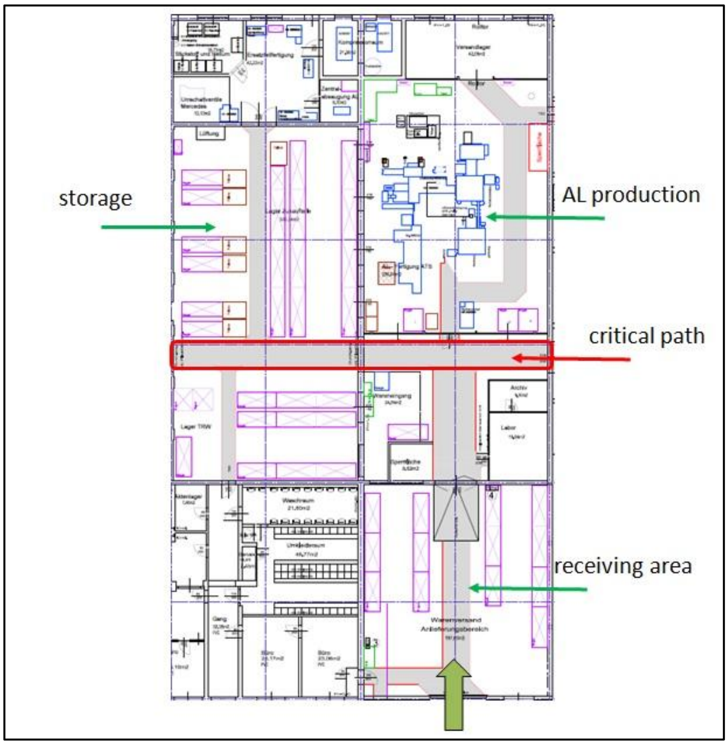


Figure 5-16: Critical path

Free available spaces

The aim of the current analysis period is the definition of free available areas and areas which are not available for the setup of the new production machines. In addition, knowledge is acquired about the annual production volumes of the different production machines and knowledge about the company's organization in terms of the storage system and material flows. Thus it is possible to consider the current manufacturing capability, particularly that of the Automotive Lighting articles. As can be seen in the following figure 5-17, the green marked areas are available meaning that a huge area arises near to the dispatch warehouse. The second big area includes the bought-in part storage and the clean room storage. Moreover, the automatic assembly machine PL2 can be moved in front of the Daimler and Kohnsberglinie in the left corner in figure 5-17. PL2 is marked green because of this. To obtain more space, there is also the opportunity of rotating the UKL machine by ninety degrees anti-clockwise. This information was collected during the material flow analysis in cooperation with Kendrion.

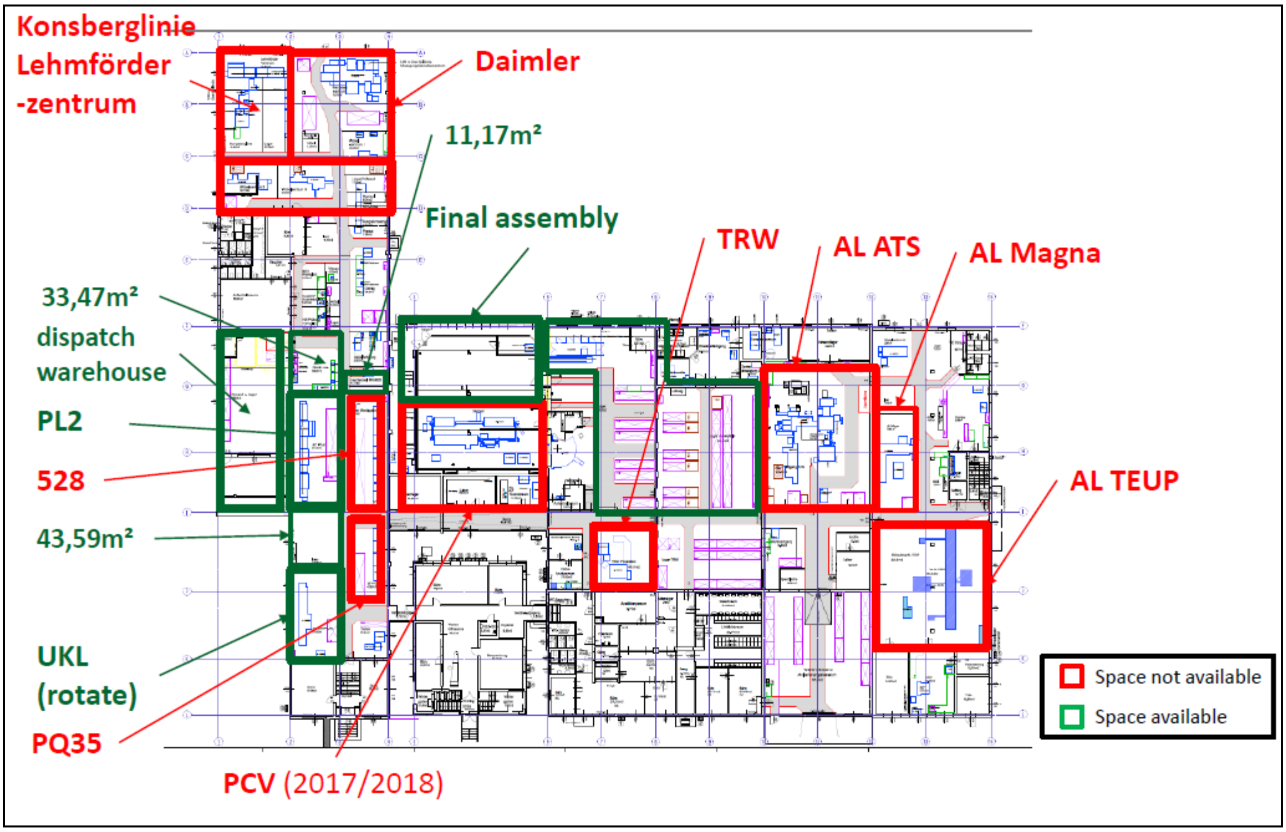


Figure 5-17: Spaces which are available

5.3 Factory Design

This chapter is based on the results from the current state analysis and has been divided into 3 main parts. The first section defines the different departments and shows a Sankey diagram to illustrate the whole process operation in terms of the transport intensity. Then it shows the Transport Intensity Matrix and the optimum succession, which results from the Schmigalla scheme. It also explains several simplified drafts. Section number two indicates and evaluates the real layouts and discusses the advantages and disadvantages of the different variants. Finally, the last section provides more details about the material requirement calculation and about the calculation of needed storage space.

5.3.1 Approach

The intention of this section is to outline the approach of the facility design. It can be seen from the figure 5-18 that it's possible to work on two different processes at the same time until to reach to a defined process stage. This process stages is marked with the thick black line. After that stage it is necessary to have the information about the needed storage space on the one hand and to get the results from the transport intensity matrix as well as from the Schmigalla schema on the other hand. Based on those outcomes the further process steps can be developed and finally evaluated and compared.

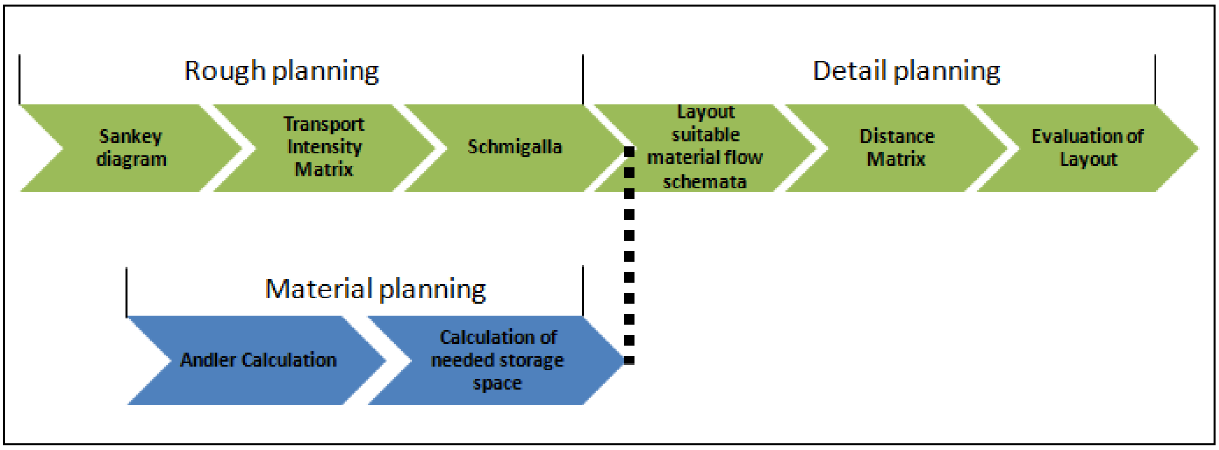


Figure 5-18: Approach

5.3.2 Rough planning

The rough planning has been divided into three core process which is illustrated in the figure 5-18. Section number one explains the sankey diagram with some detailed information about the defined departments. Afterward, the following section two represents the transport intensity matrix with the elaborated Schmigalla algorithm and finally the last section illustrates and compares the several simplified drafts.

Sankey diagram

It is necessary to provide an introduction to the defined departments and the colour selection before we explain the Sankey diagram and other content.

Colour selection

To obtain a clearer understanding about the material streams and to know which materials flows between the departments in the following illustration, we decided to define a colour selection. This means that every assembly receives a defined colour. Figure 5-19 shows the several subassemblies and the finished product marked with the colour. It is also recognizable that the components from an assembly receive the same colour. This makes it possible to capture most of the information with one glance.

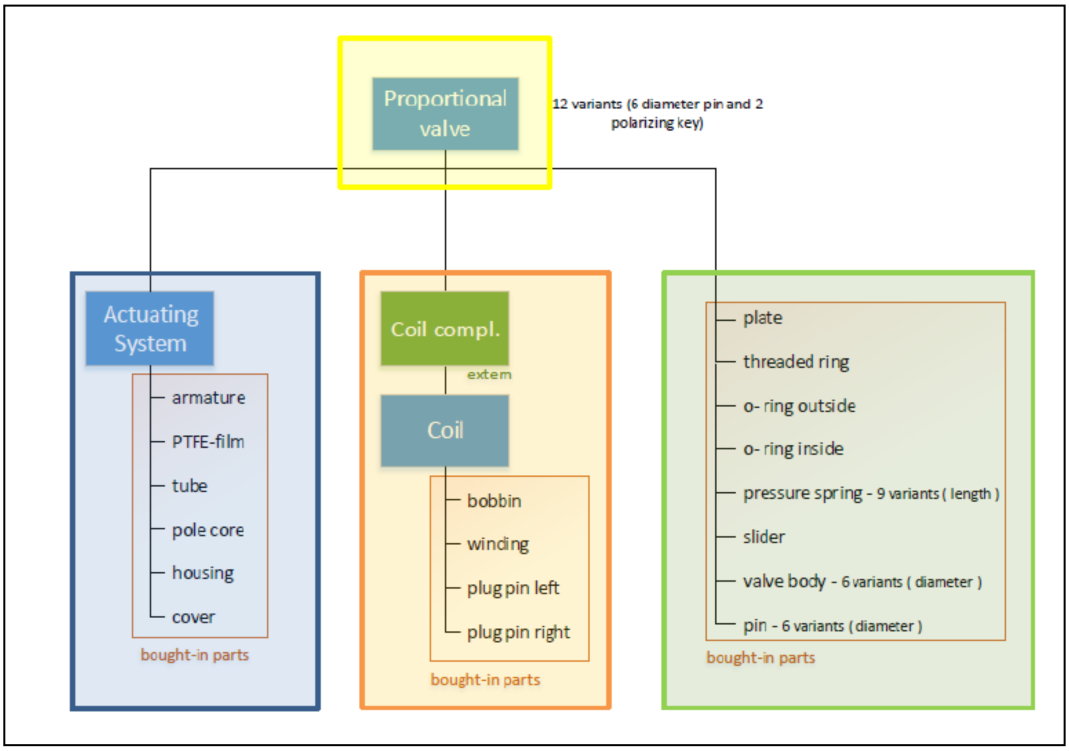


Figure 5-19: Colour selection

Departments

A Sankey diagram requires departments to illustrate the material flow through the company. Thus this section explains and identifies a number of departments.

Figure 5-20 shows the defined departments. The field materials handling/storage are departments that store materials, change the packaging, or load and unload trucks. This field consists of the receiving area to take delivery of the goods. The copper storage stores the copper wire required for all products. Storage 1 is responsible for the supply of the pre-assembly and the winding machine, and storage 2 stores all bought-in parts for the final assembly. The dispatch warehouse represents the interface to the customer and loads the trucks.

In the middle, the field cleaning does the preliminary work for the manufacturing lines. It cleans or washes the parts to ensure that the welding processes are possible and to ensure the high quality standard of the products.

Finally, the last field is called assembly/quality and consists of three production machines and one unit to test the finished products. After the last manufacturing process, every product has to pass the hydraulic test to ensure the functionality.

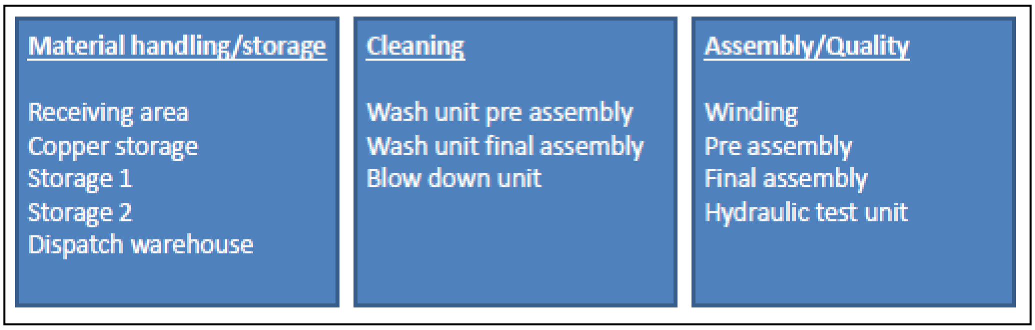


Figure 5-20: Defined departments

Diagram

The aim of the Sankey diagram is to outline the material flow through the company. This knowledge about the further material flow helps to come to a real understanding of the importance of the distance between different departments. The numeric value in the following diagram is shown in the unit transport containers per year and the percentage relates to the whole material flow in a year.

It can be seen from the sankey diagram in the figure 5-21 that the material flow starts at the top of the picture at the receiving area. After the receiving are the materials are delivered to the storages. It is recognizable that the main material flow runs to the storages one and two and that just a negligibly amount flows to the copper storage, wash unit final and blow down unit.

Next, there is also a not negligibly flow from the storages to the necessary preliminary cleaning departments like a big one from the storage one to the wash uni_pre and a little smaller one from the storage two to the wash unit_final and to the blow down unit. As can be seen from the figure, that there is also a tiny connection between the receiving are and the wash unit_final and aslo to the blow down unit. These very small material flows represent tiny parts which go directly to the cleaning unit and are stored at the manufacturing line.

After four hours of cooling down, the parts go on the one hand from the wash unit_pre to the pre-assembly and on the other hand from the wash unit_final to the final assembly. By the consideration of the department final it is identifiable that there is also a big narrow from the blow down unit. This narrow consist of a big flow from the pre-assembly and one from the storage two which are the over moulded coils. Afterwards, there is a material flow through the hydraulic test unit to the dispatch warehouse.

If it’s possible to see that whole winding process are worked parallel to the other processes. For that process the materials go from the receiving area to the cooper storage and to the storage one. After that they are fitted at the winding machine and go directly to the dispatch warehouse. The orange narrow which goes from the receiving through the storage two to the blow down unit are the over moulded coils delivered by Hiebler.

To summarize it, there is an intensive relationship between the receiving area and the storages and from the storages to the cleaning departments. If we look at the bottom of the picture, there is a high intensity between the dispatch warehouse to the final manufacturing and to the winding machine. It is also identifiable that whole winding process is worked in parallel to the other processes. This information should be considered in the next stages of planning.

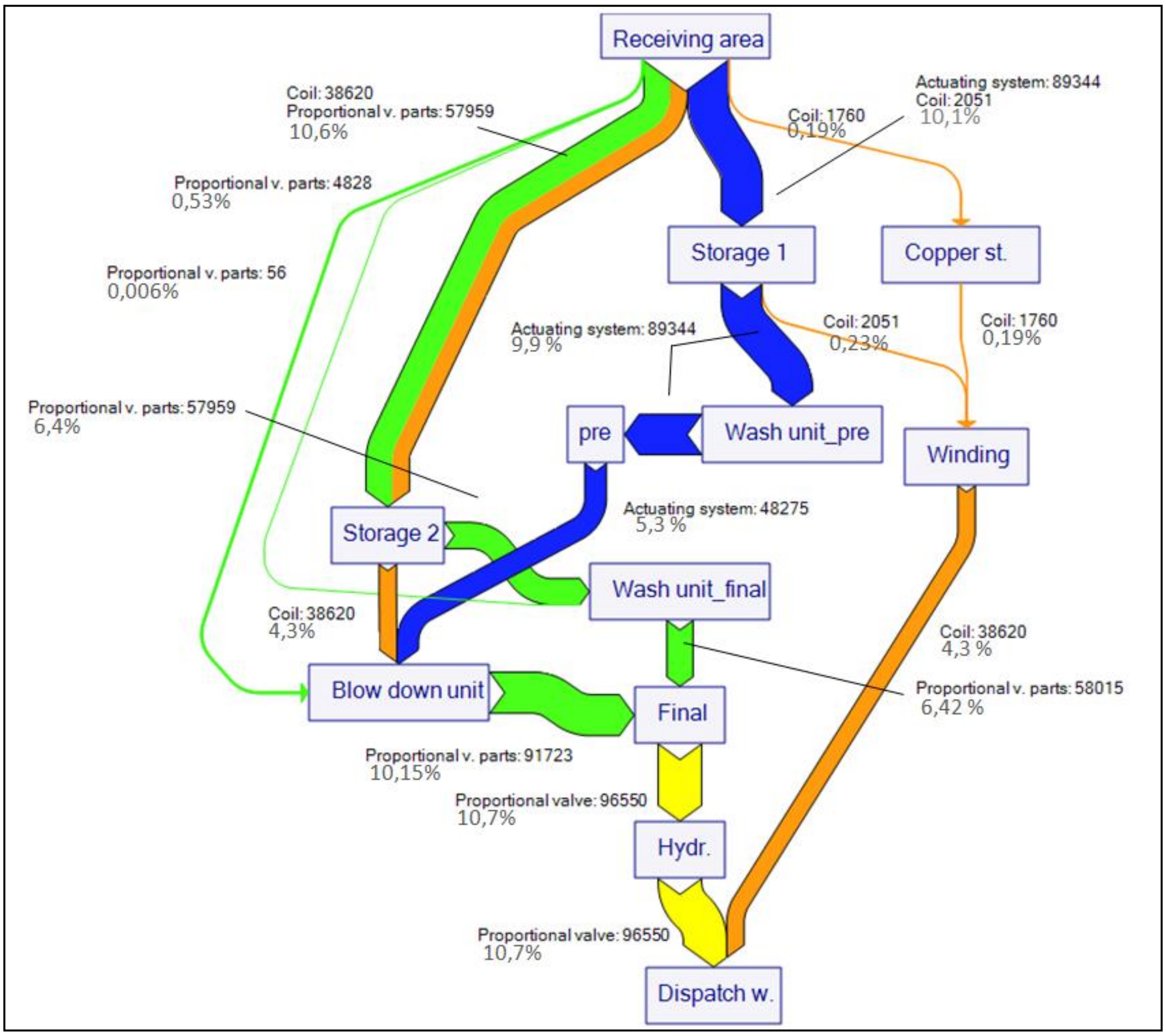


Figure 5-21: Sankey diagram

Transport intensity matrix

As chapter 4.2.4 already discussed, is the transport intensity matrix a helpful method to illustrate clearly the transport volumes of a complex systems. This matrix is an understandable way of showing where and in which quantity the several materials are going. The left vertical column describes where the parts are delivered and the horizontal row describes where the delivery takes place. It also demonstrates the high intensity between the storage and the receiving area, between the cleaning departments and the storages and between the final and the dispatch warehouse.

