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Sourcing of axle boxes for railway bogies

A feasibility study for strategic factory and technology planning at the Siemens plant in Graz

Master Thesis

Production Science and Management

Graz University of Technology

Faculty of Mechanical Engineering and Economic Sciences

Institute of Industrial Management and Innovation Research

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Abstract

The firm Siemens develops and produces high-tech bogies to meet the widely varied requirements of modern passenger transportation in Graz. These bogies are used for urban transportation, such as trams and metro trains, or in the field of commuter and regional transportation, or also in locomotives for freight transport as well as for high-speed passenger transportation.

The aim of this thesis is to clarify the technical and commercial possibility to insource the production of axle boxes at the Siemens plant in Graz. Axle boxes are safety-related components. An axle box is the only connection between the wheel set and the frame of the bogie. In the event of a failure of an axle box, the train will lose the track and will inevitably derail. So for this reason special care is needed during development and manufacturing. Currently all axle boxes are manufactured by external companies. Nevertheless, some axle boxes are also being developed at the Siemens plant in Graz.

This master thesis is divided into three major parts. First, common benefits of an in-house production are described, topics of factory planning and central terms in connection with an investment appraisal are discussed. The second part is a target planning. This part primarily includes a detailed task and target definition containing medium and long-term objectives, as well as a portfolio analysis of the current production program. The third part is a feasibility study. In the framework of this study, a system and structure planning, a global planning as well as an investment appraisal is carried out. The structure planning mainly deals with a detailed analysis of the required production steps from raw casting to a finished axle box and makes potential improvements of the current manufacturing step visible. The global planning deals with a material flow analysis that is supported by simulation software, then various layout concepts are generated and evaluated against each other.

Finally, an investment appraisal is created which includes the collected information for each variant and all alternatives are studied from a commercial perspective. The results of this thesis are a supportive tool for the plant management which will help to make an important decision on whether or not to invest in an axle box production at the Siemens plant in Graz.

Kurzfassung

Der Siemens Standort Graz in der Eggenbergerstraße ist das Zentrum für die Fertigung und Entwicklung von Drehgestellen innerhalb des Siemens Konzerns. Diese Drehgestelle werden innerhalb der Siemens Sparten in diverse Produkte für den Personentransport oder Frachttransport verbaut.

Das Ziel dieser Master Thesis ist es sowohl die technische als auch wirtschaftliche Möglichkeit zu beleuchten, ob Radsatzlagergehäuse am oben erwähnten Standort gefertigt werden können. Radsatzlagergehäuse sind sicherheitsrelevante Bauteile. Sie sind die einzige Verbindung zwischen dem Drehgestellrahmen und dem Radsatz, welcher die Verbindung zur Schiene darstellt. Diese Bauteile werden derzeit teilweise am Standort selbst entwickelt aber ausschließlich von Zulieferern gefertigt. Um die Produktivität am Siemens Standort Graz Eggenbergerstraße weiter zu steigern und die Wertschöpfung zu erhöhen, soll im Rahmen dieser Arbeit eine Planung für eine neue Produktionslinie dieser Radsatzlagergehäuse vorgenommen werden.

Diese Masterarbeit wird in zwei Teilbereiche unterteilt, die Anhand von Literaturrecherche und praktischen Erarbeitungen erläutert werden. Der erste Teilbereich beschäftigt sich mit einer ausführlichen Analyse des derzeitigen Portfolios und gibt einen Ausblick auf die zu produzierende Stückzahl. Als zweiten Teilbereich wird eine „Feasibility-Studie" durchgeführt. Im Rahmen dieser Studie werden eine Strukturplanung und Dimensionierung, eine Globalplanung und eine Investitions- und Kostenplanung erstellt. Die Sturkturplanung beschäftigt sich hauptsächlich mit der Analyse der einzelnen Produktionsschritte und zeigt diverse Verbesserungspotentiale auf. Als nächster Schritt wird in der Globalplanung eine Materialflussanalyse der Produktionslinie erstellt und dieses Simulationsmodell wird computerunterstützt optimiert. Danach werden diverse mögliche Layoutvarianten beschrieben. Im Planungsschritt „Investition- und Kostenplanung" werden alle zuvor erstellten Varianten anhand ihrer Ausgaben und Einnahmen kaufmännisch untersucht. Am Ende der Arbeit werden auch alle nicht monetär darstellbaren Vor- bzw. Nachteile einer eigenen Produktion von Radsatzlagergehäusen aufgezeigt, um eine Unterscheidung der einzelnen erarbeiteten Varianten zu ermöglichen und eine Unterstützung bei der Entscheidungsfindung zur Realisierung dieses Projektes zu geben. Die erarbeiteten Ergebnisse werden außerdem der Werksleitung präsentiert um bei einer möglichen Investitionsentscheidung zu unterstützen.

Contents

1 Introduction

“Renaissance in Manufacturing” is the title of an article in the Siemens magazine for research and innovation, “Pictures of the Future”[1]. The author mentioned that after the financial crisis the industry in Western countries is undergoing a renaissance. For example, in Germany, manufacturing industries, excluding the construction sector, are producing more, as a percentage of GDP, than at any time in the last five years. Moreover, manufactures play a major role in the research and development activities within a country, which makes in-house production an important topic and new as well as intelligent factories are the backbone of this growth.[2]

1.1 Siemens AG - Sector Infrastructure & Cities

In 2011, Siemens defined its new sector Infrastructures & Cities in order to offer customers in urban centers technological solutions and infrastructures in a more focused way than before. This new sector is divided in five divisions, such as building technologies, low and medium voltage, mobility and logistics, rail systems as well as smart grid. In addition, the Infrastructures & Cities Sector addresses high-margin growth markets such as airports and data centers.[3]

The Siemens plant in Graz is a part of the rail systems division. This division provides rolling stock and related services, as shown in figure 1-1. The Siemens plant in Graz is also called the world competence center for bogies and offers high-tech bogies to meet the widely varied requirements of modern passenger transportation.

[1] cf. S. Trage (2013)
[2] cf. S. Trage (2013)
[3] cf. Siemens AG (2013), retrieved 26.09.2013

As seen in figure 1-1, these bogies are used for urban transportation, such as trams and metro trains, or in the field of commuter and regional transportation, or also in locomotives for freight transport as well as for high-speed passenger transportation.

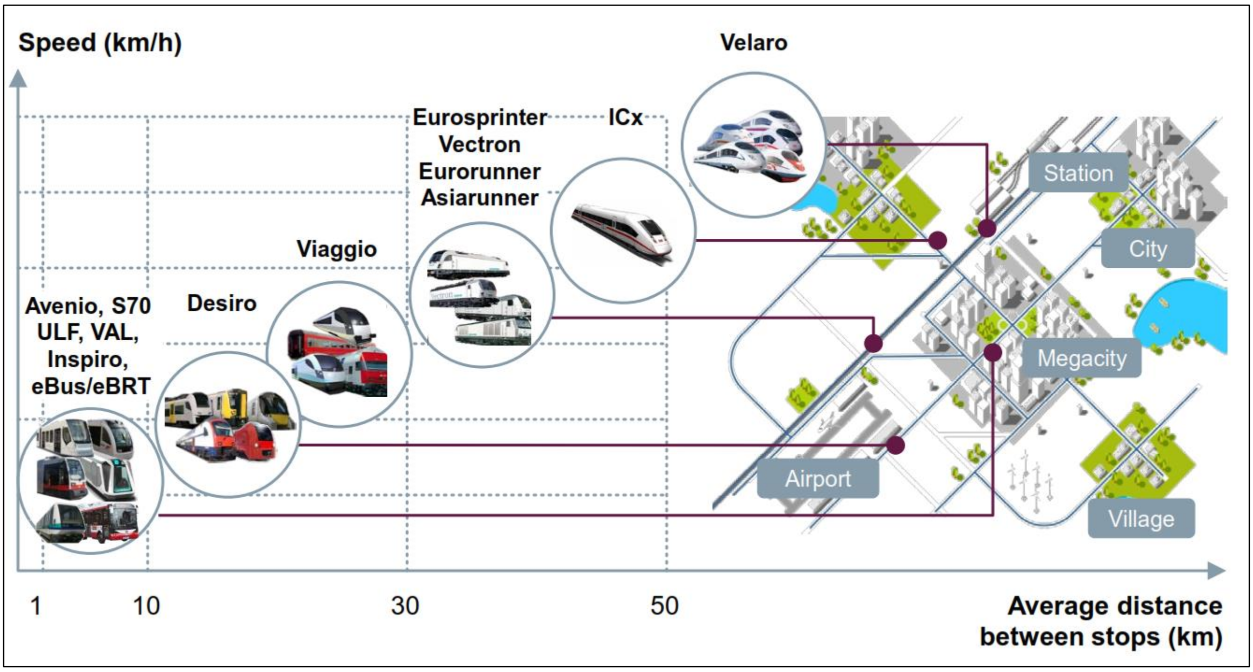

Figure 1-1: Overview of solutions for moving people and goods in cities and between cities[4]

A modular concept is used for the design of Siemens bogies. This gives the possibility to adapt easily to specific requirements and in addition, increases the efficiency of every individual solution. Some examples can be mentioned as follows:[5]

- Bogies for the high performance locomotive TAURUS of the Austrian Federal Railways, 22 tons axle load and maximum speed of 230km/h
- Bogies for the high speed train ICE 3 of the German Railways and VELARO E in Spain, for maximum speeds up to 350km /h
- Bogie for AVANTO, low-platform urban rail vehicles with a low-floor portion of more than 70 % and a floor level height of 381mm and 655mm respectively

Apart from the specific advantages of the different types, these products which are used worldwide provide high operational safety, particularly smooth running, high reliability, low life-cycle costs and efficient maintenance.

Siemens is one of the world’s leading manufacturers of rolling stock. The development and production of bogies is the responsibility of the Siemens plant in Graz

[4] cf. Siemens AG (2013), retrieved 26.09.2013
[5] cf. Siemens (2006)

Eggenbergerstraße. At the Siemens plant in Graz, design engineers and manufacturing experts work under the same roof. This immediate proximity of ideas and their means of realization is one of the decisive factors for the flexibility and quality Siemens offers.[6]

The core competences in the field of system engineering, component development, vehicle dynamics as well as welding of bogie frames enables the emergence of innovations and bogie designs at the highest technical level for all application areas.[7]

1.2 Aim of the master thesis

Siemens invested in 2011 in a new wheel set assembly facility at the plant in Graz. Since that date, the plant management of this factory location is selecting several parts. Then in-depth research is made if an internal production is possible, or not. One of these parts is an axle box. Every wheel set consist out of two axle boxes. An axel box is the only connection between the wheel set, which in conjunction with the rail and the frame of the bogie, is the connection to the car body. Hence, the plant management in Graz Eggenbergerstraße wishes to clarify the technical and commercial possibility to insource axle boxes. A new production line has to be planned which should be used exclusively to produce axle boxes from raw castings. In addition, the needed machinery is described.

To obtain and collect all the necessary information, several meetings with potential suppliers will be carried out during the project time and target price offers will be collected. The plant management expects as an output of this thesis a detailed documentation of possible future scenarios to make a profound decision on whether or not to invest in a new axle box production.

1.3 Approach

The following statements and figure 1-2 describe the stepwise approach of this master thesis and the studies and calculations which will be carried out in the following sections:

[6] cf. Siemens (2013a)
[7] cf. Siemens (2013a)

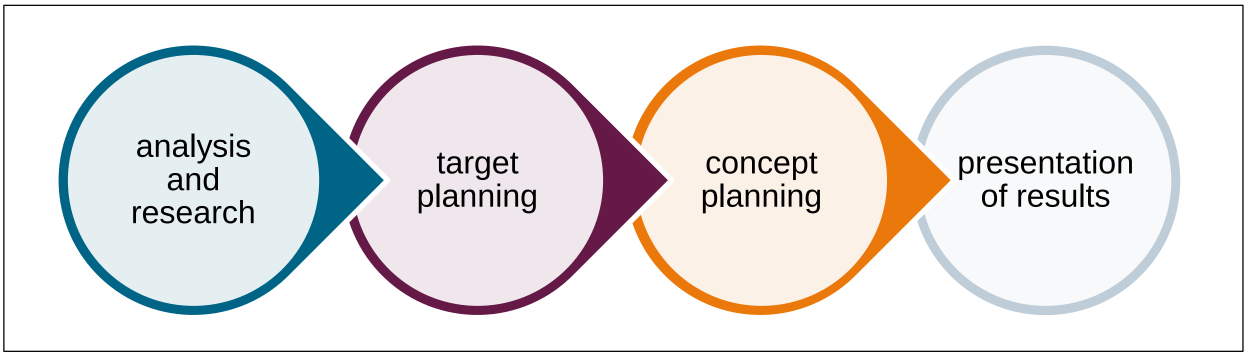

Figure 1-2: Procedure of the master thesis

- First, to define the field of this thesis common benefits of in-house production are collected, then important topics of factory planning are defined and developed in order to understand the procedure of a planning task and finally the central terms in connection with an investment appraisal are described.

- A target planning will be carried out. It is important to evaluate the initial situation and to define the suitable target concept. This step includes a detail task and target definition containing medium and long term objectives, a situation study, a portfolio analysis of the current production program, an overview of the existing operational structures, a value stream analysis as well as an outline schedule for an possible ramp-up scenario.