from \ to	receiving area	copper st.	storage_1	storage_2	wash unit_pre	wash unit_final	blow down unit	pre- assembly	winding	final assembly	hydraulic test	dispatch w.	sum
receiving area		**1.760**	**91.395**	**96.579**	0	**56**	**4.828**	0	0	0	0	0	194.618
cooper st.	0		0	0	0	0	0	0	**1.760**	0	0	0	1.760
storage_1	0	0		0	**89.344**	0	0	0	**2.051**	0	0	0	91.395
storage_2	0	0	0		0	**57.959**	**38.620**	0	0	0	0	0	96.579
wash unit_pre	0	0	0	0		0	0	**89.344**	0	0	0	0	89.344
wash unit_final	0	0	0	0	0		0	0	0	**58.015**	0	0	58.015
blow down unit	0	0	0	0	0	0		0	0	**91.723**	0	0	91.723
pre- assembly	0	0	0	0	0	0	**48.275**		0	0	0	0	48.275
winding	0	0	0	0	0	0	0	0		0	0	**38.620**	38.620
final assembly	0	0	0	0	0	0	0	0	0		**96.550**	0	96.550
hydraulic test	0	0	0	0	0	0	0	0	0	0		**96.550**	96.550
dispatch w.	0	0	0	0	0	0	0	0	0	0	0		
sum	0	1.760	91.395	96.579	89.344	58.015	91.723	89.344	3.811	149.738	96.550	135.170	

Figure 5-22: Transport intensity matrix

The aim of this chart is to outline the intensity between the different departments and it is necessary to carry out the Schmigalla method. The Schmigalla algorithm is a useful tool to obtain the knowledge about the succession of the departments to create a layout with as low a transport coefficient of performance as possible.

The following table 5-14: shows the results from the Schmigalla algorithm and the optimized succession that is helpful to create some simplified drafts.

pos.	Department	pos.	Department
1	Receiving are	7	Final assembly
2	Storage 2	8	Hydraulic test unit
3	Storage 1	9	Dispatch warehouse
4	Wash unit pre	10	Wash unit final
5	Pre-assembly	11	Winding
6	Blow down unit	12	Cooper storage

Table 5-14: Optimized succession of the departments

Simplified drafts

The next stage is to create simplified drafts together with the information about the transport intensity from the “from-to chart” and the optimal succession from the Schmigalla algorithm. The intention of this method is to create the first layouts by neglecting some criteria such as the required space of each department and the transport direction.

Variant 1- Ideal layout

The ideal layout is the best technical and organizational layout with the lowest transport coefficient and this layout is considered without any economic, geographical or other restrictions. Thus, the ideal layout represents a layout create only under the aspect of the material flow. It should give a reference value to compare it with other simplified drafts to know how efficient they are. It can be seen from the figure 5-23 that all defined departments are placed on this pattern and it is already discussed in chapter 4.3.1.1 that the intensity is the product from the distance multiplied by the transport volume from the transport intensity matrix. The thick orange connections represent the highest transport intensity with a value from 50.001-100.000 TU (transport unit) per year and it is obviously that all the orange connectors have the value one. That arrangement has a value from **975.362**.

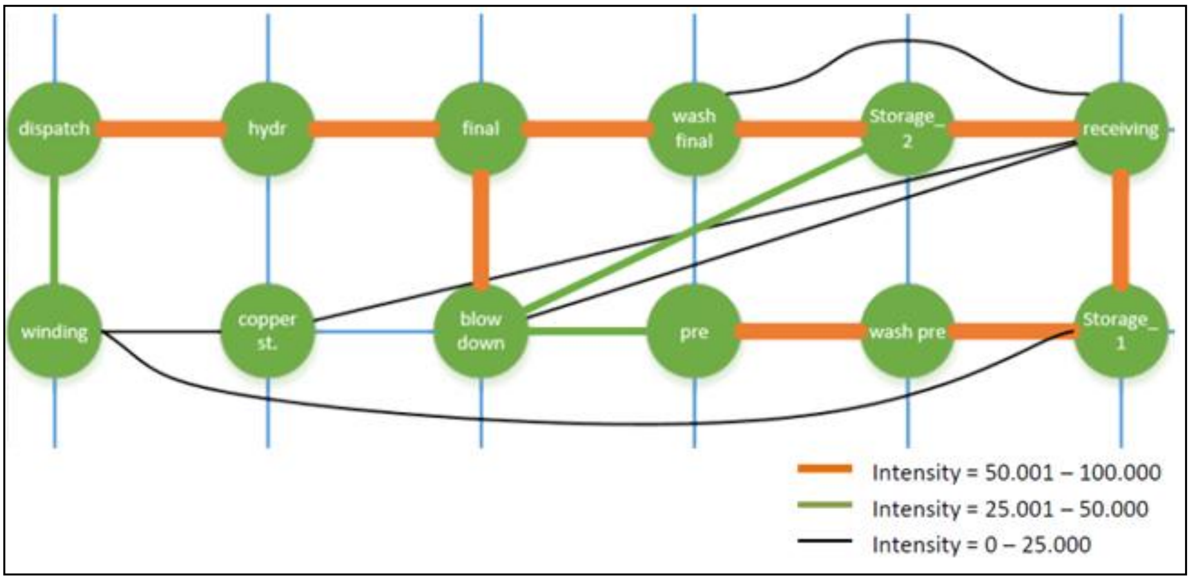


Figure 5-23: Variant 1- Ideal layout

Variant 2- One way material flow

Variant one represents an idea to modulate a material flow that starts at one point in the company, goes through it, and ends at another point. It can be seen in the following figure 5-24 that the material flow accrues in the right bottom of the figure and the material flow ends on the left side at the dispatch warehouse. Thus, the material flow runs fluently through the company without any crosses and that is the reason for the very low Intensity of **1.091.484**. By comparing the intensity with the intensity from the ideal layout it is reconcilable that the gap between them is very tiny. It has to be mentioned that the orange circles like the final or the copper storage are departments that already have a fixed defined area. Thus, only the green circles are able to be moved on this pattern.

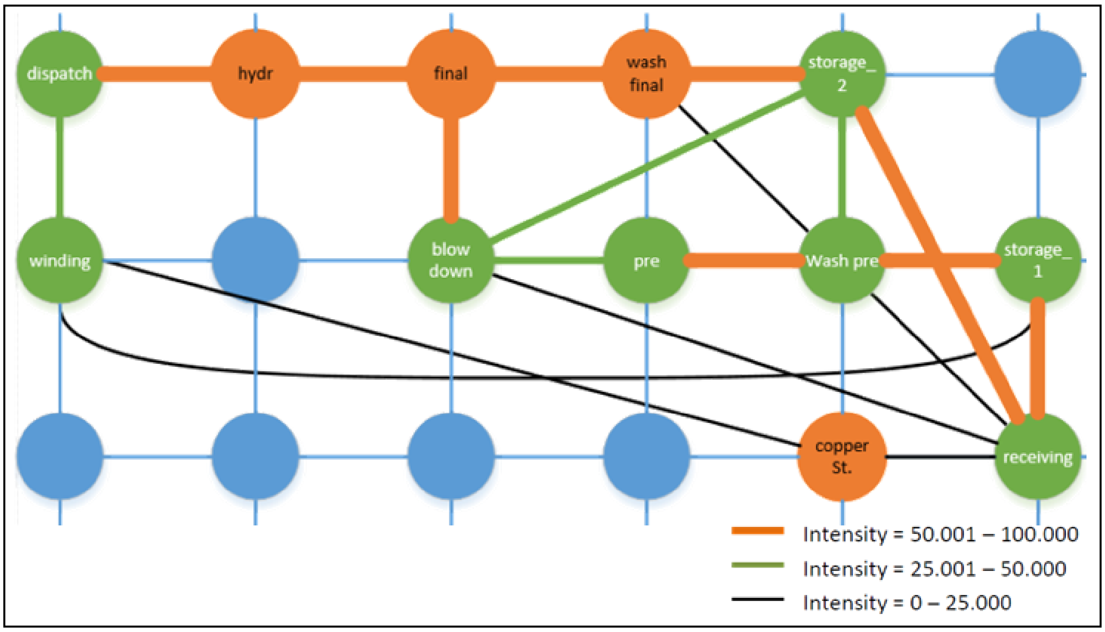


Figure 5-24: Variant 2-One way material flow

Variant 3- Competence Centre

Third, variant number two shows a layout with a material flow like a circle. This means that the materials enter the company at the right side at the receiving area and leave the company at the dispatch warehouse also placed on the right side. Figure 5-25 illustrates the material flow which starts in the receiving area and goes through storage one to the pre-assembly and over wash unit final to the final assembly and leaves the company after the hydraulic test at the dispatch warehouse. Thus, the material flow runs only in a part of the company with the advantage of minimizing the effect on other productions and the possibility to build up a Bilstein competence centre. The transport intensity is little bit higher than the variant before with a value from **1.291.021**.

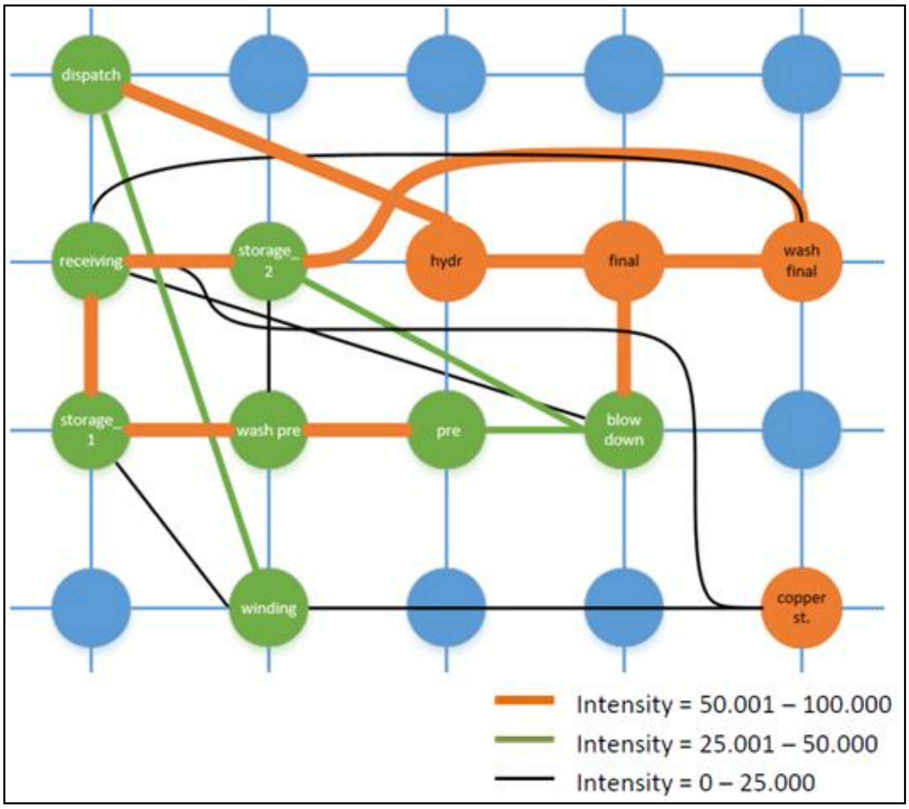


Figure 5-25: Variant 3- Competence centre

Variant 4- Existing Infrastructure

Finally, variant three follows the idea of using the existing infrastructure and keeping the investment costs as low as possible. That means for example that the existing dispatch warehouse or storages are also used by the new contract and that the new wash unit_pre is located near the existing one to use the same hydraulic attachment points. But the disadvantage is the highest transport intensity from **1.383.450** based on the long distances between the several departments.

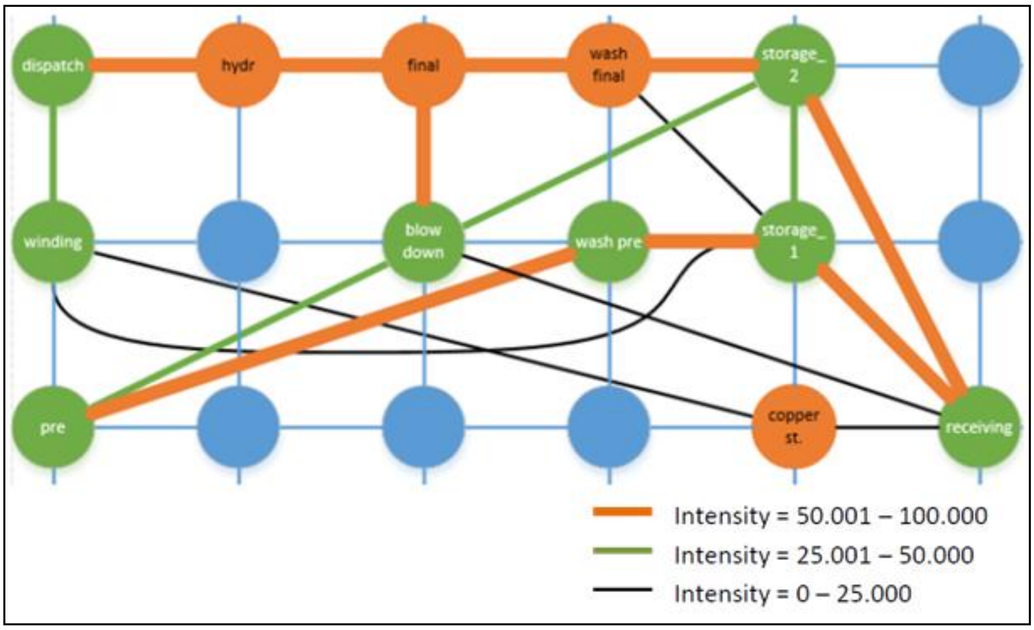


Figure 5-26: Variant 4- Existing Infrastructure

5.3.3 Optimum order quantity

This chapter consist of three sections. The first section illustrates all required information for the calculation of the logistic costs. The second section shows the results, the batch sizes and the order frequency. Section number three shows the required storage space in terms of the batch sizes.

Logistic costs

The optimum batch size is calculated based on the strategy to reduce the logistic costs which is illustrated in the chapter 0. The logistics costs consist of two main parts the order costs on the one hand and the inventory on the other hand.
Some cost factors have to define before it's possible to carry out the calculation. As can be seen in the following Table 5-15 that are six factors are needed to calculate the order cost and in the Table 5-16 can be seen that five factors are needed for the inventory cost. Most of these several factors are defined in cooperation with the controlling and logistic department and some are defined in the lecture.

Order costs

The first item of information required is the consumption based on period which can be calculated based on the production volume. Together with the logistic department, we defined the minimum order quantity and the capacity of the several transport units for each bought-in part. It has to be mentioned that the agreed price per unit consists of the price for the part and that price includes all costs in terms of the transportation and all external costs for an order. That is the reason that these factors have the value zero. The last two costs are defined in the literature.

Order costs:			
λ	Consumption based on period [#/pe]	-	Kendrion
q_D	Order quantity [#]	-	
C_{Pcon}	Costs for an order (internal + external) [€]	**17€ + 0€**	Literature
C_{Te}	Transportation costs [€/Tu]	**0€**	Kendrion
C_{Ti}	Internal Transportation (Receiving area – Storage) [€/pallet]	**3,5€/pallet**	Literature
C	Capacity of the transport unit	-	Kendrion

Table 5-15: Needed information to calculate the order costs

Inventory costs

All required costs shown in table 5-16 were worked out in cooperation with Kendrion. These are for example the interest in terms of capital commitment, or costs that occur to carry a pallet over a year. The amount of the safety stock is defined by about one day. This means that the safety stock for parts that are needed to produce the pre-assembly is defined by half a day, in addition to that the safety amount of the finished actuating system are defined by one day. Parts that are needed for the final assembly have a safety stock to protect against procurement issues or production process of one day. Finally, the last storage coefficient represents the storage strategy, which means that every part has a fixed defined storage place.

Inventory costs:			
P_{ma}	Price per unit [€]	-	Kendrion
i_L	Interest in terms of capital commitment[%]	**6%**	Kendrion
q_S	Safety stock[#]	-	
c_{SP}	Costs of carry [€/pallet*pe]	**182,5€/pallet*a**	Kendrion
f_S	Storage coefficient	**1**	Kendrion

Table 5-16: Needed information to calculate the inventory costs

Those are the defined costs that are fundamental for the following order quantity calculation.

Resulting batch sizes

The following section illustrates the results from the calculation. It has to be mentioned that the characteristic of the order costs is described by a flat curve. The reason for this is that the price per unit includes all costs for the transportation and based on this the logistic costs describes a similar curve. The result is that the optimum order looks more like a defined area instead of a significant point. The arising advantages are discussed in the chapter 3.4.3. Generally, the calculation is carried out for every year in the defined period of investigation with a distinction of the product volume and thereby with a different consumption. The following table represents the defined order quantity in the different units and the frequent of the procurement order. The result looks similar to most of the supplier with a delivery frequent of 2-4 days.

Supplier: MESA

pos.	designation	2017	2018	2019	
1	armature	46.512	52.896	52.440	pcs/assignment
		102,0	116,0	115,0	Tu/assignment
		3,1	3,5	3,4	days/delivery
3	cover	35.640	39.960	39.420	pcs/assignment
		132,0	148,0	146,0	Tu/assignment
		2,3	2,6	2,6	days/delivery
4	tube	52.000	58.000	57.000	pcs/assignment
		52,0	58,0	57,0	Tu/assignment
		3,4	3,8	3,8	days/delivery
5	pole core	32.130	36.180	35.640	pcs/assignment
		119,0	134,0	132,0	Tu/assignment
		2,1	2,4	2,4	days/delivery
16	valve body	24.000	27.120	26.640	pcs/assignment
		200,0	226,0	222,0	Tu/assignment
		1,6	1,8	1,8	days/delivery
17	slider	35.530	40.018	39.644	pcs/assignment
		95,0	107,0	106,0	Tu/assignment
		2,3	2,6	2,6	days/delivery

Table 5-17: Order quantity / Supplier: MESA

Supplier: Frank & Pignard

pos.	designation	2017	2018	2019	
6	housing	25.040	28.240	27.760	pcs/assignment
		9,0	10,0	9,0	pallet/assignment
		1,9	2,1	1,9	days/delivery

Table 5-18: Order quantity / Supplier: Frank&Pignard

Supplier: Hiebler

pos.	designation	2017	2018	2019	
11	bobbing	80.000	90.000	88.000	pcs/assignment
		40,0	45,0	44,0	Tu/assignment
		5,2	6,0	5,8	days/delivery

Table 5-19: Order quantity / Supplier: Hiebler

Supplier: Vegu

pos.	designation	2017	2018	2019	
8	threaded ring	38.000	42.500	42.000	pcs/assignment
		76,0	85,0	84,0	Tu/assignment
		2,5	2,8	2,8	days/delivery

Table 5-20: Order quantity / Supplier: Vegu

Supplier: Saxonia Franke					
pos.	designation	2017	2018	2019	
7	plate	35.000	39.500	38.500	pcs/assignment
		70,0	79,0	77,0	Tu/assignment
		2,3	2,1	2,1	days/delivery

Table 5-21: Order quantity / Supplier: Saxonia Franke

Supplier: Salix					
pos.	designation	2017	2018	2019	
2	PTFE Folie	210.000	240.000	240.000	pcs/assignment
		7,0	8,0	8,0	Tu/assignment
		13,5	15,1	15,5	days/delivery

Table 5-22: Order quantity / Supplier: Salix

Supplier: Kernliebers					
pos.	designation	2017	2018	2019	
19	pressure spring	324.000	324.000	324.000	pcs/assignment
		1	1	1	pallet/assignment
		20,2	16,8	16,8	days/delivery

Table 5-23: Order quantity / Supplier: Kernliebers

Resulting storage space

Three different storages are defined with the advantage of storing the different part as close as possible to the wash units. Therefore storage one, which is placed near the wash unit_pre, contains all parts for the pre-assembly. Storage two follows the same strategy and stores all parts that are needed for the final assembly and finally storage number three is responsible for the actuating system, which is just a safety stock.

It can be seen from table: 5-25 that the storage space is divided into a net and a gross space. The net space is calculated regarding the using storage inventory. The company use shelves with different loads and footprints, which are listed in the following table 5-24. The gross space represents space that is required to load and unload the storage.

Shelf 1	load [pallet]	dimension [m]	footprint [m²]
	15	5 x 3,9 x 1,2	**6**
Shelf 2	load [pallet]	dimension [m]	footprint [m²]
	9	3,5 x 3,9 x 1,2	**4,2**
Shelf 3	load [pallet]	dimension [m]	footprint [m²]
	6	2,5 x 3,9 x 1,2	**3**

Table 5-24: Shelf space

The required storage place is defined on the basis of the defined safety stock and the calculated order amount. The shelf space from the following tables has a load from one pallet with a footprint of 1,20 x 0,8m and a maximum height of 1,20m. Therefore, it results in a required shelf space for each part in terms of the height of the different transport units (Tu). This means that one layer on a plate consists of four transport units, which are containers, and the maximum amount of layers depends on the height of the transport containers. The results for the storage one and two are a required gross space of 24,5m² and for the storage three 22,7m².

Storage 1

parts	Tu	layer	Shelf space	
armature	68	17	3	
PTFE- film	4	1	1	
tube	34	9	3	
pole core	87	22	4	
housing	-	-	7	
cover	94	24	5	
bobbin	24	6	2	
plug pin left	-	4	1	
plug pin right	-	4	1	
		∑	**27**	
			12 m²	Net space
			24,5 m²	Gross space

Table: 5-25 Storage 1

Storage 2

parts	Tu	layer	Shelf space
coil compl.	-	-	4
plate	-	-	2
threaded ring	68	18	6
slider	68	17	4
pin	-	-	1
o-ring	-	-	1
pressure spring	-	-	1
valve body	163	41	7
		∑	**26**
			12 m² Net space
			24,5 m² Gross space

Table: 5-26 Storage 2

Storage 3

parts	Tu	layer	Shelf space
Actuating System	378	95	24
		∑	**24**
			10,2 m² Net space
			22,7 m² Gross space

Table: 5-27 Storage 3

5.3.4 Detail planning

This chapter is divided into three sections. In starts with define and explain the several evaluation criteria to assess and compare the elaborated real layouts. Afterwards, section number two shows the several real layouts and illustrates the different advantages and disadvantages. Finally, the last section summarizes the results and defines the chosen layout which will be simulated in the simulation program Plant Simulation.

Evaluation criteria

This section explains the evaluation criteria of the different layout variants. The evaluation criteria are divided in two main divisions with some under criteria. Additionally, the several under criteria are explained more in detail. The figure 5-27 illustrates that the evaluations criteria are divided into economical and the technical criteria.

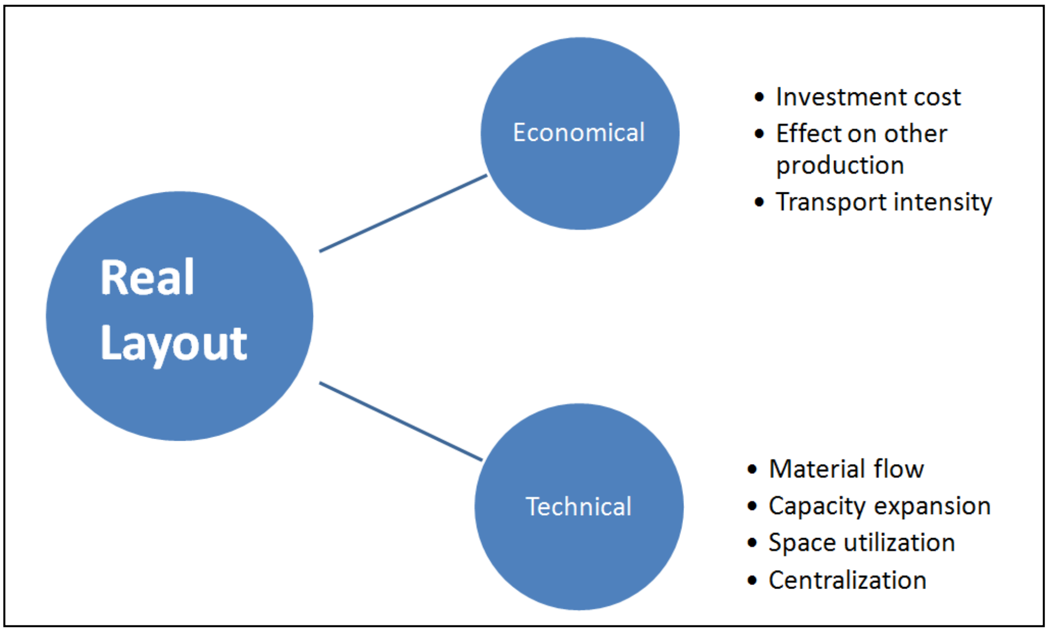


Figure 5-27: Evaluation criteria

Economical criteria

Apart from the technical criteria it is also very important to take a look about costs for new investments or costs they occur because of alteration of the existing company structure. Those alterations have also an effect on other production and are associated with costs. The main division "economical criteria" contains three varying kinds of criteria:

- Investment costs
- Effect on other productions
- Transport intensity

a. Investment costs

Investment costs come up with necessary building alterations for example for implementation of new inventory or for buildings modifications for the law in terms of employee’s security or fire prevention. To evaluate a real layout it is necessary to estimate the roughly investment cost which are required to implement al the technical details. It’s unrewarding to realise a real layout which has an excellent transport performance coefficient but on the other hand it needed a huge capital for investments.

b. Effect on other Productions

Another important considered criterion is that the installation of the new production line should have hardly any effect on other productions. Based on the high production target of the other articles it’s necessary that the integration of the new product line doesn´t interrupt other productions in terms of the transport, capacity expansion or storage space.

c. Transport intensity

The transport intensity, which means the amount of the transportations between department’s times the distance between them, is closely related to the costs for the internal transportation. Thus to minimize the internal transportation costs and optimize the material lead time it’s necessary to evaluate the real layouts about the transport intensity and try to keep the distances as low as possible. Only this criterion is possible to calculate and make a quantitative comparison between the different layout variants.

Technical criteria

a. Material flow

As opposed to the transport intensity the material flow represent the “material way” through the company. It is worthwhile to invest a lot of efforts to plan the material flow to prevent intersection, branching and bottlenecks and to ensure the productivity of the company.

b. Capacity expansion

In the course of the material flow analyse was determined that there is a demand to expand the productions target. Because of that it is necessary to keep in mind the opportunity to expand the capacity of the production and storage. On the other hand it’s also to consider the possibility for an expansion of other actual productions.

c. Space utilization

Chapter 0 consist already the definition about spaces which are "free" and spaces which are impossible to use for the layout planning. From the material flow analysis has been seen that some "green" spaces , that means that they are free, are already be used from other productions lines for example as a storage or something like that. The criteria space utilization considered if the used areas in the layout planning are vacant or not.

d. Centralization

The last considered criterion is the centralisation which means to setup the production line very compact in the company. A very compact layout has the advantage of a better controlling, a easier coordination of the different activities, faster induction of modifications in the manufacturing and the closeness of the different departments forming the possibility that employees are able to supervise certain machines together.

5.3.4.1 Real layouts

The real layouts are carried out on the different strategies from the simplified drafts. It represents a real existing layout and the defined departments are placed on it. All material flows between the departments are drawn in the defined colours from chapter 0. Additionally, it lists all advantages in green and all disadvantages in red. The arrows represent the delivery of parts in green on the one hand and the shipping process in red on the other hand. Finally, the table illustrates the transport effort in euro, but it has to be mentioned that this transport effort is calculated without considering the loading and unloading time which is needed to store pallets. This means it is calculated with an average speed and the costs of the forklift, costs of the employee and with an average load.

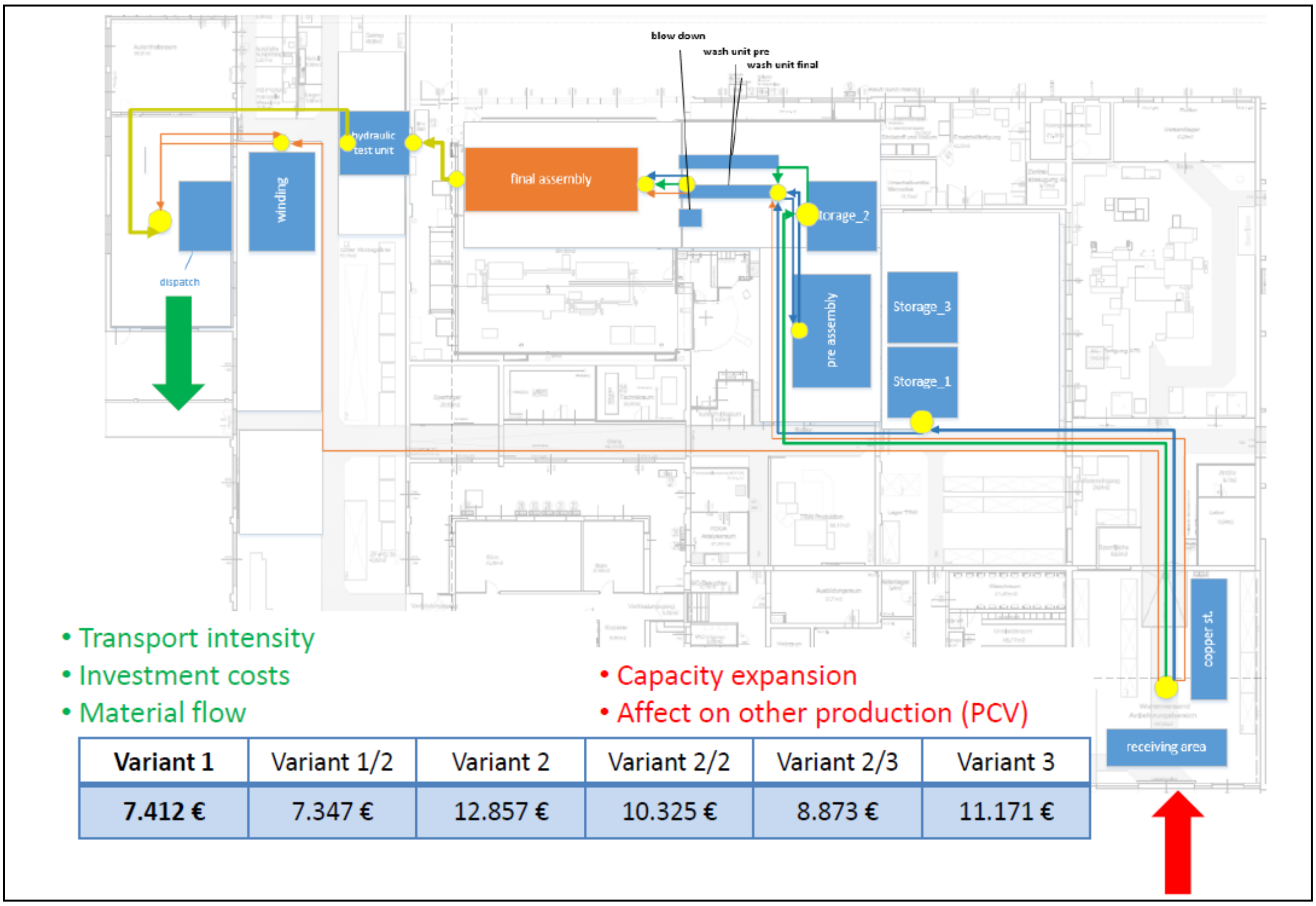
Real layout variant 1 and 1/2

The first two layouts are comparable with the second variant of the simplified drafts illustrated in the figure 5-24. This layout tries to realize a fluent material flow through the company.

Variant 1

The first layout is comparable with the first variant of the simplified drafts. This layout tries to maintain fluent material flow through the company.

Variant 1 is shown in figure 5-28 and demonstrates the material flow starting at the receiving area at the bottom, which is marked with the big red arrow. Next, it moves from that department directly to storage one or two. It can be seen in the layout that the two washing machines are placed next to each other to use the same attachment points and as a result the opportunity arises to handle these two machines with just one place of work. The cleaned materials go straight into the clean room or go back to the pre-assembly, all the time with short distances. Finally, the finished products move through the test unit to the dispatch warehouse. It can be seen on the left that the winding machine is also placed close to the dispatch warehouse, which will reduce the transport effort. It is easily identifiable that there is fluent material flow through the company without any crosses and few flows that go backwards. The advantages of this layout are the low transport intensity based on the short distance between the departments, the low investment costs and the opportunity to handle the washing machines by one employee. But the disadvantages are the impaired ability to expand the capacity and the affect on production, because the pre-assembly is placed in the storage area of another manufacturing line.



Variant 1	Variant 1/2	Variant 2	Variant 2/2	Variant 2/3	Variant 3
7.412 €	7.347 €	12.857 €	10.325 €	8.873 €	11.171 €

Figure 5-28: Real layout: Variant 1

Variant 1/2

As the designation implies is that layout more an improvement from the previous layout. The aim of this variant is to reduce the affect on the other production which is also situated in the clean room. The material flow is similar the same but with the significant distinction that the pre-assembly is placed in the bought-in parts warehouse. The result of that adjustment is on the one hand that the affect is reduced but on the other hand the investments increase because of the building modification which is needed to get a connection between the storage and the clean room. The connection ensures the low transport intensity and short distance between the wash unit and the pre-assembly which is important.

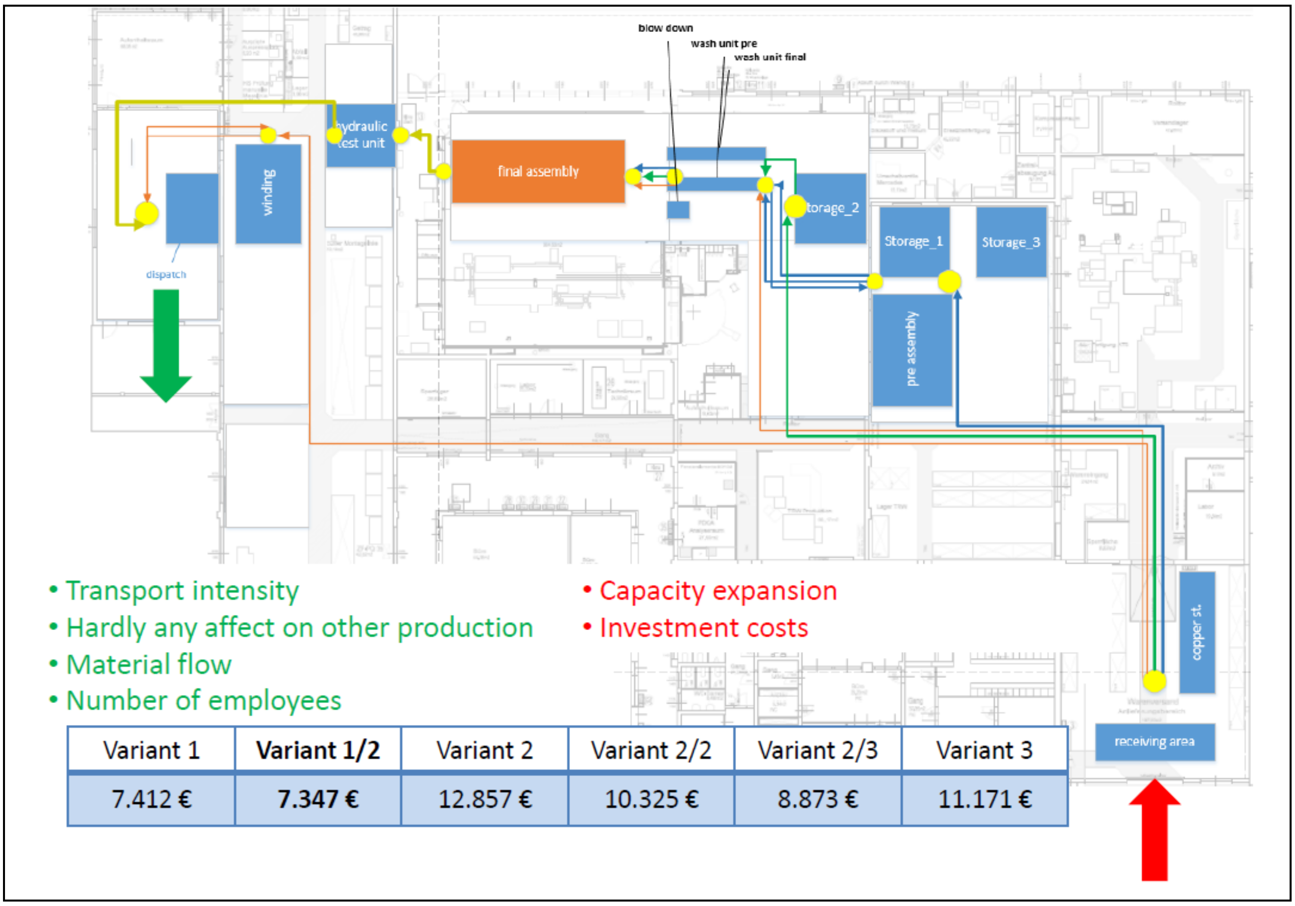


Figure 5-29: Real layout: Variant 1/2

Real layouts 2

The following layout is carried out based on the simplified draft “competence centre”. This layout variant covers the strategy to build up a Bilstein centre and try to place all required production machines in a small part of the company.