- A feasibility study for the planned production facility will be prepared. In the framework of this study, a system and structure planning, a global planning as well as an investment appraisal will be carried out. The structure planning mainly deals with an detail analysis of the required production steps from a raw casting to a finished axle box and tries to make potential improvements of the current manufacturing step visible. The global planning deals with a material flow analysis that will be supported by simulation software, then various layout concepts will be generated and evaluated against each other. Finally, an investment appraisal will be created which will include the collected information for each variant and all alternatives will be studied from a commercial perspective. The dynamic payback period, compound annual growth rate and economic value added will be calculated. In addition, a value benefit analysis tries to include all non-monetary factors of an in-house production. The completed feasibility study is a supportive tool for the plant management which will help to make an important decision on whether or not to invest in an axle box production at the Siemens plant in Graz.

2 Strategic Sourcing

There is an increase in the complexity of today's products and many companies do not have the capacity to develop each part of these products on their own. For this reason, companies have to depend on others and it is very difficult to find the right partner for critical tasks and processes. There are three general reasons why companies want to source specific tasks to a supplier:[8]

1. A company does not have the facilities to manufacture a certain product at the present
2. A supplier has operational advantages in terms of delivery times, production facilities, know-how, costs and other factors as far as exchangeable products are concerned
3. A supplier has an edge in the required production processes

Besides these factors, companies have systematically overinvested in commodity parts in the past decade and have neglected to develop new components that have the possibility to become a source of competitive advantage. In an opinion survey, over 250 managers gave their reasons behind this. The most important factor was that different groups within the company pursue conflicting sourcing strategies. In addition, they fear being exploited by opportunistic suppliers. Another reason was the lack of a relevant cost accounting system and finally they are concerned that outsourcing will "hollow out" their company.[9]

The most important terms in the field of strategic sourcing are outsourcing, make-or-buy and core competencies. These describe in the broadest sense the decision problems between in-house or external manufacturing. Because of the lack of a clear definition of these terms in literature and practice, some characterizations are discussed on the following pages.[10]

[8] cf. C. Ramsauer (2009), p. 87
[9] cf. R. Venkatesan (1992)
[10] cf. M. Bacher (2000), p. 35

Make-or-buy decision

The most common type of alternative choice problems is the make-or-buy decision. It is natural that a company produces some goods with its own resources and pays a different company to carry out other activities. There are always two important questions which need to be answered in connection with this decision problem: First, should a firm contract an external business unit to perform an activity which it currently performs itself? Second, should a firm perform some functions that are now done by someone else?[11]

To sum up, a make-or-buy decision characterizes the decision between internal or external value performances.[12]

Core competences

It is important to focus on one's own resources; that means core competencies generate a unique value for customers. Moreover, activities that are not significantly valuable for a company or goods that require no special knowledge to be produce should be outsourced.[13]

In literature, it is stated that the concentration on core competencies is a guarantor of success in fluctuating markets in terms of productivity, innovation and sustainable growth.[14]

The main ideas behind a core competence are:[15]

- Setting standards for the competitors and not just satisfying customer demand
- Developing new performance levels
- Increasing the value for the customer and business unit
- Continuous improvement of success factors

2.1 Outsourcing

In general, outsourcing means to shorten the supply chain or the depth of services of a company due to a shift of value-adding activities to suppliers. Company overheads can

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[11] cf. P. V. Jenster et al. (2005), p. 4 ff.
[12] cf. M. Bacher (2000), p. 35
[13] cf. C. Ramsauer (2009), p. 91
[14] cf. H. Wildemann (2010), p. 64 ff.
[15] cf. H. Wildemann (2010), p. 64 ff.

often be reduced by using qualified and specialized suppliers of components, services for production or product development. By concentrating on core activities, cost benefits are achieved and improvements of the company's own operative and strategic market position can be gained. What is strategically important is that technologies and skills will not be abandoned through the outsourcing process, as otherwise this could create an undesirable dependence on suppliers.[16]

In addition to the general meaning of the term outsourcing, it can also be described as a process of functional and inter-organizational division of labor, which assigns an in-house task to an external company. The result of outsourcing is that a supplier carries out these processes exclusively. The objective of strategic outsourcing is also to generate a competitive advantage gained through specialization.[17]

In other words, outsourcing is the process of shifting tasks and services which were previously done in-house to an outside firm. The challenge of outsourcing is not just a simple make-or-buy choice problem. On the one hand, it is a response to typical production tasks, but on the other hand it also covers upscale tasks, such as product development, research projects, technical service support and even financial analysis, all of which are being sourced in countries with lower wage costs.[18]

2.1.1 Fields of outsourcing

Outsourcing projects are no longer limited to information technology services or manufacturing. Outsourcing is used as an efficient tool in the whole production process or service delivery.[19]

Four different fields of outsourcing can be distinguished in general: First, the well-known field of external management consultancy with the aim of solving strategic problems. Especially for smaller companies, the consistently use of external consulting is an important tool; second, the shift to external procurement is an emerging field in the outsourcing discipline. As a consequence of grouping parts, which have a minor importance for the final product, a more efficient procurement process can be achieved and a reduction of the fixed costs is possible; third, external production is in particular an important topic for manufacturing processes in the textile industry. Most companies in this industrial segment shift their production to low-wage countries. However, external

[16] cf. Gabler Wirtschaftslexikons (2013), retrieved 06.03.2013
[17] cf. M. Bacher (2000), p. 29
[18] cf. P. V. Jenster (2005), p. 1
[19] cf. U. Koppelmann (2000), p. 205

production is popular across all industry segments. For example, Porsche reports that it is manufacturing just 20% of its production volume in its own facilities. The more a company decides to outsource production, the more the logistics should be kept in-house; otherwise, control and management problems may occur; fourth, the product development sector is another good example for outsourcing activities. Many companies outsource their entire development activities and the production of a specific work task or product to a supplier. The development cost of a specific product is usually included within the price of the part. In addition, outsourcing activities are widely used in staff recruiting, marketing and production sub-processes.[20]

2.1.2 Trends to start outsourcing activities

As mentioned in the beginning, the diverging cost factors and growth are the driving forces for companies to start outsourcing activities, because they have realized that the wage gap is not going to close between the so-called developing countries and industrialized countries in the coming decades.[21]

There are many trends and pressures to start outsourcing activities, which have been increasing since the 1980s. Since then, it is important to constantly improve the performance of a business unit. These trends are summarized in the following factors:

- Competition has expanded and it is no longer possible for most firms to cope with the competition within the boundaries of a country or a specific industry sector. Technological improvements have meant that computers, cameras, copiers and smart phones have all crossed into the territory of each other, which increases the number of competitors and makes some products obsolete. More and more firms have to think in global terms, either because their customer demand is globally orientated, or because it is only possible to stay remain on a par with competitors' costs when serving a large market area.[22]
- Customers have higher expectations and more choice between different products. Industrial customers are demanding more in order to reach the right cost level, quality and timeless delivery in order to stay competitive.[23]
- The product lifecycles of various products are shortening. On the other hand, this trend has the positive effect that it keeps the markets growing. Firms that cannot afford

[20] cf. U. Koppelmann (2000), p. 207 ff.
[21] cf. E. Abele et al. (2008), p. 9
[22] cf. P. V. Jenster (2005), p. 7
[23] cf. P. V. Jenster (2005), p. 7 ff.

to update their products frequently and to include innovations have a huge competitive disadvantage. These firms need, for example, support in the field of product development.[24]

- Emerging countries are facing a very high market growth in most industrial segments. These greatly increasing opportunities make the markets outside the industrialized world very attractive for companies and at the same time increases the incentives to outsource production.[25]
- As well as economic changes, the past decade has also seen political changes too. As a result, fewer trade barriers exist in the global market and tariffs as well as custom duties have been reduced in order to boost the international exchange of goods.[26]
- Mass customization leads to an increase in complexity which in turn influences the logistics supply chain and the fixed cost of production, and therefore new location networks within a company are required to satisfy the needs of costumers in different markets.[27]
- Structural changes in production technologies, such as the introduction of IT-systems, completely change the value creation chain of a business unit and increase the need to manage such IT-systems.[28]
- Demand volatility leads to capacity requirements with the possibility to manufacture variable lot sizes and flexible production processes.[29]

In addition, the following reasons are strong arguments for external production or development of a specific product or service:[30]

- High quality because of high specialization of the supplier’s production plant
- Use of external know-how
- Avoidance of a low workload at highly specialized production facilities
- No capital commitment to durable means of production
- Concentration of investments on core competencies
- Low share of development cost and fixed cost
- Risk diversification through allocation to different suppliers
- Low risk of additional cost due to development failures and a drop in production

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[24] cf. P. V. Jenster (2005), p. 8 ff.
[25] cf. E. Abele (2008), p. 10
[26] cf. E. Abele (2008), p. 12
[27] cf. H. Wildemann (2010), p. 11 ff.
[28] cf. H. Wildemann (2010), p. 11 ff.
[29] cf. H. Wildemann (2010), p. 11 ff.
[30] cf. U. Koppelmann (2000), p. 203

2.1.3 Potential advantages and aims of outsourcing

The aim of outsourcing projects is to achieve cost saving, improvement of performance and improvement of flexibility. Measures designed to reduce risks are more often used to prevent a project from being outsourced.[31]

Many different criteria define the right outsourcing partner, as described in section 2.1.4. However, the most important factor is cost savings. The most common influencing aspects are listed and discussed below.[32] Moreover, performance advantages are still important, but it is very hard to measure and anticipate these effects.[33]

- **Cost reduction through "Economies of Scale" and "Economies of Scope"**
  "Economies of scale" means a cost reduction through customer-independent consolidation of production volumes and standardization. This advantage in terms of cost is extremely valuable. "Economies of scope" has a different effect. The basis of "Economies of Scope" is the reduction of fixed cost as a consequence of filling existing capacity gaps by means of various processes.[34]
- **Cost reduction through load levelling**
  A good example of load levelling can be found in the logistics sector. Outsourcing transfers the capacity utilization risk to a level where it is easier to handle. For instance, seasonal fluctuations can be compensated across all industry sectors. There is a valid benefit for the costumer, which is derived from a switch from fixed cost to variable cost.[35]
- **Reduced labor expense**
  Not only the cost of labor defines a possible cost saving. It is also important to include the productivity and increase of flexibility. This increased flexibility can be achieved due to the fact that weaker trade unions normally exist in low-wage countries, which gives the opportunity, for example, to run more late night shifts and increase the percentage of part-time employee.[36]
  It is stated that newly industrialized countries will not attain the same level as high-cost countries in terms of labor expenses in the long-term perspective. Therefore, firms have to consider their network strategy due to the labor costs, which directly influence the price of the produced good.[37]

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[31] cf. U. Koppelmann (2000), p. 203
[32] influence by the doctoral thesis "Erfolgreiches Outsourcing" by M. Lang (2007)
[33] cf. W.-R. Bretzke (2010), p. 342 ff.
[34] cf. W.-R. Bretzke (2010), p. 342 ff.
[35] cf. W.-R. Bretzke (2010), p. 343 ff.
[36] cf. W.-R. Bretzke (2010), p. 346 ff.
[37] cf. E. Abele (2008), p. 9 ff.

- **Shareholder value effect**
  This effect means that if a company uses the available capital which is no longer invested in in-house production facilities, and reinvests it in the areas of their core competencies, then the company will increase its enterprise value more than by producing on its own.[38] Moreover, the shareholder value emphasizes the need to focus on achievement of higher enterprise value although the reduced size of the asset investment needs to achieve those higher profits.[39]
- **Saving in terms of "Economies of Skill"**
  This term can be described as that an outsourcing partner has generated a very moral knowledge in a specific field of production or by offering a specific service. This best practice approach offers an advantage in terms of productivity and costs.[40]
- **Productivity increase through motivation effects**
  In this stage, outsourcing is combined with expectance that this radical intersection breaks down established structures to reach new insights. Moreover, the management is not willing to increase its efforts in this field and that is why they want to outsource this business area.[41]
- **Reduction of inventory cost**
  The risk of building up too high inventory levels within the production chain is eliminated by outsourcing. This cost is shifted to the supplier that is responsible for its own inventory system and include this cost in the price of the purchased part.[42]

2.1.4 Outsourcing problems and risks

In-house activities for a specific product gain importance when an outsourcing project is likely to fail. The following factors are the major indicators of failed outsourcing activities:[43]

- Financial difficulties or bankruptcy of the outsourcing partner
- Collapse of the project in the start-up phase due to management failures
- The outsourcing partner does not meet contractual agreements such as service level, quality or cost
- Cultural differences between the parties involved

[38] cf. W.-R. Bretzke (2010), p. 346
[39] cf. P. V. Jenster (2005), p. 9 ff.
[40] cf. W.-R. Bretzke (2010), p. 348
[41] cf. W.-R. Bretzke (2010), p. 348
[42] cf. C. Ramsauer (2009), p. 96
[43] cf. J. Dittrich and M. Braun (2004), p. 95 ff.