Variant 2

One significant distinction is that both red and green arrows are located at the same place. That means that the materials are delivered and shipped from the same department. The result of this is that the material flow runs through the company like a loop or circle and that the new assignment makes use of just a part of the company. There is a major difference to the previous concept because the material flow uses just a manageable part on the right side of the company with the outcome that this concept hardly has an effect on other productions and that the critical path as we explained in section 5.2.50 is not used. Another advantage is the possibility to expand the capacity. If the production volume increases, there is the possibility of extending the area with the department's storage one/two, receiving area and dispatch warehouse, because the bordering area left from the dispatch warehouse is a useable parking place.

Although, the main disadvantage of that layout is the long distance between the pre-assembly and the wash unit_pre. The result is a high transport coefficient of performance because of the distance in cooperation with the high intensity.

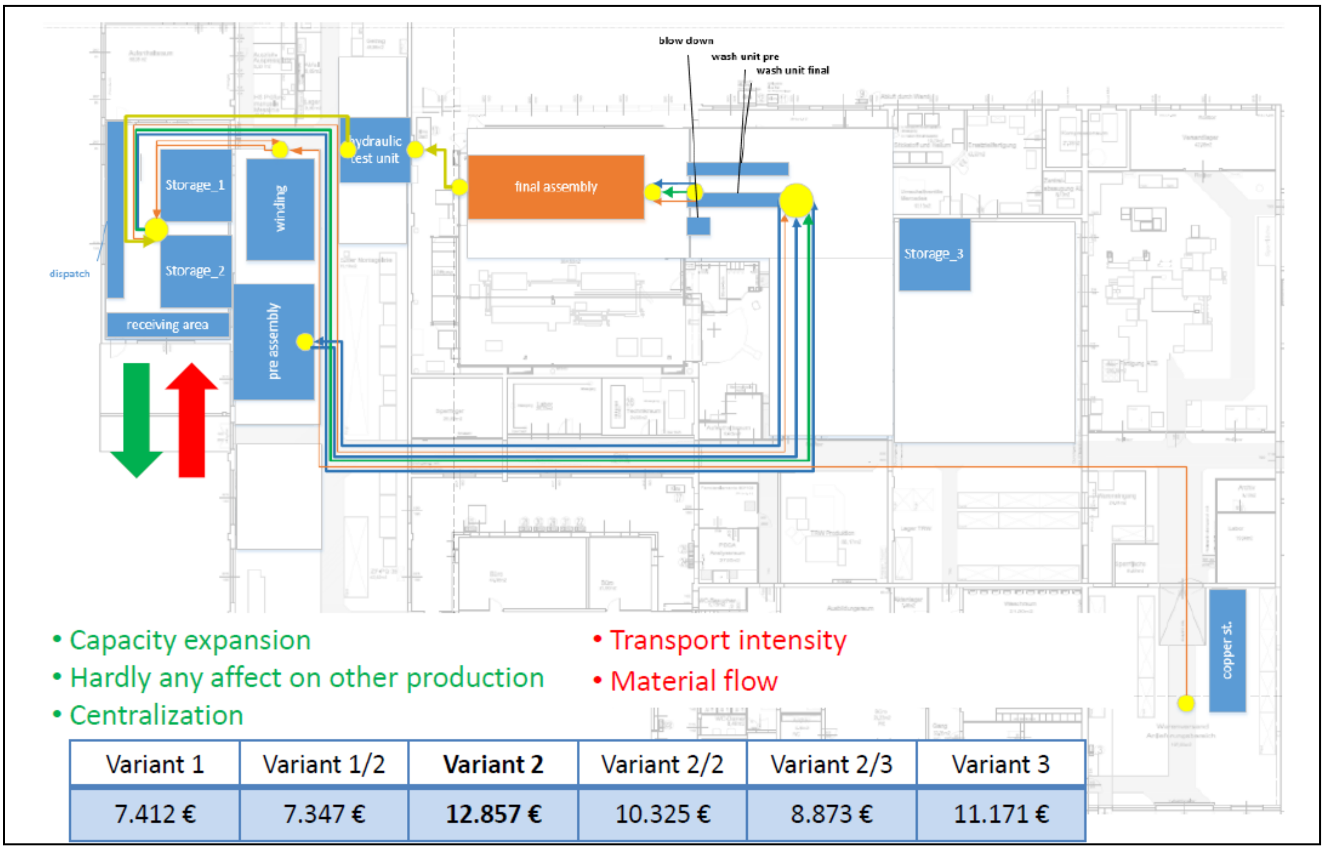


Figure 5-30: Real layouts: Variant 2

Real layouts 2/2 and 2/3

Like the variant 1/2 these following variants are improvements in terms of the elaborated layout variant 2. It has to reduce the negative effect of the long distance between the pre-assembly and the wash unit. To reduce this distance there are exists to possibilities on the one hand to place the manufacturing line for the actuating system near to the washing unit like in the previous layouts. The second opportunity is to place the wash unit_pre close to the pre-assembly which means that both the manufacturing line and the wash unit_pre are located at left side of the layout.

Variant 2/2

This variant is carried out with the aim to reduce the distance with the possibility to place the pre-assembly near to the clean room. The result is on the one hand the significant reduction of the transport effort and a fluent flow through the company without any material flow which are going back. The possibility retained that one employee handle the three washing machines and another advantage is the proximity between the winding and dispatch warehouse. However, the main disadvantage is the little affect on other manufacturing line which is also situated in the clean room. To consider that affect more in detail it turned out that the pre assembly is placed on the storage which is used by that manufacturing line.

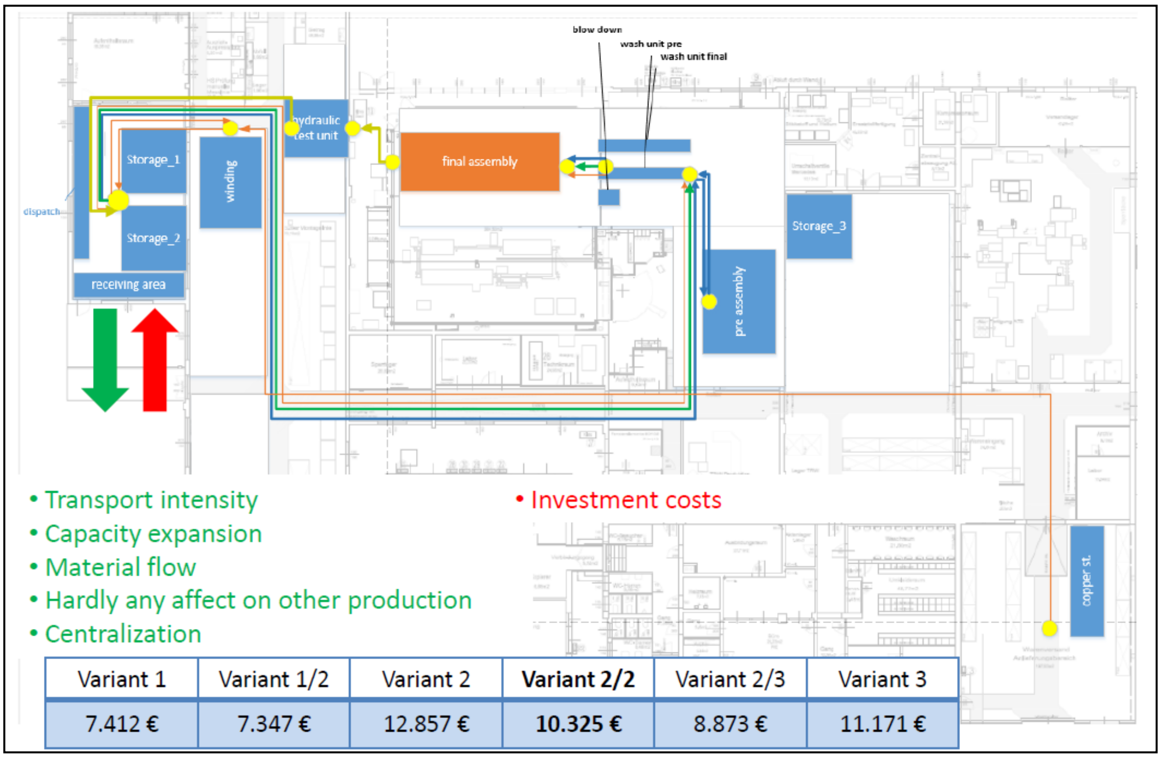
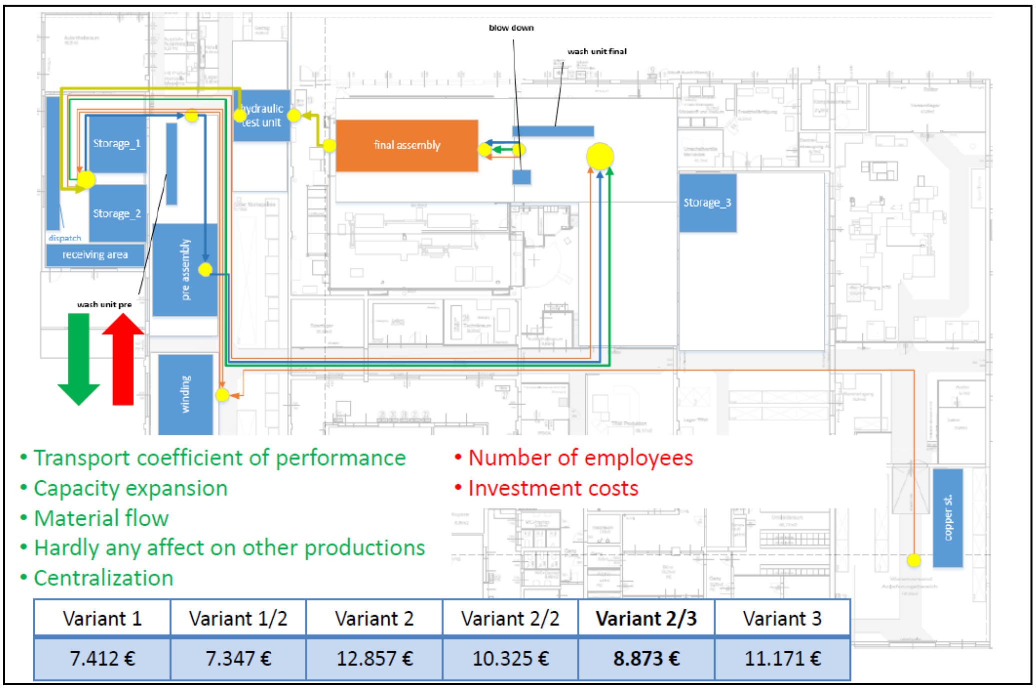


Figure 5-31: Real layouts: Variant 2/2

Variant 2/3

Variant 2/3 is similar to the previous solution based on the layout 2 with the intention to improve the transport coefficient of performance. The different to the variant 2/2 is that the wash unit_pre is located near by the pre-assembly on the left side. The result is that the transport coefficient decrease to a remarkable value because of the short distance to the storage one. The material flow is comparable with that from the previous variant but the path between the wash unit_final and the pre_assembly relieve in terms of the transport frequency and intensity.

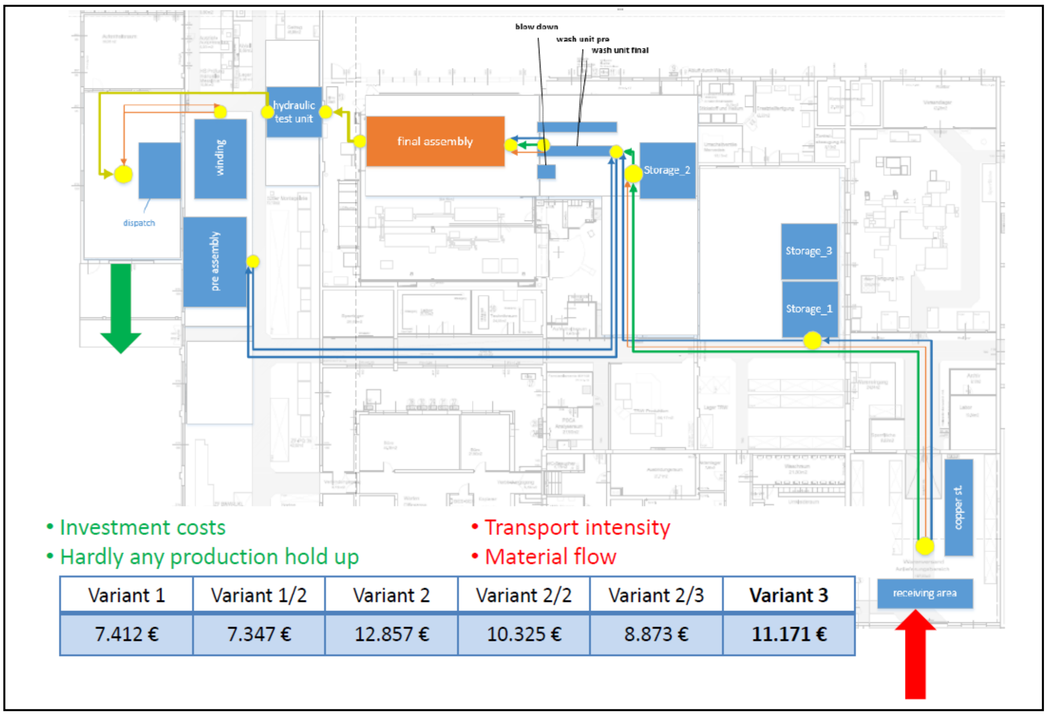


Variant 1	Variant 1/2	Variant 2	Variant 2/2	**Variant 2/3**	Variant 3
7.412 €	7.347 €	12.857 €	10.325 €	**8.873 €**	11.171 €

Figure 5-32: Real layouts: Variant 2/3

Variant 3

The final layout is carried out based the last simplified draft with the strategy to reduce investment costs and use existing infrastructure of the company. That means that the existing storages, dispatch warehouse and the receiving area are also used by the new assignment. The advantage is what we have already mentioned that the investment costs are low as possible, but with the main disadvantage that the transport intensity increases significantly.



Variant 1	Variant 1/2	Variant 2	Variant 2/2	Variant 2/3	**Variant 3**
7.412 €	7.347 €	12.857 €	10.325 €	8.873 €	**11.171 €**

Figure 5-33: Real layouts: Variant 3

The final solution

After a presentation about the elaborated solutions and a subsequent workshop together with the company, was developed a final solution based on these layouts in cooperation with new restrictions. Based on the law, it is forbidden to have a workplace on a manufacturing line without a view to the environment. That means that it is preferable to place the pre-assembly on the left side near the dispatch warehouse, because the investment cost are too high to put the pre manufacturing line close to the wash unit_final. The advantage is that it is now possible that just one worker is responsible for the winding machine and for the pre-assembly at the same time. Additionally, there is the possibility that the capacity of the clean room will increase over the next few years and that the company will enlarge that room. The effect is that it is also not possible to locate the pre-assembly as in variant 1. The final solution looks similar to the variant 2 with the distinction that the storage is located close to the pre-assembly and that the wash unit_pre is placed near to the receiving area.

The difference between these two variants is the receiving area. It can be seen from figure 5-34 that in variant one, all parts are delivered in one receiving area, which is situated on the left with the disadvantage that all parts that are needed for the final assembly have to be transported through the company. In variant two, the receiving area is split into one area on the right, which receives all parts for the pre assembly and the other receiving area located on the right receiving all parts for the final assembly.