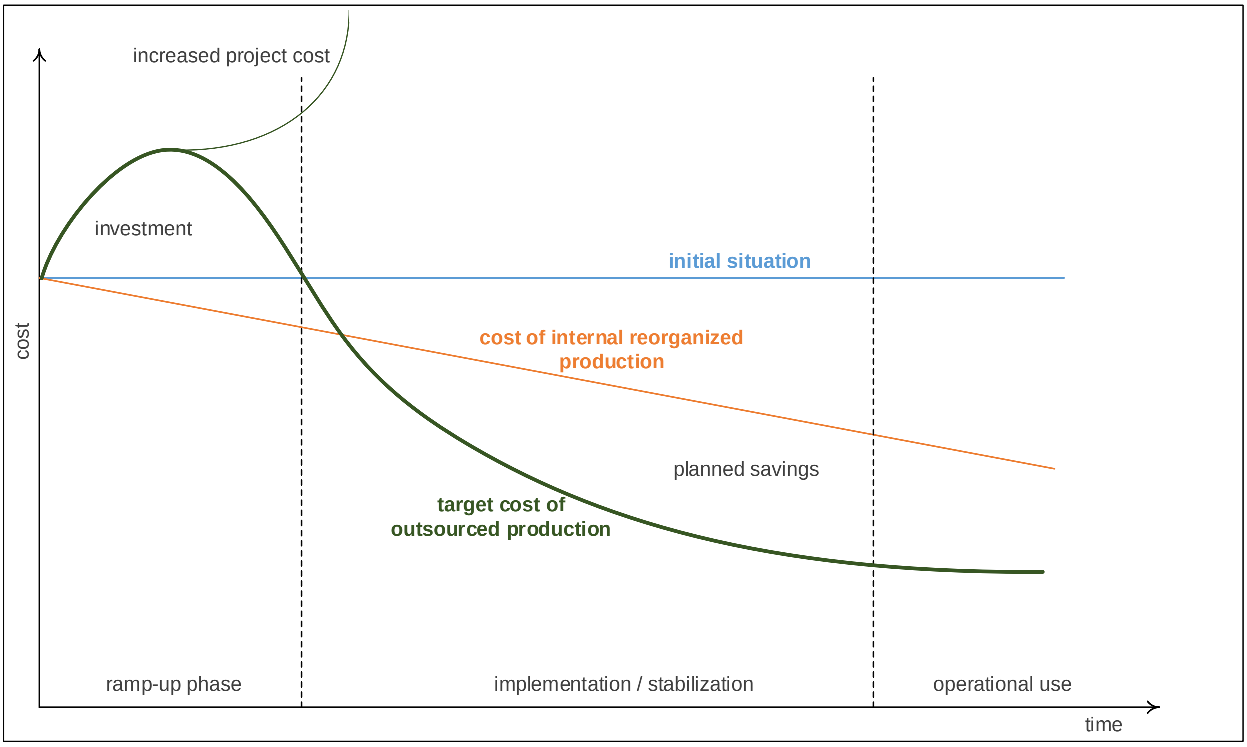

Figure 2-1: Cost situation for failed outsourcing projects[44]

Figure 2-1 shows the relation between the cost and time of an outsourcing project. Such a project is on the verge of failing if stated savings are not reached in a certain period.[45]

Beside the cost criteria, the risk profile of an outsourcing project tends also to reorganize the internal structures of a company in terms of insourcing. In combination with an increase of project risk, the anticipated savings have to increase or the payback time of a certain project has to decrease faster than is the case for an insourced project.[46]

However, outsourcing is not always the best option for every product or service. That is why some common problems have to be mentioned and described:

- **Loss of know-how**
  Over time, skills developed for solving a specific problem are no longer used within a company. It follows from a detailed research which areas of work are strategically important for the sustainable growth of a company, and which are not.

[44] cf. J. Dittrich (2004), p. 96
[45] cf. J. Dittrich (2004), p. 96
[46] cf. J. Dittrich (2004), p. 97

The strategically important fields -core competencies- should be retained within the company.[47]

- **Management problems**
  Processes within a firm are easier to control because of the hierarchical structure of a company. The coordination process with different suppliers has a negative influence on the flexibility of a company. In addition, a new communication interface is needed between the two partners. It is necessary to establish the means of cooperation to be able to work together to solve problems that may arise. The project members should perceive themselves as working in a virtual company.[48]
- **Control problems**
  During an outsourced project, a number of interfaces must be designed between the two partners. In particular, good information and warning systems are needed for a zero error strategy. Due to an aligned documentation, all project partners can be taken into account.[49]
- **Choose the right partner**
  Outsourcing assumes that a possible supplier exists who is more specialist and efficient in manufacturing goods than an in-house production. It may be difficult to find this supplier. Furthermore, during the development phase of a new product, it would be a good idea to include standardized parts as these parts provide a simple route to external production.[50]
- **Additional cost due to the transaction cost effects**
  In general, transaction costs are defined as the cost of coordination and monitoring of specific remote productions. The idea behind transaction cost is that the management and monitoring process becomes more complex when the influences on the operational events of a product or service and the possibility to influence these events are reduced. Many companies are afraid of “losing control” if a project is outsourced. This is because of a variety of potential disadvantages such as the detection of quality problems at a later stage, or not satisfying price adjustments due to a change of performed services. These problems can be avoided through an increase in monitoring and management activities, which again increases the monitoring costs. It is not a good idea to start an outsourcing project if this increased monitoring cost is higher than the cost advantages to be

[47] cf. U. Koppelmann (2000), p. 205
[48] cf. U. Koppelmann (1996), p. 6
[49] cf. U. Koppelmann (2000), p. 205
[50] cf. U. Koppelmann (1996), p. 7

achieved through external production.[51] Nevertheless, the effort to manage a supplier should not be underestimated. Occasionally, more time and effort is needed to deal with specific topics than is gained from improvements of the internal process.[52]

Therefore, it is important to make an in-depth assessment before an outsourcing activity starts. It is essential to calculate the true costs of manufacturing, which are then weighed against the cost of acquiring from a supplier. The strategic, operational and organizational targets of a firm assist in alternative choice problems. For instance, in-house development and manufacturing provides the opportunity for fast ramp-ups and prevents the loss of technological know-how to external companies. This leads to the question: Does the ownership of a process have any strategic importance for the company's business goals, or not?[53]

2.2 Insourcing

Insourcing means the re-integration of performance processes which are connected to the core competence of a company and may have been outsourced before.[54]

In comparison to the definition of the term outsourcing, insourcing means assignment of functional and organizational tasks to responsible business units which are located within the firm. A consequence of insourcing is that these tasks are exclusively carried out within the company. In contrast, outsourcing is defined as solely external production and with the result that in-house production is reduced or stopped. Insourcing is described as the start of exclusively internal production.[55]

Compared to outsourcing, in-house production has also many advantages. The most important factors are listed below:[56]

- Production and engineering departments can work closely together
- Ongoing control of the quality is possible
- Acquirement of specific skills and expertise in the production of a certain good

[51] cf. W.-R. Bretzke (2010), p. 342 ff.
[52] cf. C. Ramsauer (2009), p. 99
[53] cf. S. Doig et al. (2001)
[54] cf. Gabler Wirtschaftslexikons (2013), retrieved 06.03.2013
[55] cf. M. Bacher (2000), p. 32
[56] cf. U. Koppelmann (2000), p. 203