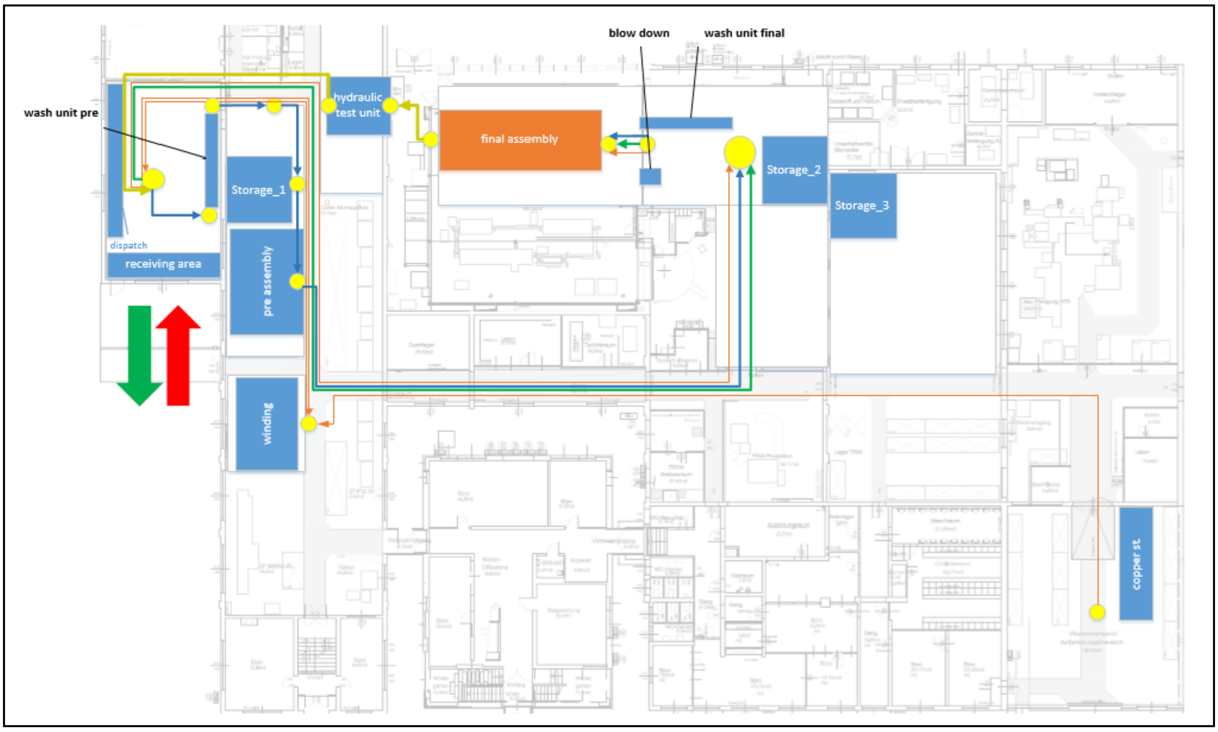


Figure 5-34: Final solution: Variant 1

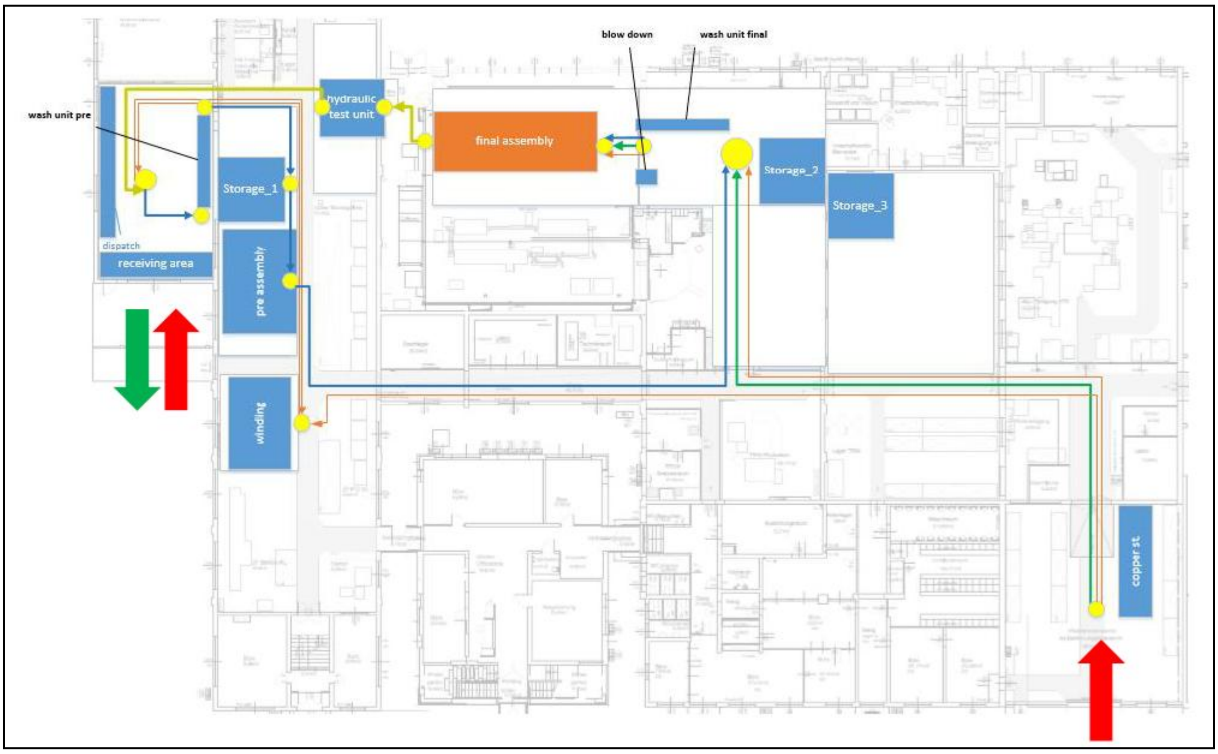


Figure 5-35: Final solution: Variant 2

6 Simulation models and results

This chapter illustrates the different simulation models and has been divided into five main parts. Section one describes the simulation models used to analyse the utilization of the defined wash units. Section two and three contain several breakdown models that simulate a breakdown of the wash unit_pre and a malfunction of two from six hydraulic test units. Section number four focuses on the several employees required and their different tasks. Section five shows the effort of the internal transportation.

6.1 Utilization of the wash unit_pre

In order to analyse the utilization of the wash unit_pre, it is necessary to know how many wash baskets are needed to produce the production volume for one shift. Thus, the preliminary work is to simulate the pre-assembly with the aim of knowing the accurate amount of finished pre-assemblies and the amount of wash baskets. Figure 6-1 shows the finished pre-assembly simulation model with all assembly and production stations and buffers for the several parts.

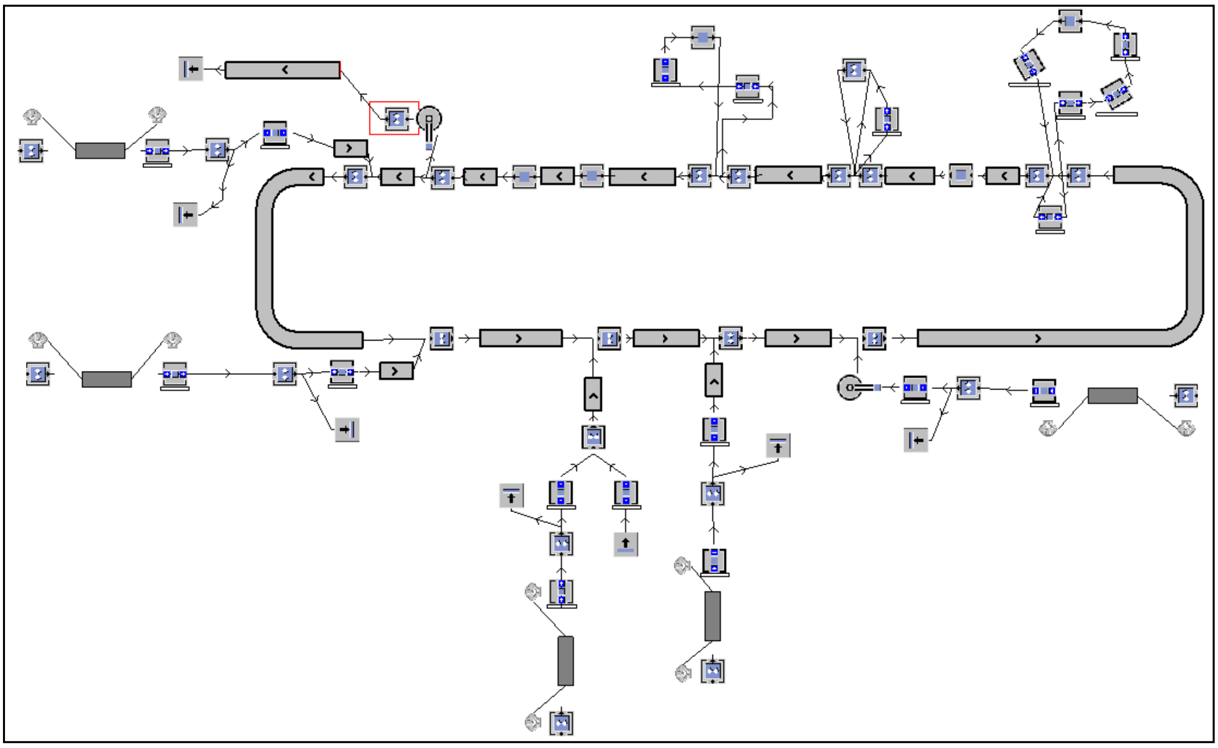


Figure 6-1: Simulation model: pre-assembly

The following table represents the simulation parameters consisting of the simulation time, the availability of the manufacturing line, the machine setup time which is needed every morning and after a break that is longer than 4h and finally the produced number of completed actuating systems.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability	85 %
Machine set-up time	20 minutes
Outcome	**4746 pieces**

Table 6-1: Simulation Parameter: wash unit_pre

With the results from the preliminary work and with the data of the maximum wash basket load for each part, it is possible to calculate the required amount of baskets that are needed to produce 4,746 actuating systems. Table 6-2 shows the several loads.

Wash unit_pre				
Designation	#/tray	tray/wash basket	#/wash basket	**wash baskets/shift**
tube	-	-	400	11,87
armature	228	3	484	6,94
cover	135	4	540	8,78
pole core	135	3	405	11,72
housing	40	2	80	59,33
			sum	98,64

Table 6-2: Needed amount of wash baskets

It can be summarized that with a cycle time of 5s and a defined availability of the pre-assembly of 85% there are 99 wash baskets required per shift. This data is the basis for the following simulation of the wash unit _pre.

6.1.1 Simulation model and parameters of the wash unit_pre

In addition to the data from the previous chapter, it is necessary to build up the simulation model shown in the following figure 6-2 on the left. Wash unit pre is marked with a red rectangle together with several workstations, which will be discussed more in detail in chapter 6.11 with the aim to simulate the different worker utilizations. The wash unit-pre looks similar to a conveyor belt with the possible load of three wash baskets. That means that the wash unit is able to wash three baskets at the same time with an average washing time of fourteen minutes. These defined simulation parameters are summed up in the following table 6-3 on the right.

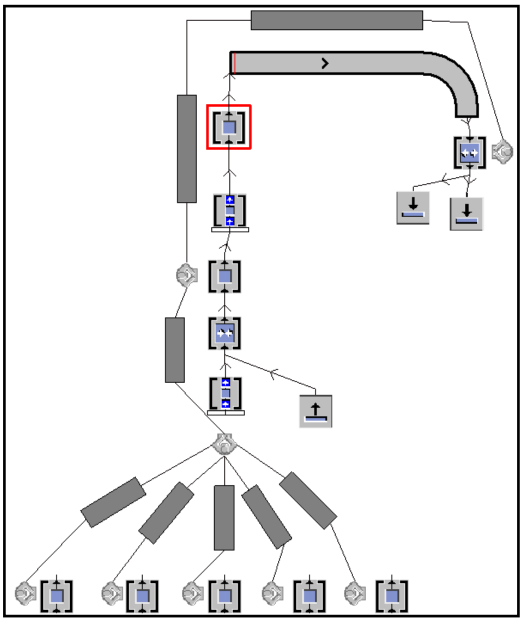


Figure 6-2: Simulation model: wash unit_pre

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability	100 %
Load	3 wash baskets
Washing time/load	14 minutes
Needed wash volume	99 wash baskets

Table 6-3 Simulation parameter: wash unit_pre

6.1.2 Results

The findings strongly support the view that wash unit_pre is a significant bottleneck by a first consideration of the pre-assembly manufacturing. As can be seen from the bar chart, the wash unit_pre has a utilization of 98% with a defined availability from the pre-assembly of 85%. This means that wash unit_pre is able to wash the required amount but it also shows that the wash unit is undersized if the availability of the pre-assembly increase to 90%.

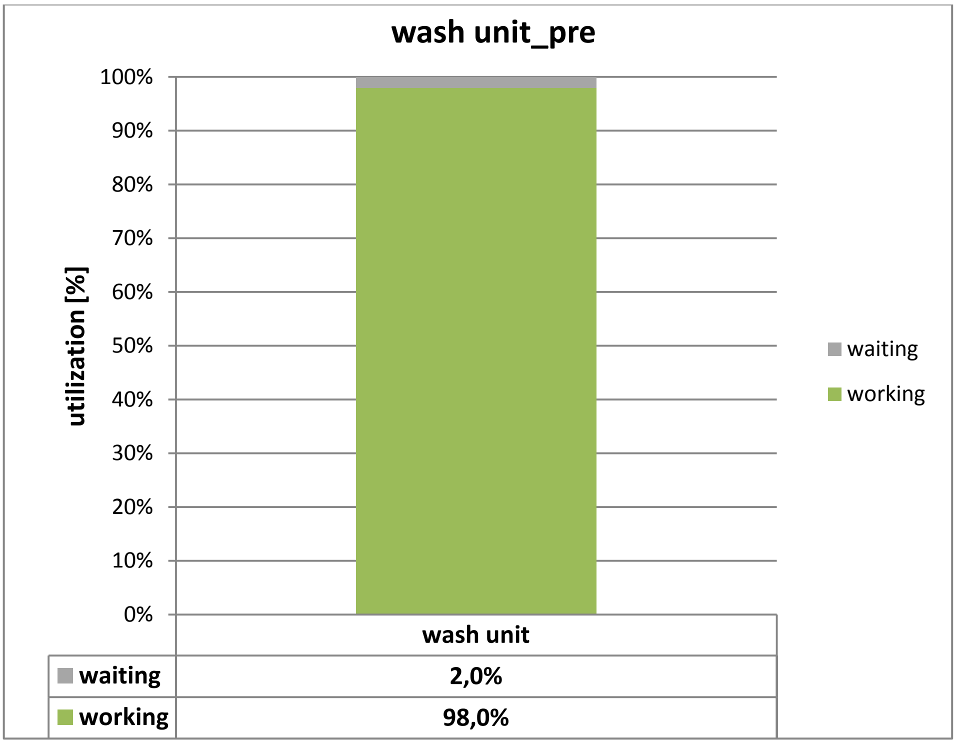
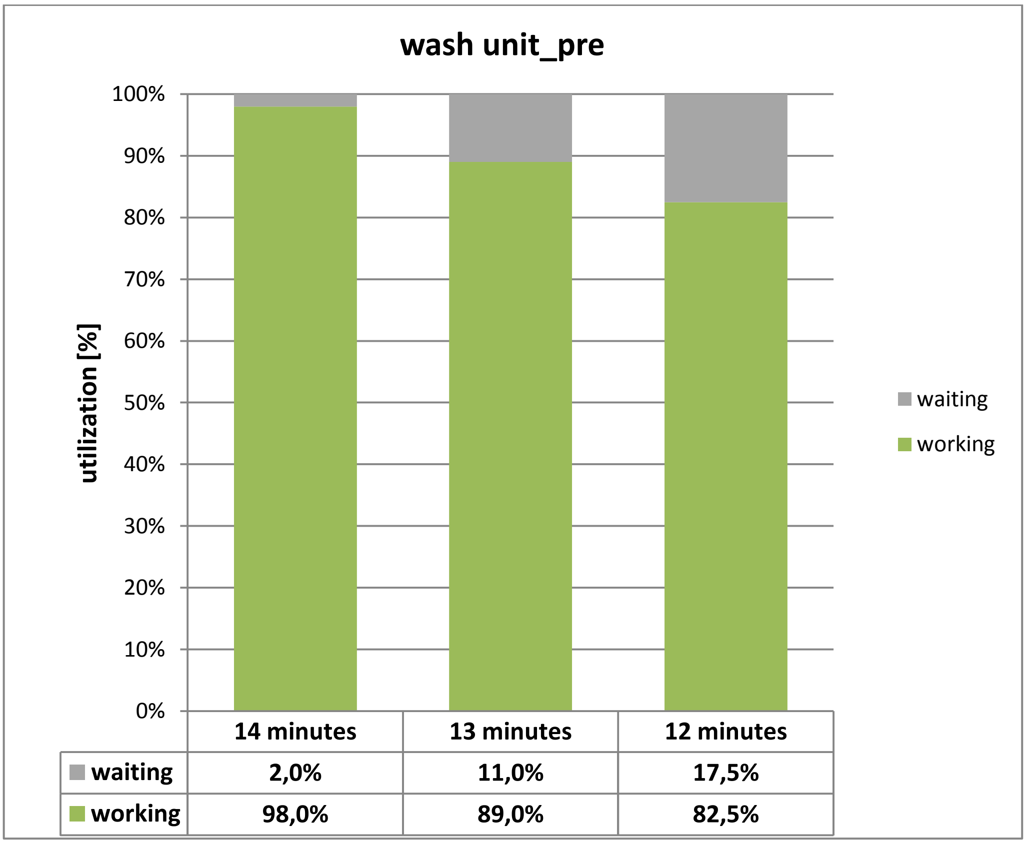


Figure 6-3: Utilization of the wash unit_pre

6.1.3 Improvements

Theoretically, there are two opportunities to improve the utilization. On the one hand there is the opportunity to increase the load of each wash basket or to decrease the washing time on the other hand. Because of the defined dimension of the wash baskets, it is not possible to put more pieces in the baskets, thus the only parameter to improve the utilization and to increase the washing amount at the same time is to decrease the washing time. With this in mind, we simulated two experiments with the model and with a washing time in the first simulation of 13 minutes and in the second with 12 minutes instead of 14 minutes. The result shown in the bar chart is that the utilization decreases significantly to a value of 82,5% with a defined washing time of 12 minutes. It has to be checked if the reduction in the washing time has an impact on the welding process during assembly.



	14 minutes	13 minutes	12 minutes
waiting	2,0%	11,0%	17,5%
working	98,0%	89,0%	82,5%

Figure 6-4: Improvements for the wash unit_pre

6.2 Utilization of the wash unit_final

The approach to simulate the utilization of the wash unit_final is similar to the previous chapter. At first, to find out the required number of wash baskets, the preliminary work is to build up a model of the final assembly. Afterwards, this model is simulated and the results are the basis for further experiments to gather information about the utilization of the wash unit_final. The following figure 6-5 represents the final manufacturing line, which is built up in terms of a machine layout.

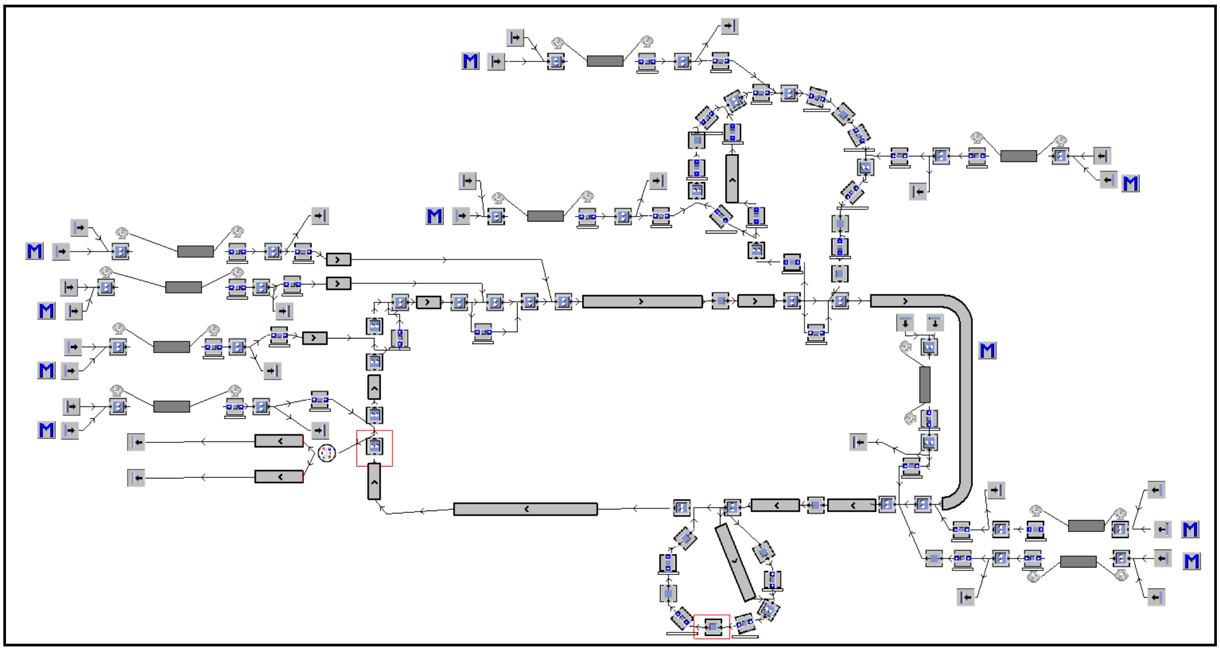


Figure 6-5: Simulation model: final-assembly

The following table 6-4 shows the simulation parameters which consist of the same parameters as the pre-assembly, for example the simulation time, the availability of the manufacturing line, the machine setup time which is needed every morning and after a break which is longer than 4h, and finally the produced volume of completed proportional.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability	85 %
Machine set-up time	15 minutes
Outcome	**4542 pieces**

Table 6-4: Simulation parameter: final-assembly

Table 6-5 shows the several maximum wash basket loads for each part and, on the basis of the outcome, the required number of baskets to assemble the 4,542 pieces of proportional valves.

Wash unit_final				
Designation	#/tray	tray/wash basket	#/wash basket	wash baskets/shift
plate	-	-	400	11,35
threaded ring	-	-	200	22,71
pin	-	-	2000	2,27
pressure spring	-	-	1000	4,54
valve body	60	3	180	25,23
slider	187	4	748	6,07
			sum	72,17

Table 6-5: Needed amount of wash baskets

The information delivered by the simulation is that with a cycle time of 5.25s and a defined availability of 85%, there is a required number of 72 wash baskets per shift. This data is the basis for the following simulation.

6.2.1 Simulation model and parameter of the wash unit_final

As before, it is necessary to modify the simulation model that covers the tasks of the wash unit_final. This simulation model is shown in figure 6-6 and the wash unit final is marked with a red rectangle. This model also consists of a blow down unit which is located on the left and all buffer and workstations to simulate the worker utilization. The following table on the right defines all required parameters to simulate the wash unit_final.

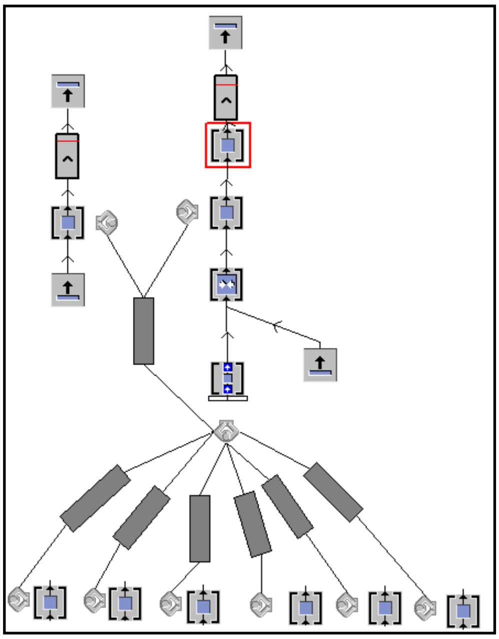


Figure 6-6: Simulation model: wash unit_final

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability	100 %
Load	3 wash baskets
Washing time/load	14 minutes
Needed wash volume	72 wash baskets

Table 6-6: Simulation parameter: wash unit_final

6.2.2 Results

In conclusion, it can be noted that the wash unit_final has a utilization of 70%, if the final manufacturing line produces with an availability of 85%. This means that if the availability of the final assembly increases, the wash unit has enough capacity to wash the needed parts as is illustrated in the following bar chart.

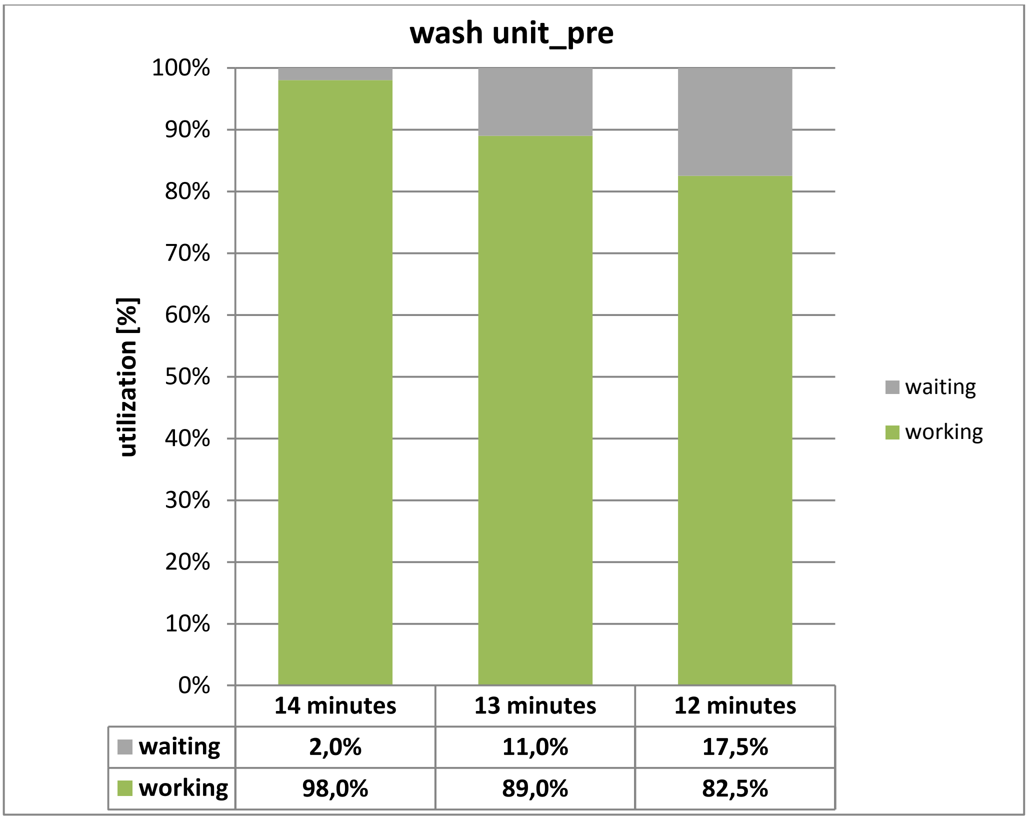


Figure 6-7: Utilization of the wash unit_final

As can be seen from the table 6-7 which shows the maximum output, decreasing the washing time by 13 minutes makes it possible to wash the required volume of 216 wash baskets per day in two shifts instead of three.

Simulation results	
washing time/load	output
14 minutes	99 wash basket/shift
13 minutes	108 wash basket/shift
12 minutes	117 wash basket/shift

Table 6-7: Simulation results: wash unit_final

6.3 Scenario breakdown wash unit_pre

This section simulates a breakdown of the wash unit_pre with the aim of considering the possible delivery time. As can be seen from chapter 6.2, the utilization of the wash unit_final is approximately 70% and that enables the opportunity to wash the defined wash baskets for the final assembly and at the same time parts for the pre-assembly.

6.3.1 Simulation parameters

The wash unit final has to wash 72 wash baskets to ensure the final production and with this capacity results in a utilization of 70%. Now there is the opportunity to increase the utilization close to 100% with a capacity of 99 wash baskets and that means that it is possible to wash 27 baskets filled with parts for the pre-assembly.
The different safety stocks are on the one hand, the safety stock filled with already washed parts for the pre-assembly with an amount to ensure the production for 12 hours, and on the other hand, the safety stock with mounted actuating system with an amount of approximately 14,000 pieces.
Now the idea is to wash during a breakdown of the pre assembly some baskets at the wash unit_final to extend the possible deliver time.

Simulation parameter	
Simulation time	6 shifts
Availability	100 %
Capacity	3 wash baskets
Wash time / load	14 minutes
Wash volume/shift	99 wash baskets
Wash volume	72 wash baskets (final-assembly)
Wash volume	27 wash baskets (pre-assembly)

Table 6-8: Simulation parameter: breakdown wash unit_pre

6.3.1.1 Results

The following bar chart shows a red bar that represents the possible delivery time just by using the safety stock and the blue bar that represents the strategy to wash some parts in the wash unit_final. The strategy extends the possible time from 36 hours to 47 hours.

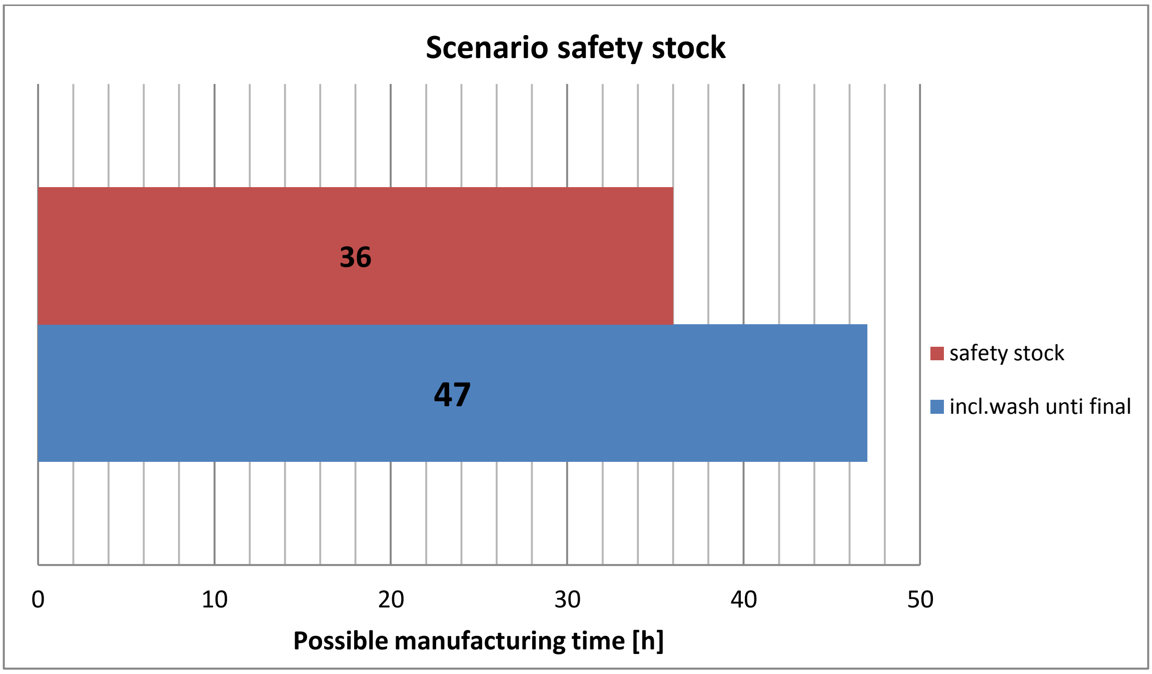


Figure 6-8: Result of the breakdown wash unit_pre

6.4 Scenario breakdown hydraulic test unit

This scenario simulates a breakdown of two from six hydraulic test units. As can be seen from the figure 6-16 that six hydraulic test units are placed directly after the final manufacturing line. This model is intended to deliver data showing which amount cannot be tested and how long it takes to empty this buffer of proportional valves.
Simulation parameter
Figure 6-16 shows that a buffer is placed in front of the hydraulic test unit. This means that if the hydraulic test centre does not have enough capacity to test faster at the final assembly, because of a breakdown, the untested valves are stored in this buffer.

Simulation parameter	
Breakdown time	24hours
Availability final-assembly	85%
Availability hydraulic test centre	90 %
Test time/valve	30 seconds

Table 6-9: Simulation parameter: breakdown hydraulic test centre

6.4.1 Results

The following table illustrates the results from the simulation. It shows that the buffer increases to an amount of 3,204 pieces with a breakdown time of 24 hours and after that time all six test units are working and the figure shows how long it takes to empty this buffer. This amount of 3,204 pieces equates to about 2,5 pallets and a required buffer space of 3m².

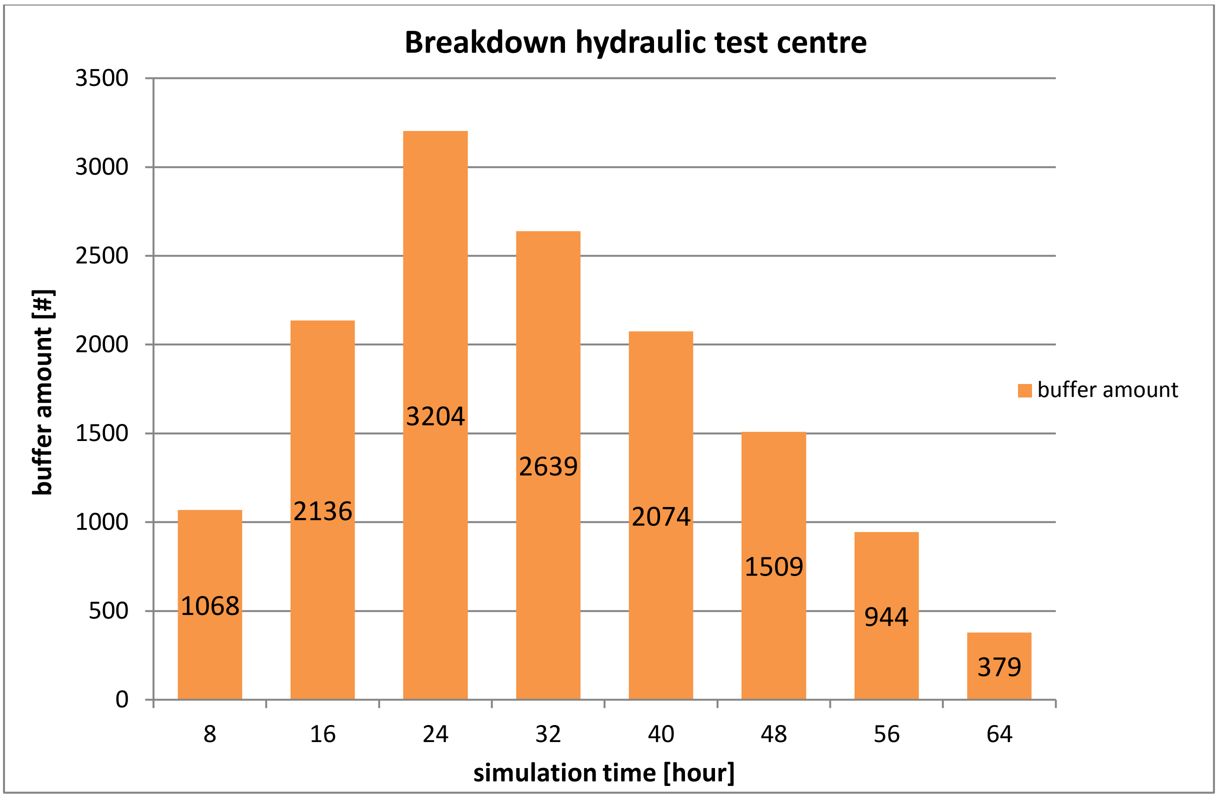


Figure 6-9: Result: breakdown hydraulic test centre

6.5 Worker utilization

This chapter is divided into five sections, one section for each worker. We consider one employee for each wash unit, one worker to support the pre-assembly and the winding machine at the same time, one worker located in the clean room and supporting the final assembly and finally one worker at the hydraulic test unit shown in figure 6-10. All worker utilizations are simulated with the company-defined breaks and additional time representing a time to do short breaks during the shift.

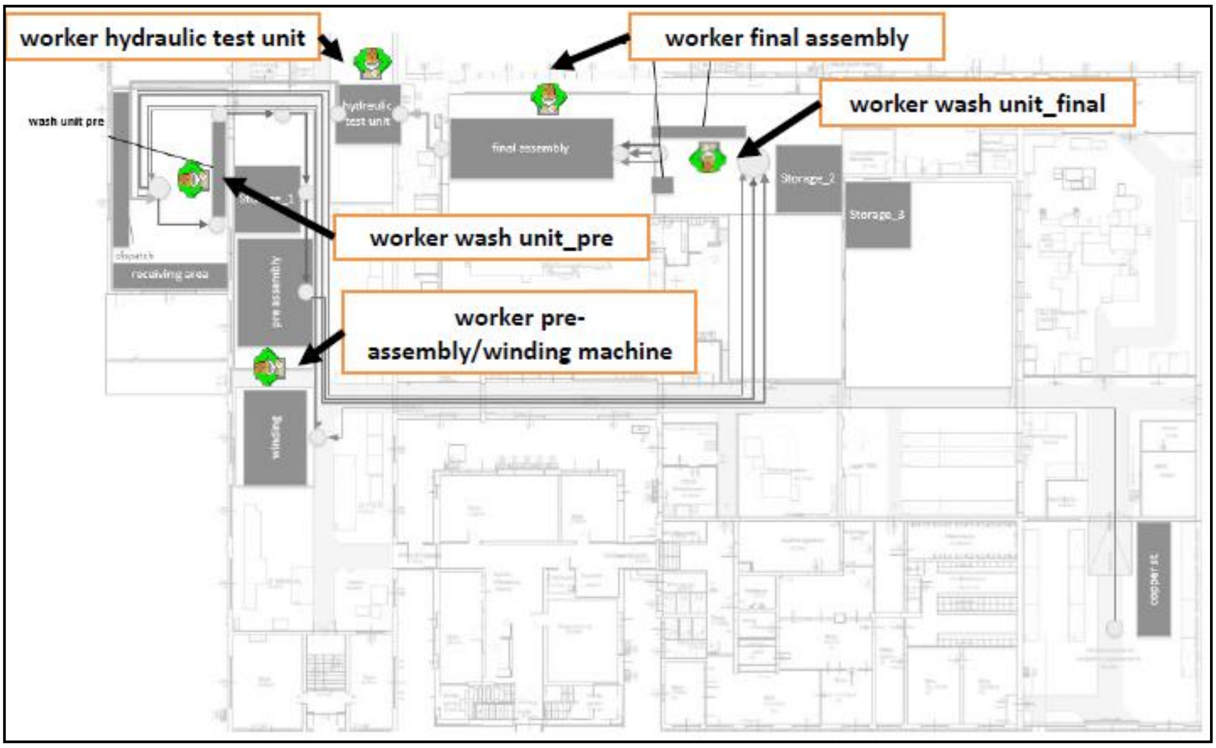


Figure 6-10: Defined worker

6.6 Worker wash unit_pre

The main tasks of the employee working at wash unit pre is to fill the wash baskets with the different parts, to load and handle the wash unit pre, and to unload the wash baskets and fill the buffer with the clean parts. The multiple workstations are illustrated in the previous figure 6-2.

6.6.1 Simulation parameter

The first task is to fill the wash basket shown at the bottom of the figure. There five workplaces, one for each part. At these stations, the first task is to open the several transport containers and remove the dunnage. If the parts are blister packed, the following task is to take a tray for the blister and put both in a special machine that upends the parts from the blister into the tray and finally puts this tray into the wash basket. This procedure has to be repeated until the basket reaches its defined maximum load. If the parts are bulk materials, the worker takes the transport container and throws the parts into the basket. Finally the last working step is to pile the empty containers on a pallet. The needed time for these different working steps is defined as the **handling time**.