- Operation at higher capacity
- Lowering of pre-tax profit through investments
- Modernization and specialization of production facilities
- Savings in terms of the elimination of suppliers' profit mark-up, transportation costs and associated packaging costs
- Independence of product price adjustments
- Non-disclosure of specific know-how
- Prevention of forward integration of suppliers
- Non-disclosure of new product developments and protection of know-how

Besides, the case of GE illustrates a new trend in the US to start an in-house production and provides a perfect example to explain the cause of the decision to insource. GE opened three new assembly lines in Kentucky to make cutting-edge water heaters, high-tech refrigerators and stainless-steel dishwashers. These are products which usually are shipped from China to the US market. GE took the decision to insource not only because of an increase in oil prices and the natural-gas boom in the US, which dramatically lowered the costs of running a factory. It was also because GE discovered during the development of the assembly process that it was able to cut down material costs and labor costs while both quality and energy efficiency rose. Moreover, the time-to-market period has been significantly shortened, from 5 weeks to just 30 minutes.[57]

2.2.1 Process improvements during the search for sourcing partners

Companies have to deal with the efficiency of their own processes while they are searching for ideal outsourcing partners. Internal processes have to undergo improvement programs in which they are restructured and significantly improved based on the make-or-buy decision issue. During this phase, a typical saving potential of 8 to 18 per cent of the overall cost can be achieved. A large percentage of these savings originate from production and material costs. Such potential savings can be increased by either in-house production or outsourcing, or a combination of both.[58]

[57] cf. C. Fishman (2012)
[58] cf. C. Ramsauer (2009), p. 95

2.2.2 Potential for innovation through insourcing

While Toyota was growing in the 1950s, the company considered both external and internal production of different assembly parts. The management of Toyota concluded that a supplier had little incentive and chance to mention improvements based on their own practical experience. This happens because the chosen suppliers had no knowledge of the whole system. The companies disclose only the data required and rarely information on the complete system. This happens because of the fear of losing exclusive know-how as described in section 2.1.4.[59]

Nowadays, various studies have shown that around two-thirds of all innovations originate from supplier and customer interfaces. This means that suppliers and customers should be motivated to contribute to the product development process in order to generate mutual benefit.[60]

Innovations lead to an improvement of core competencies and with the expansion of competence a more cost effective process can be achieved. Furthermore, technical innovation can make other processes redundant. In the case of an outsourced process, company growth depends on the willingness of the supplier to improve these processes. This also influences the company's innovative capacity to a certain degree. For example, if the supplier is not able to invest in new technology or has a different business strategy, the outsourcing company's core competence can be influenced through the low innovative ability of a supplier. A prompt modification of technology, organizational concept or business model in the work scope, which is close to the core competencies of a business unit, offers a good opportunity for in-house production. Nevertheless, if the rate of innovation is low and the elected process is not a core competence, it will be a good option to outsource the process.[61]

[59] cf. J.P. Womack et al. (1994), p. 64 ff.
[60] cf. C. Ramsauer (2009), p. 95
[61] cf. J. Dittrich (2004), p. 101

3 Factory planning

The technical, economic and operational requirements for the design of industrial facilities are very high and complex. The constantly rising number of influencing factors and constraints lead to the creation of a new scientific field: “factory planning”.

Factory planning is a complex and comprehensive planning area in which many different sub-tasks with the same uniform aim are centralized into a compact system. This system is hierarchically constructed starting at the research phase and ending at the decision-making point. Most of the results of the sub-tasks influence the subsequent tasks and simultaneously influence each other, which leads to the fact that good controlling and management is important. Factory planning is an element of corporate planning and its main objective is optimal design and efficient deployment of investments. These goals can be divided into long-term, mid-term and short-term planning tasks. The long-term planning can be viewed as the classic form of factory planning, which includes in addition the period after the economic lifetime of a production facility, and is a part of the long-term corporate planning. The mid-term planning mainly concentrates on detail design of operational facilities, which includes the design of new production facilities or the reconstruction and extension of existing operational areas. In contrast, short-term planning deals with the adaptation of existing facilities for the presently altering operational need. The design of industrial facilities deals with the procurement of a capital-intensive goods and the shop floor design. During a factory planning project, information is gathered on the optimal technical and commercial arrangements for the production of specific goods - taking a certain level of flexibility into account. Factory planning mainly concentrates on static constructions, such as buildings or machinery, but these constructions have a dynamic use. In other words, the given task of a given production facility may change over a period of time, which leads to the topic of adaptable factory planning.[62]

[62] cf. B. Aggteleky (1981), p. 26 ff.

Different interpretations of the term “factory planning” can be found in current literature, but in general, the term covers the following fields:[63]

- Strategic goals, such as strategic sourcing, strategic cooperation or strategically important research and development projects. In this field factory planning is used as a management tool, which aims to achieve economically satisfying solutions.
- Reformatting projects, such as infrastructure projects, material flow improvements, reorganization production layout or logistic projects. In this case, factory planning is a utility which is used in particular during the phase when decisions are prepared and positions developed.

3.1 Structure of factory planning

As mentioned before factory planning is a hierarchical system. Current literature mentions a macrostructure-planning scheme, which includes three basic steps: preparation, concept planning and implementation planning. These steps are described in the following section.

This factory planning scheme is shown in figure 3-1, which clarifies the accuracy of the following statements:[64]

- With progress made, the processing time required for the next task increases due to a wider spectrum of different problems and influencing factors.
- Project costs increase with progress in the planned project.
- Planning or decision errors in an early project phases have a huge overall effect on the project. For this reason, it is important to describe the planning objectives precisely.

3.2 Planning stages

Based on literature, three main planning stages can be distinguished in the systematic planning process, and these are explained more in detail in the following section.