Afterwards, the worker carries these loaded baskets and stores a maximum amount of six in front of the wash unit illustrated in the figure with the workstation above the five part buffer. Afterwards, at the next workstation, the employee loads the wash unit with three wash baskets and switches it on. The time required for loading and handling is defined as the **load time**.

The last working step is to unload the wash baskets and fill a buffer where the parts are able to cool down. The time to unload all three baskets is considered as the **unload time** in the simulation.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Handling time	40 - 140 seconds
Load time	1:00 minute
Unload time	2:30 minutes
Work order	99 wash baskets

Table 6-10: Simulation parameter: worker wash unit_pre

The problem is to define the handling time, because it is nearly impossible to estimate the effort at the first workstation. Thus, the unload time and the load time is defined with a fixed value and the simulation calculates the worker utilization with different handling times ranging from 40 to 140 seconds. The work order is defined with 99 wash baskets that represent the required amount for one shift production.

6.6.2 Results

The worker utilization is shown in the bar chart. The green working bar includes all working steps and the time to go to the different working places, the red bar represents the defined break, the blue bar illustrates the additional time and the grey bar shows the time without a work order. This result shows that the worker who is responsible to wash all required parts for the pre-assembly has enough time to do some other supporting measures.

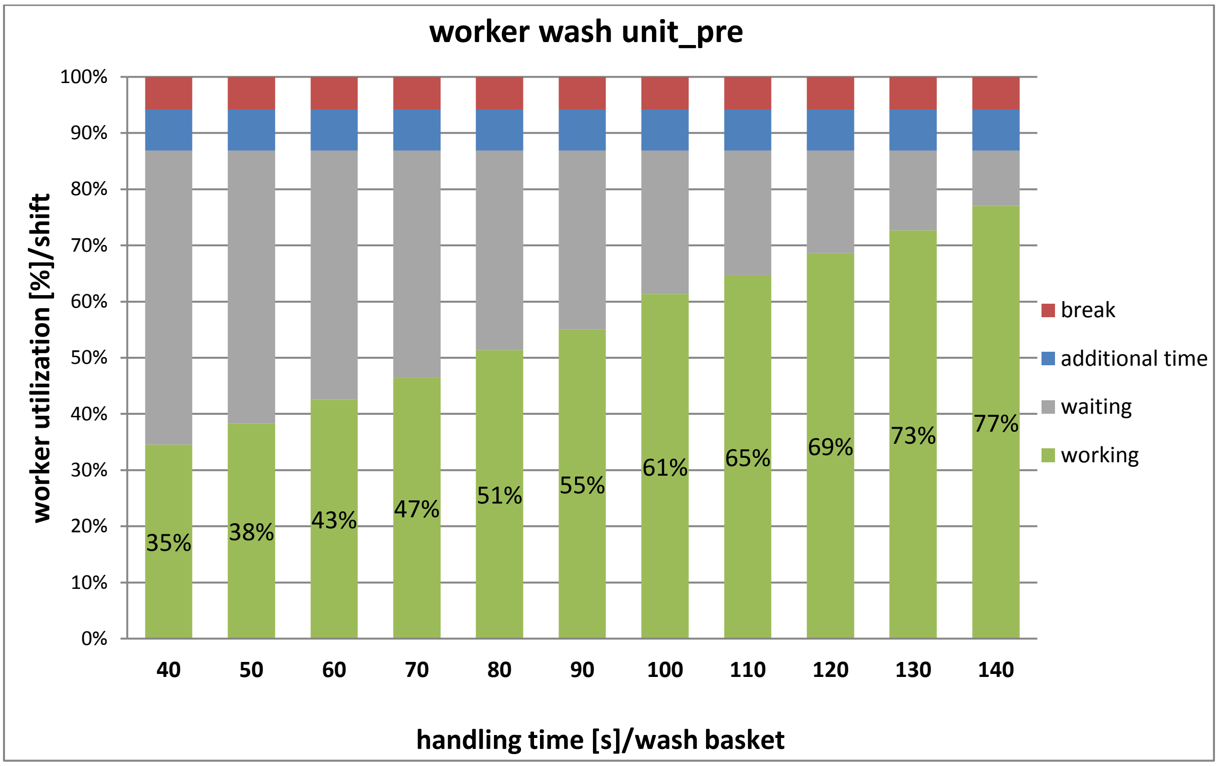


Figure 6-11: Utilization of the worker wash unit_pre

6.7 Worker wash unit_final

The simulation of the worker who handles the wash unit_final was carried out similarly to the worker wash unit_pre with a handling time which included all working steps to fill the baskets, a load time to load the wash unit with three baskets and switch it on, but without unloading time. All finished baskets go directly in the clean room and have to be unloaded by the worker inside. In addition to these defined work steps, the worker has to blow down the coil complete, which is packed with blisters. This work step is defined as **blow down time** and this effort is accounted for with 30 second per blister.

6.7.1 Simulation parameter

As before, all defined times except the handling time are defined as fixed values and only the handling time is defined as an interval from 40 -140 seconds. The work order is defined with 72 wash baskets and 89 blisters, which represent the required amount for one production shift. The left table illustrates the work order for a two shifts operation day.

Simulation time	One shift from 06:00 to 14:00
Handling time	40 - 140 seconds
Load time	1:00 minute
Blow down time	30 seconds
Washing time	14:00 minutes
Work order	72 wash baskets / 89 blisters

Table 6-11: Parameter: worker wash unit_final 3 shifts

Simulation time	One shift from 06:00 to 14:00
Handling time	40 - 140 seconds
Load time	1:00 minute
Blow down time	30 seconds
Washing time	12:00 minutes
Work order	108 wash baskets / 133 blisters

Table 6-12: Parameter: worker wash unit_final 2 shifts

6.7.2 Results three shifts per day

The following bar chart illustrates that the utilization from the worker wash unit_final is built up exactly the same as before, including the time for working, waiting, breaks and the defined additional time. The result is that this worker also has enough time to do other supporting measures.

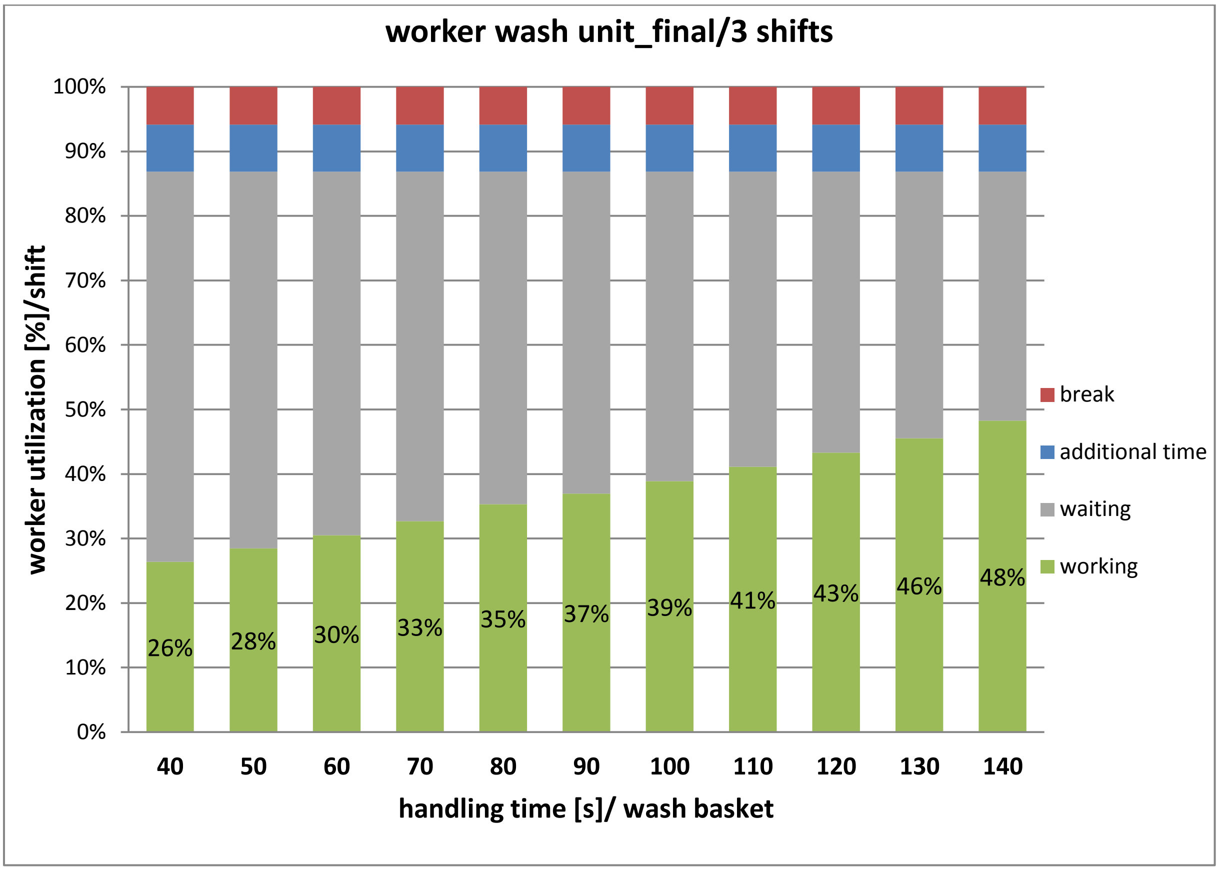


Figure 6-12: Utilization of the worker wash unit_final / 3 shifts

6.7.3 Results two shifts per day

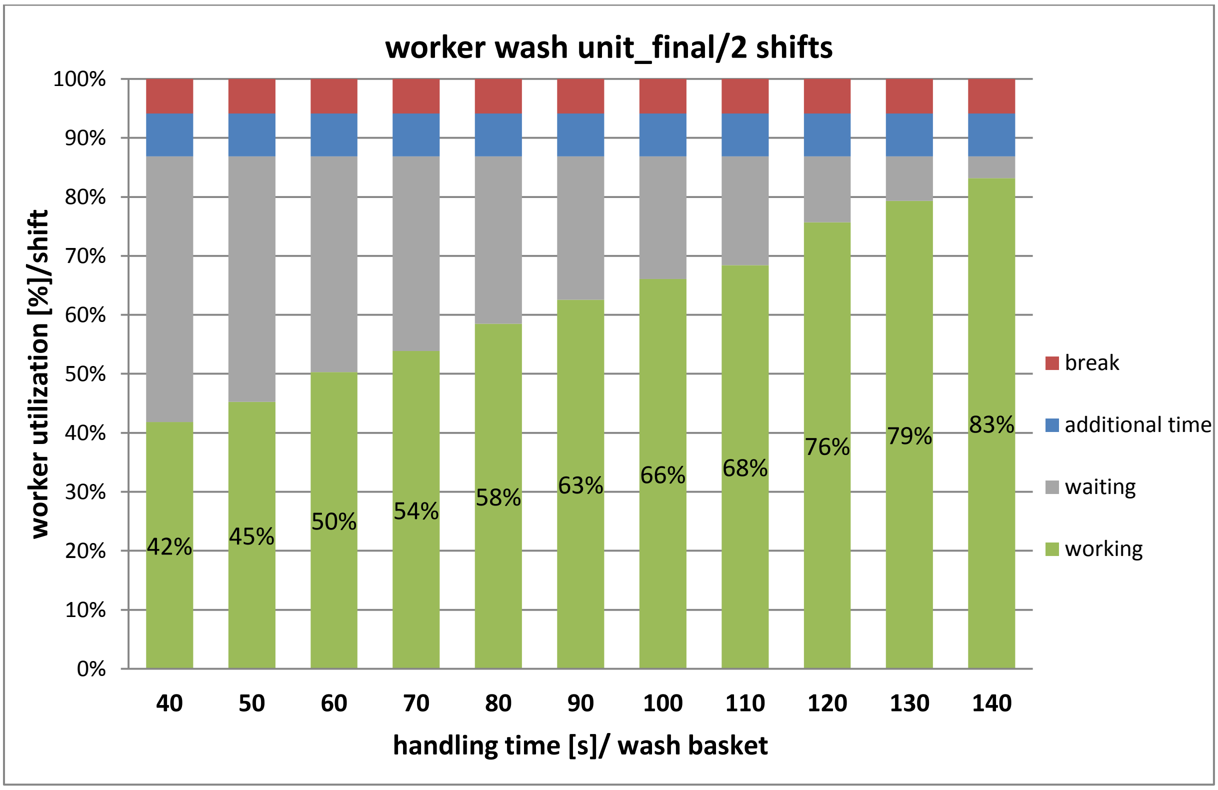


Figure 6-13: Utilization of the worker wash unit_final / 2 shifts

6.8 Worker pre-assembly-winding machine

This employee is responsible for the pre-assembly and at the same time for the winding machine. As can be seen from figure 5-34, the manufacturing line that produces the actuating system and the winding machine are located close to each other.

The main task of this worker is to refill the many buffers of the machines. There are six buffers at the pre-assembly and four at the winding machine. The winding machine buffer for the copper wire has to be refilled just once a day and the two buffers for the pins have to be refilled once a week. Additionally, the worker repairs the machine if there is a breakdown.

6.9 Simulation parameters

The simulation model only considers the refill process and defines a **load time** that represents the time to take a tray or transport container in hand and an **unload time,** which is needed to fill the buffer at the manufacturing line and put the empty tray on a pallet.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability pre-assembly	85%
Availability winding	90%
Load time	4 – 26 seconds
Unload time	4 – 26 seconds

Table 6-13: Simulation parameter: worker pre-assembly/winding machine

Results

The following bar chart shows the utilization of the worker with the main task of filling the buffers at the manufacturing lines.

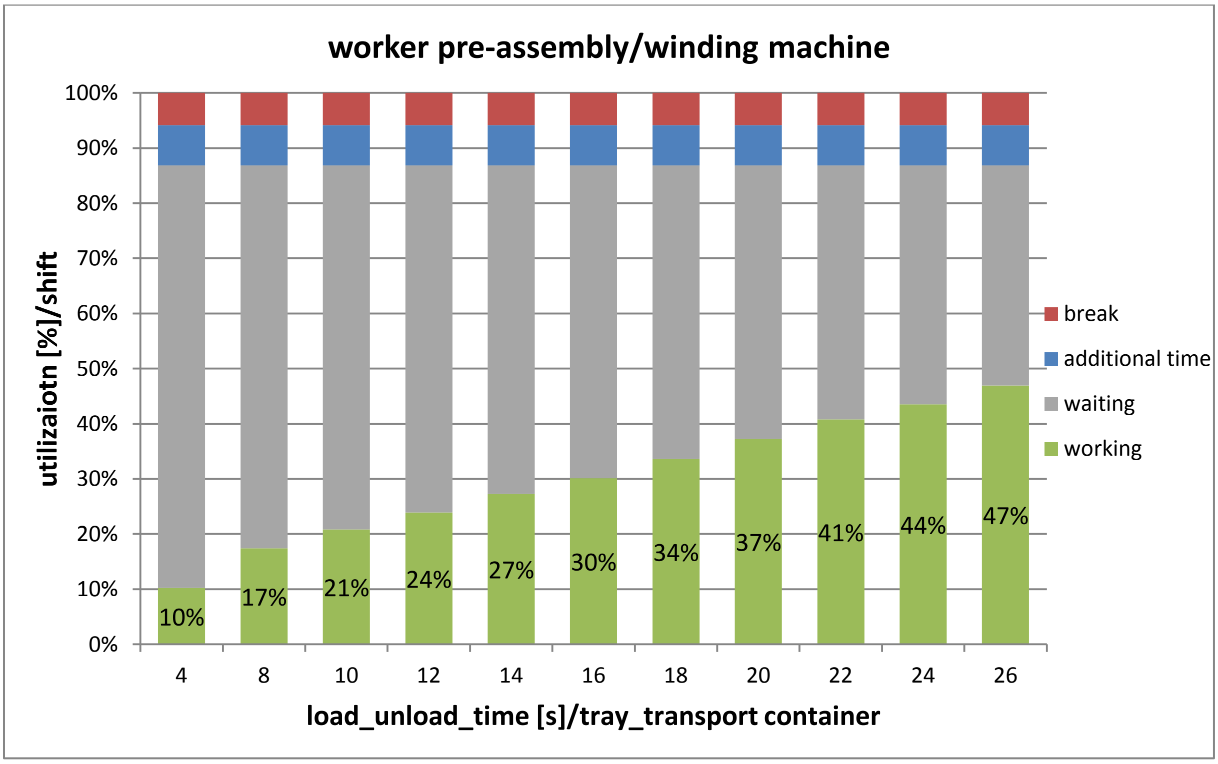


Figure 6-14: Utilization of the worker pre-assembly/winding machine

6.10 Worker final assembly

This employee is responsible for the final assembly in the clean room. The main task of this worker is similar to the previous workers and is to refill the several buffers at the final manufacturing line and additionally the worker as to support another worker at the final assembly.

6.10.1 Simulation parameters

This model defined the same times and that are on the one hand the **load time** and on the other hand the **unload time** which are already discussed in the previous chapter.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Availability final-assembly	85%
Load time	4 – 26 seconds
Unload time	4 – 26 seconds

Table 6-14: Simulation parameter: worker final assembly

6.10.2 Results

The following bar chart shows the utilization of the worker in the clean room with the main task of filling the buffers at the manufacturing lines. It shows that this worker has enough capacity to do other work orders like unloading the wash baskets that are delivered from the wash unit_final directly into the clean room.

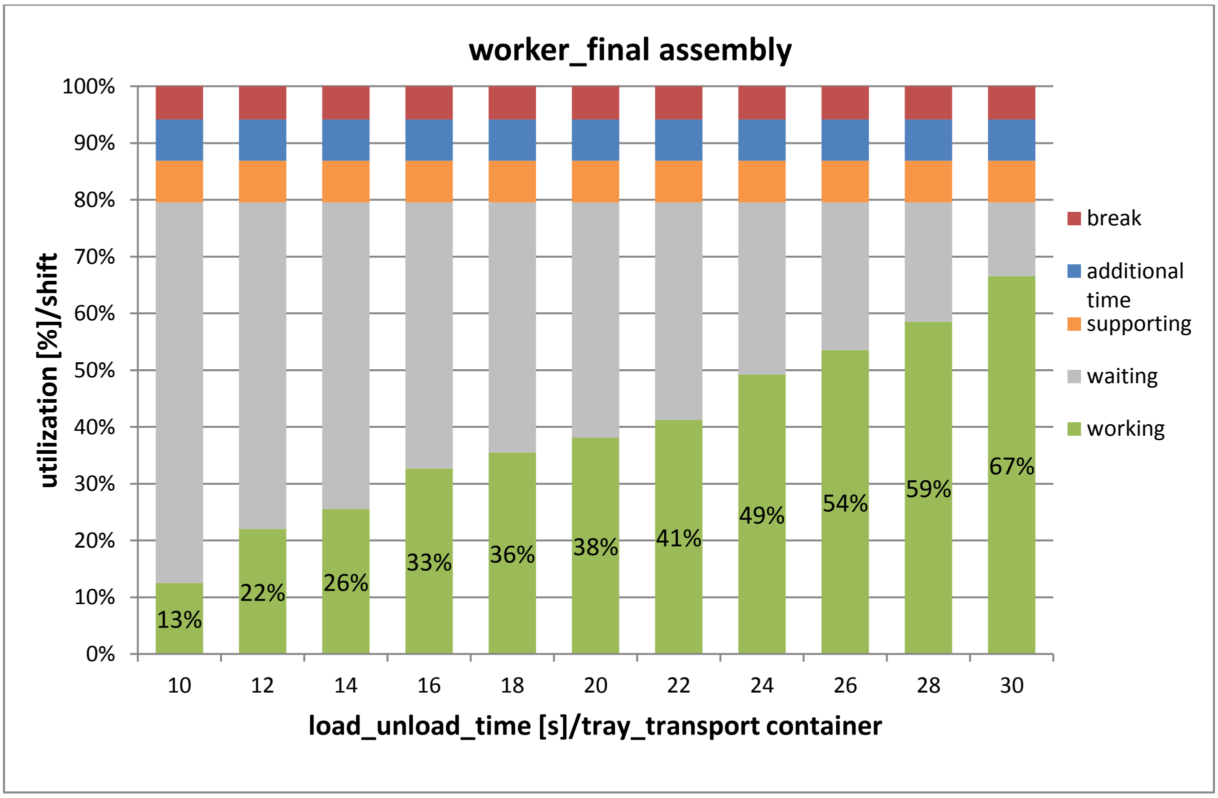


Figure 6-15: Utilization of the worker final-assembly

6.11 Worker hydraulic test unit

The final worker is placed in front of the hydraulic test unit illustrated in figure 6-16. The main task of this worker is to package the finished assembled proportional valve. As can be seen from the following figure, the final assembly, which represents the left item, produces the defined product with an availability of 85%. After the assembly process, the proportional valves have to pass the hydraulic test at one of the six test units with a testing time of 30 seconds for every valve. The machine is able to package the valves into the blister with a load of 20 pieces.

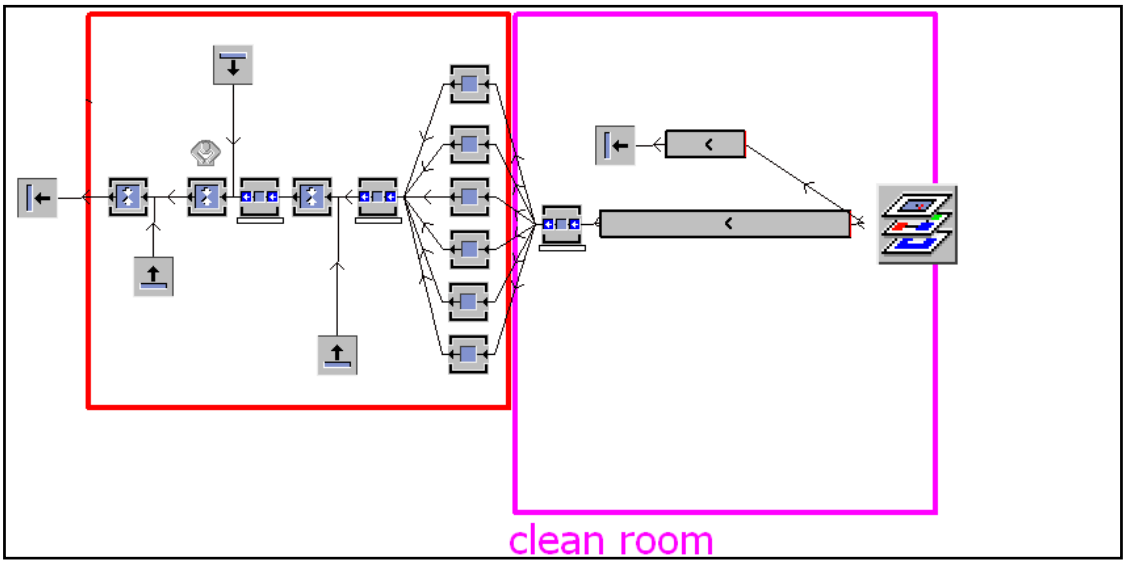


Figure 6-16: Simulation model: hydraulic test centre

Simulation parameters

After this procedure, the worker takes one transport container and puts a plastic bag into it. The second work step is to load the plastic bag/transport container with loaded blisters and close the container with the cover. Finally, the employee palletizes the container on a pallet. The time, including all of these work steps, is defined as the **handling time**.

Simulation parameter	
Simulation time	One shift from 06:00 to 14:00
Production volume	4542 pieces
Testing time	30 seconds/proportional valve
Handling time	30 – 120 seconds

Table 6-15: Simulation parameter: worker hydraulic test centre

6.11.1 Result

Assuming that the worker requires 90 seconds to fill one transport container, the simulation shows that the worker has a utilization rate of 50%, which means that the worker has enough time to support other productions or support the logistics team.

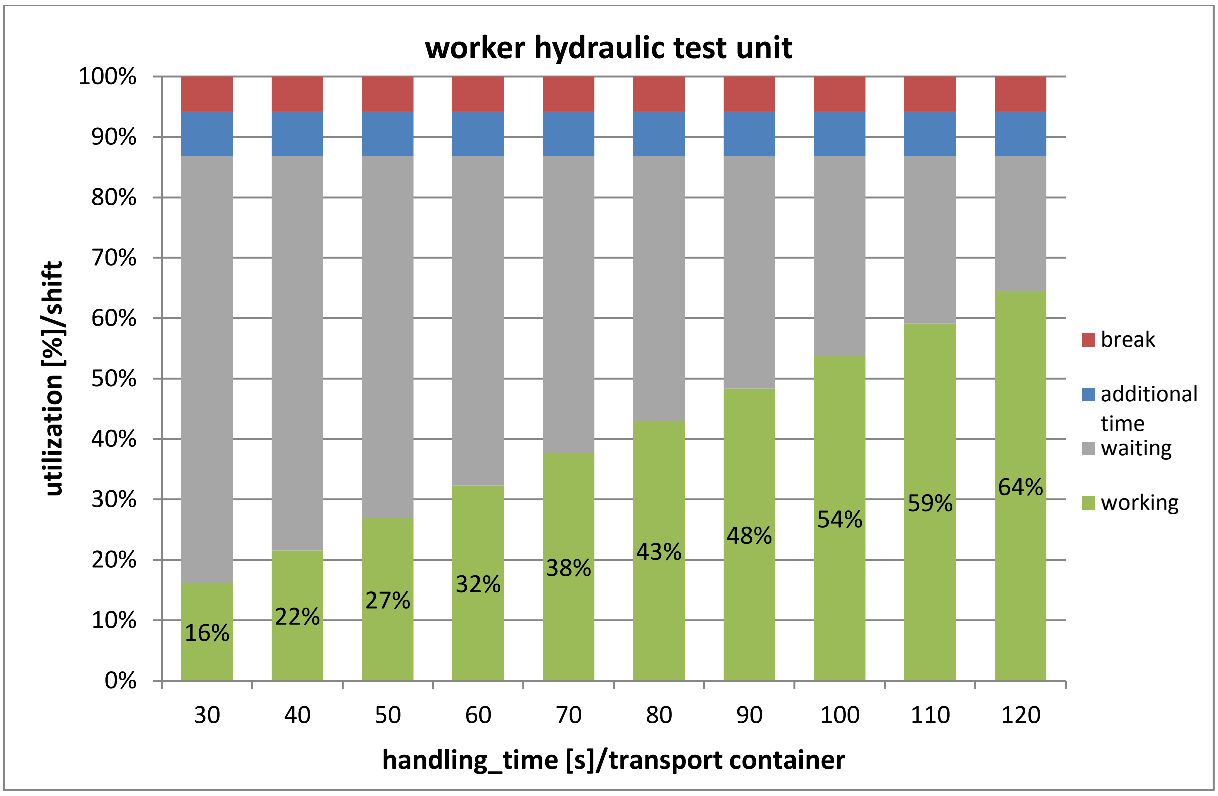


Figure 6-17: Utilization of the worker hydraulic test centre

6.12 The effort for the internal transportation

A very interesting point and difficult to define during the planning phase is the effort for the internal transportation. The aim of this simulation is to illustrate the required time to complete all logistic work steps and show the difference between the two defined final layouts in terms of the effort.

6.12.1 Simulation parameters

Thus, the model consists of all departments and there is one additionally defined employee who only works the morning shift. The tasks of the worker are to transport all finished parts from the different departments to the storage areas or to the dispatch warehouse and to transport the delivery to the storage areas or wash units. To consider this more in detail:

- Transport all packed coils and proportional valves from the manufacturing departments to the dispatch warehouse
- Transport the finished actuating systems into the storage area 2

- Deliver the coil baskets to the winding machine
- Transport all delivery from the receiving area to the defined storage areas
- Transport all empty packages into the dispatch warehouse or receiving area

The simulation starts after the morning shift and the model simulates one day. That means that after the first two shifts, all buffer are filled with finished products and the logistics worker has to empty the full buffers and transport all new deliveries. The time needed to load one pallet on the forklift is defined as the **load time** and the time which is needed to fill the shelf at the storages is defined as the **unload time**.

Simulation parameter	
Simulation time	3 shifts
Forklift speed	1,8 m/s
Capacity of the forklift	1 pallet
Load time	10 – 120 seconds
Unload time	10 – 120 seconds

Table 6-16: Simulation parameter: internal transportation

6.12.2 Result

The bar chart shows the effort for the internal transportation in blue with one receiving area which means that the parts for the final-assembly have to be transported the whole way through the company into storage area 2, and in green with two separated receiving areas. The utilization represents the workload of the logistic worker during the morning shift.

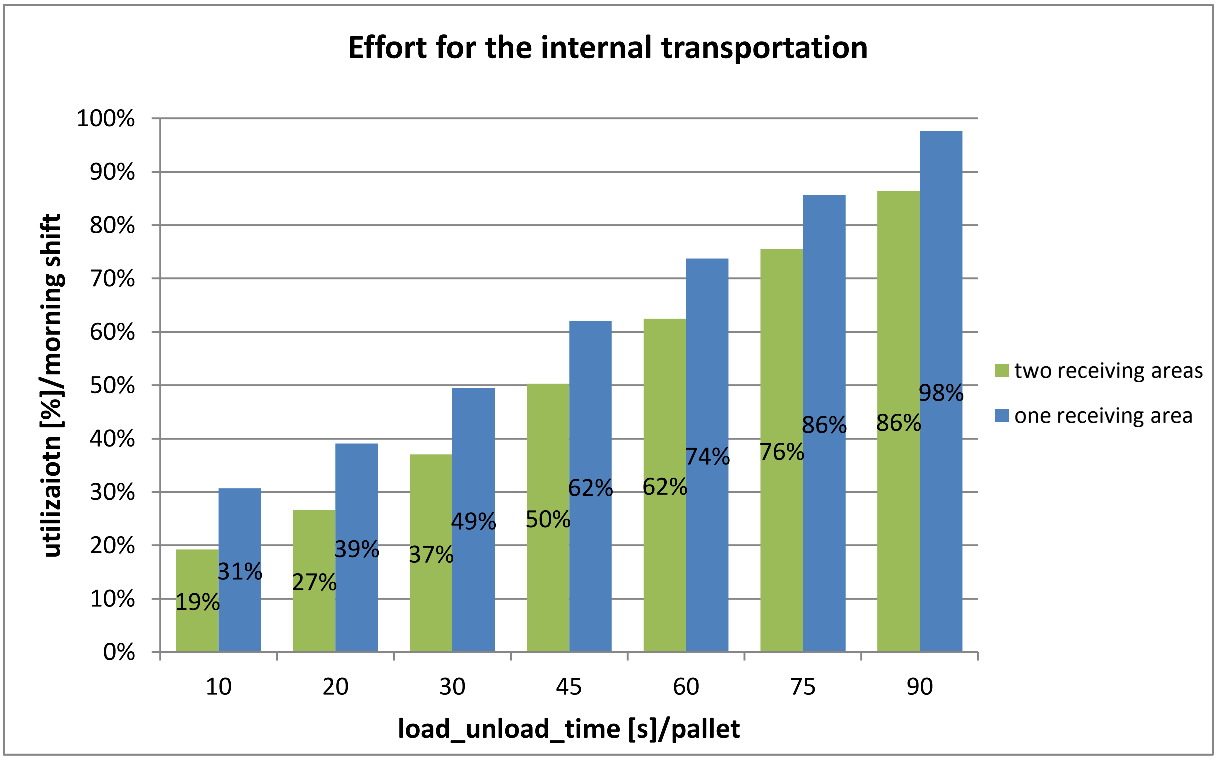


Figure 6-18: Effort for the internal transportation

6.12.3 Delivery amount

Another important outcome from the simulation model is the delivery amount which accrued during the manufacturing process. The delivery amount can be divided into two different sections. The first amount is defined as finished products and the second one as empty transport unit.

Delivery amount of finished products

These amounts are transported from the pre-assembly to the storage 2 on the one hand and between the winding machine and the hydraulic test unit to the dispatch warehouse on the other hand.

pre-assembly – storage 2 (1 shift)	
Designation	**Pallet**
actuating system	3# (32 trays/pallet)
winding machine – dispatch warehouse (1 shift)	
Designation	**Pallet**
coil	1#
hydraulic test unit – dispatch warehouse (1 shift)	
Designation	**Pallet**
proportional valve	3#

Table 6-17: Delivery amount of finished products

Delivery amount of empty transport units

These amounts are transported internal between the different defined departments which are illustrated in the following tables.

pre-assembly – wash unit_pre (1 shift)	
Designation	**Tray**
housing	118#
pole core	35#
armature	20#
cover	35#

Table 6-18: Delivery amount of empty transport units_1

final-assembly – wash unti_final (1 shift)	
Designation	**Tray**
valve body	75#
slider	24#
final-assembly – winding machine (1 shift)	
Designation	**Blister**
coil	90#
final-assembly – pre-assembly (1 shift)	
Designation	**Tray**
actuating system	114#

Table 6-19: Delivery amount of empty transport units_2

wash unit_pre – dispatch warehouse (1 shift)	
Designation	**Transport unit**
housing	1,5# pallet
pole core	17,5# KLT
armature	10,5# KLT
cover	17,5# KLT
tube	4,7# KLT
wash unit_final – dispatch warehouse(1 shift)	
Designation	**KLT**
valve body	37,85#
slider	12,2#
threaded ring	9,1#

Table 6-20: Delivery amount of empty transport units_3

7 Conclusion

As part of this thesis the material flow of the company Kendrion was analyzed with the aim to integrate the new manufacturing machines into the existing layout. Additionally, several simulation models were created to gather more information about the worker and machine utilization and to value the effort for the internal transportation. The actual state analysis was carried out mainly on the basis of documents from the company; further information was collected by interviewing employees from different departments and by observations of other manufacturing processes. The collected data was on the one hand illustrated in a Sankey diagram, to provide an overview about the material flow, and in a transport intensity matrix on the other hand which was needed for the Schmigalla algorithm. Based on this data some simplified drafts were developed in cooperation with different material flow strategies. At the same time the material requirement planning was carried out to get more information about the required storage space and order amounts. With this collected data some real layouts were developed with the intention to derive the elaborated strategies from the simplified drafts into the real layouts. The final solution was defined after a presentation and a workshop in cooperation with the company. The last point was to outline some bottle necks and the utilization from the washing units and worker with a simulation program.

The actual state analysis with the information about the new assignment and the production volume shows clearly the importance to consider and plan the arising material flow. In addition, the result was the collection of information about the design, parts and subassemblies from the proportional valve, the supplier and their packaging strategies, the manufacturing process and the actual layout. The consideration of the manufacturing process indicated the huge effort to wash most of the parts, which is needed for the welding process during manufacturing. Another outcome was the definition of the critical path, which has already a high frequent transportation because of the good selling product Automotive Lighting, and the definition of available and non available spaces in the actual layout.

The preliminary work to create simplified drafts was the Schmigalla scheme. This tool delivered the optimum succession of the different departments on the one hand and illustrated the transport intensity between departments on the other hand. Examples for high intensity relationships are: the receiving area with the two storages or the wash units with the final- and pre-assembly and the hydraulic test unit with the dispatch warehouse. On the contrary the winding machine has a negligible transport relationship to the other departments. Afterwards, some simplified drafts were developed with several material flow strategies. This phase of planning included also the calculation of the required order amount and the calculation of the needed space to store the bought-in parts. The result is a delivery rate of about three days with a required storage space of almost 22m² for each storage.

Based on this knowledge some real layouts were developed by following the elaborated strategies from the simplified drafts. That means that there were created three main layouts. The first layout builds up a fluent material flow through the company, the second variant creates a bilstein competence centre and finally the last variant is developed with the aim to reduce investment costs. It turned out that the first two variants achieved a similarly good transport coefficient of performance with some advantages and disadvantages. Finally, after a workshop together with the company, two final layouts were defined which have a similar arrangement of the departments to the elaborated second variant. The only distinction of the two final solutions is the amount of the receiving areas. That means that in one final layout all bought-in parts are delivered in the receiving area on the left side of the company. This generates one disadvantage; all needed parts for the final-assembly have to be transported through the whole company to the clean room. This disadvantage is eliminated in the second variant with two separate receiving areas. One is located near to the wash unit_pre on the left side for all parts which are needed to assemble the actuating system, and the existing receiving area for parts which are needed for the final assembly.

The aim of the simulation was to verify the final layout in terms of the effort for internal transportation, to illustrate the worker and wash unit utilization and finally to simulate some scenarios. The first unexpected but very important result is that the wash unit_pre has to work with a utilization of 98% to be able to wash all needed parts for assembling the production volume of a shift. The production volume of the actuating system was simulated with an availability of 85%. That means, if the machine availability increases near to 90% the wash unit_pre is no longer able to handle the required amount. Thus, the wash unit is the bottle neck of the whole manufacturing process. The only way to improve this process is to decrease the washing time from 14 minutes to 13 or 12 minutes. This reduction of 2 minutes of washing time has the consequence to decrease the utilization from 98% to 82,5%. The second essential result is, if the washing time from the wash unit_final also decreases to 12 minutes instead of 14 minutes, it would be possible to wash the needed amount for three shifts just in two and also rationalize one employee. Another significant result accrued by the simulation of the internal transportation. The simulation model showed that the internal transportation is manageable with one employee which works just in the morning shift. This simulation model also compared the two different final layouts in terms of the internal transportation, with the result that the separation of the receiving area decreases the effort of about 12%.

These elaborated results will be included in the further considerations for example the company works on the reduction of the washing time to mitigate the bottle neck on the one hand and to rationalize one washing shift in the department wash unit_final. To improve the worker utilizations the company define more supporting or logistics tasks for the several employees. Finally, the company pursue and develop the strategy to fulfil all internal transportation tasks just in the morning shift.

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