[63] cf. G. Pawellek (2008), p. 13 ff.
[64] cf. C.-G. Grundig (2012), p. 39

Each factory planning project is an unique entity. They vary in terms of the given task, scope of the issue and solution leeway. Due to this reason, it can happen that planners focus in more detail on one stage and ignores other stages.[65]

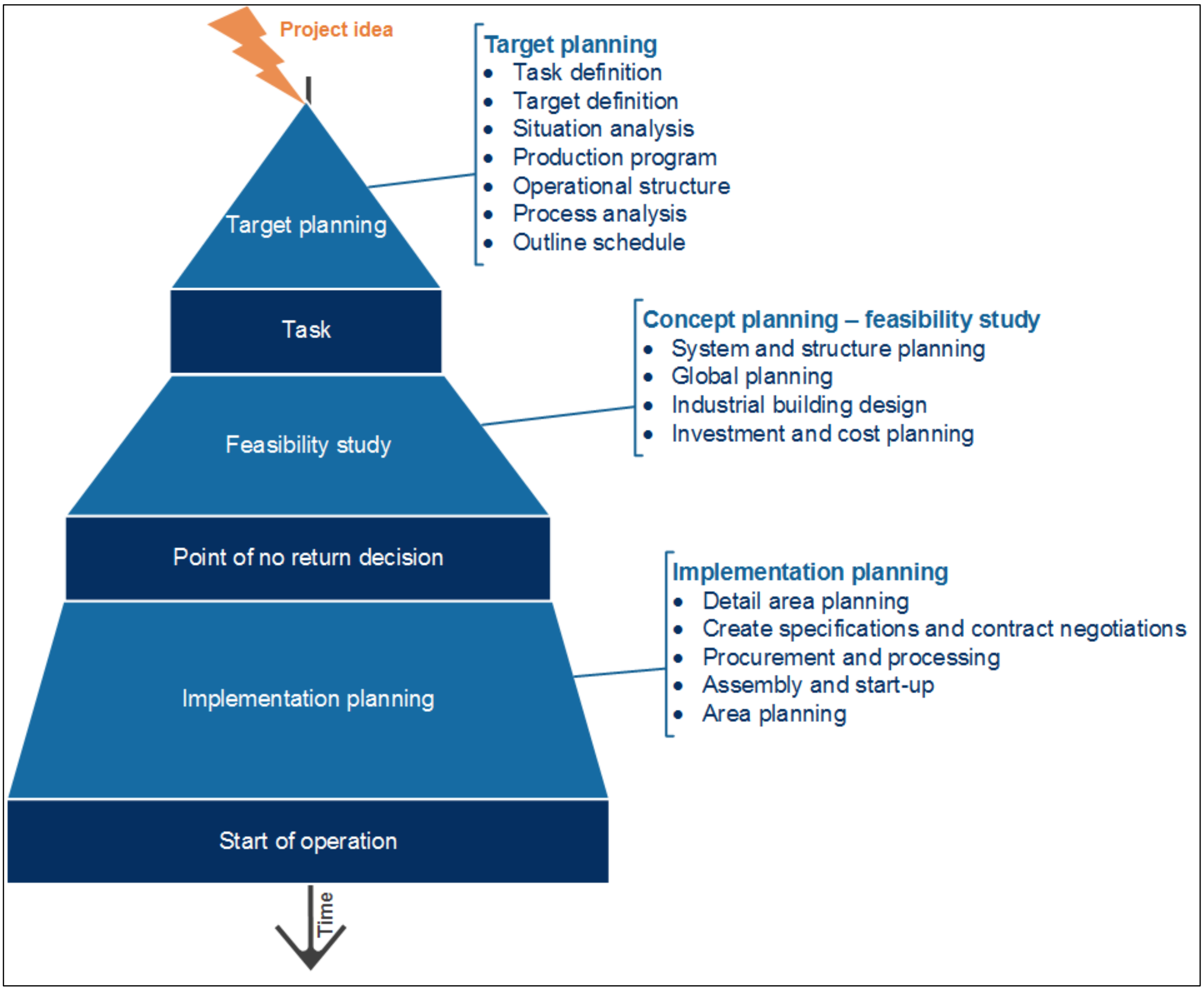

Figure 3-1: Factory planning pyramid[66]

[65] cf. M. Schenk and S. Wirth (2004), p. 234
[66] cf. B. Aggteleky (1982), p. 672

3.2.1 Target planning

The starting point is a project idea arising from the identification of a problem in the operational use, which leads to a reconstruction or construction of production facilities. Another starting point can be an improvement of the existing product.[67]

The main task of target planning is the introduction of innovative scenarios which cope with the perceived deficit or new requirement. The basic requirements, targets and investments to fulfil these scenarios have to be described. This description is the foundation of the whole planning cycle.[68]

In general, the output of this phase can be described in an opportunity study and a pre-feasibility study, which includes the following points:[69]

- Task definition
- Problem description, need for change
- Target (short, medium, long term)
- Presetting of flexibility
- Solutions direction
- Outline schedule
- Project management and organization
- Analysis of the initial situation (production potential)
- Clarification of the manufacturing program
- Draft of logistics concept
- Checking of boundaries and feasibility of the project
- Estimations of investments and time required
- Assist in the decision-making process, generation of a pre-feasibility study

The pre-feasibility study is abbreviated version of a feasibility study. It is a fast procedure to clarify the value of carrying out project planning. The pre-feasibility study is restricted to estimations and assumptions based on the target planning. Because the pre-feasibility study does not deliver accurate results, it can only be used as a pre-evaluation procedure for a project. If the result of this study is positive, the next step is a systematic feasibility study, as described in section 3.2.3.[70]

[67] cf. B. Aggteleky (1981), p. 31
[68] cf. C.-G. Grundig (2012), p. 54 ff.
[69] cf. C.-G. Grundig (2012), p. 56 ff.
[70] cf. B. Aggteleky (1981), p. 227 ff.

3.2.2 Task

The first action in this step is preparation. It is important to carry out a requirement analysis and then to define the goal and tasks. This phase is influenced by the market analysis, production portfolio, process technology, expertise, licensing issues, financing possibilities and raw material procurement. In addition, the right location and environmental issues have to be clarified. All the gathered information is summarized in the task description. This is the basis for further planning steps.[71]

This step is complete by a decision. Due to this decision, modification and adaption of the planned project may be necessary which leads to an iterative and cyclical character of a factory planning project. The following decision are likely in the task step:[72]

- Cancellation of the planning activities
- Release for continuation without significant changes in the planning objectives
- Release for continuation, but significant changes are necessary due to new influences

3.2.3 Concept planning – feasibility study

All the information that is created in the previous step is used within this planning stage. The aim is to take the concepts from the target planning and adjust these to fit in the real and physical structure.[73]

In addition, a feasibility study, which is the core element of the factory planning process, is carried out. It is important to define the ideal combination of technical and economic utilization of a production facility. The first step in this study is a detail analysis of the existing production procedure, as described in section 3.2.1. This analysis can be used simultaneously to improve the existing procedure, which leads to cost savings.[74]

[71] cf. B. Aggteleky (1981), p. 31
[72] cf. C.-G. Grundig (2012), p. 39
[73] cf. C.-G. Grundig (2012), p. 47
[74] cf. B. Aggteleky (1981), p. 31

This study is the most important part of the whole planning. Aggteleky concluded that the feasibility study is the optimization study to instigate the technically and economically most suitable concept. The feasibility studies can be structured in the following steps.[75]

- The system and structure planning concentrates on the determination of the operating procedure, outlining and dimensioning of functional areas and designing of the ideal layout.
- The global planning deals with the investigation of solution concepts including the specified boundaries and given facts. Finally, all different solution concepts are evaluated. These include material flow planning, land-use planning, layout planning and industrial building design. These elements are described in more detail below.
- The chosen concepts are analyzed closer in the detail-planning step. These concepts are further optimized and compared with each other.
- The cost-planning step deals with investment appraisal, which is described in Section 4.

The feasibility study is uniformly established and widely used. The results provide the foundation for the investment decision when the concept planning is finished.[76]

3.2.3.1 Material flow analysis

The material flow calculation is an important part of a feasibility study. In general, the industrial production is structured into a chain of different working steps. During these steps, the raw material undergoes an upgrading process with the support of human labor, energy, tools, machinery and so on. The aim of this procedure is to transform the raw materials into finished parts. Various production steps are conducted at different locations and furthermore, these steps need different handling times. Overall, the material flow calculation includes all the mentioned aspects.[77]

To sum up, the material flow can be defined as a chain of manufacturing processes including the distribution of resources in a certain area. A material flow includes the following basic processes:[78]

[75] cf. B. Aggteleky (1981), p. 32; cf. B. Aggteleky (1982), p. 349
[76] cf. C.-G. Grundig (2012), p. 53
[77] cf. B. Aggteleky (1982), p. 514
[78] cf. C.-G. Grundig (2012), p. 116

- Manufacturing processes, such as assembly, machining and checking
- Handling processes, such as transportation of goods or handling of semi-finished parts
- Storage processes, such as buffering and storing of raw materials or finished parts

During the production steps, the goods generally undergo three different states. First, production is the transformation of the good. Second, moving from one working step to another. Third, waiting for the next production step. These three different states lead to a treatment of the goods, which adds work and cost. This is important because the aim of the material flow calculation is to minimize costs. This cost reduction is achieved as result of reduced transportation costs, inventory cost and the shortening of the door-to-door time.[79]

3.2.3.2 Land use planning

Land use planning is used as a tool for dimensioning the operational area. This is the basis for layout planning. This planning involves a quantitative and qualitative demand, which has to be satisfied in later planning phases. The quantitative demand is a description of the space required for each operational area. This is usually a specification of the floor area (m^2) required for the production hall. On the other hand, the qualitative demand describes the prerequisites on the premises, such as the required height of the hall, floor loading capacity, shape of the room or other special requirements. Both aspects can be summarized in a table which is used in layout planning.[80]

3.2.3.3 Layout planning

The objective of layout planning is to gather the results of the structural plan, material flow calculation and land use planning and to create from these a real and suitable production facility layout. It is important to fulfil the requirements in such a way that the economic goals are also met. In addition, structural properties and official directives have to be taken into account.[81]

The primary focus of layout planning is on the material flow between each workstation and how they interact with each other. Layout planning can be summed up in three basic rules. First, a planned project should have a hierarchic structure from global layout

[79] cf. B. Aggteleky (1982), p.514 ff.
[80] cf. B. Aggteleky (1982), p. 563 ff.
[81] cf. B. Aggteleky (1982), p. 578 ff.

planning to detail planning. Second, each layout planning should consist of a step-wise variant definition and elimination. Broad considerations of various variants is essential in the field of layout planning. A step-wise description of these variants and the elimination of those that are not feasible is useful in order to cope with the large number of variants. Third, layout planning should be organized in stages as described below.[82]

As mentioned before, the practical use of the layout planning describes this step-wise scheme:

1. **Ideal layout:**
   The aim of the ideal layout is to create the best possible layout without taking the special restrictions of the project into account. The result of this planning is a determination of the technological elements required and the functional procedures of the planned production facility. The necessary procedures and equipment are determined. A calculation is then carried out which specifies the workforce, space and supply requirements Furthermore, the ideal planning includes a predefinition of layout containing all the required elements, which meets the technological, operational and economic guidelines.[83]
2. **Outline layout planning:**
   In this step, the data collected in the previous step is transformed into an actual layout plan of the specified building structure. It is important to generate test layouts to make sure that all possible options are taken into account.[84]
3. **Optimization:**
   The economic aspects play a key role in factory planning and for this reason it is important to draw cost-use-relations between the different sub-parts and major factors of influence. Layout planning includes various factors of influence, which are very hard to quantify. It is advisable therefore to carry out a value-benefit analysis including all different layouts and to evaluate this in teamwork.[85]

3.2.3.4 Industrial building design

An industrial building design has to include besides operational and civil engineering aspects the economic aspects in terms of investment, operational costs and maintenance costs. Furthermore, building structures are elements of the long term planning with a

[82] cf. M. Schenk (2004), p. 274 ff.
[83] cf. C.-G. Grundig (2012), p. 46 ff.
[84] cf. B. Aggteleky (1982), p. 583 ff.
[85] cf. B. Aggteleky (1982), p. 583 ff.

useful life of approximately three generations of machinery. These industrial buildings offer primarily three important functional aspects: protection against environmental influences, a load-bearing function for the manufacturing equipment and provision of the right production conditions.[86]

In other literature, this planning stage is also mentioned in the implementation planning stage, section 3.2.5. Based on the results of the outline layout and the exact building structure a further improvement of the layout is carried out. This improvement relies on various smaller elements which have not been focused on in detail, such as waste containers, elements of the technical building structure and distribution boxes for electricity, water or pressurized air. Due to their fixed positions, these elements can cause unexpected rearrangement of the layout.[87]

3.2.4 Point of no return

The general management makes its investment decisions and chooses the most suitable concept on the base of the collected data.[88]

It is only possible to make a definite statement about the quantification of the required investment costs and the profitability of the planned project after the concept planning is finished. This is due to the important figures which have been calculated during the feasibility study. Therefore, it is only practicable to compare several investment projects and define priorities for the projects after the feasibility study step is finished.[89]

3.2.5 Implementation planning

The goal of implementation planning is the further improvement of the concept planning results until the project reaches the quality level for execution. All data has to be verified, specified and completed. In some cases, further improvements may be necessary. The basis for a contract specification is also stated within this step. There is a broad spectrum of possible work steps in the implementation planning which are different in each factory planning project. Nonetheless, the basic principle is a perfectly aligned interaction between human, machine and material that meets the requirements and is failure-free.[90]

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[86] cf. B. Aggteleky (1982), p. 636 ff.
[87] cf. H.-P. Wiendahl et al. (2009), p. 482 ff.
[88] cf. B. Aggteleky (1981), p. 32
[89] cf. B. Aggteleky (1981), p. 39
[90] cf. C.-G. Grundig (2012), p. 208 ff.

The operational units are positioned with an accuracy of 5-10cm in a detailed layout. In addition, the position of the internal offices and routes for the transportation of parts are determined. In close collaboration with an architect, all supply and disposal systems are described and moreover special requirements such as exhaust air systems are further clarified.[91]

All technical, operational and economic activities, which are necessary for the construction of a facility, are covered within this stage. The final step of this phase is the start of operations. Despite this fact, some tasks of this phase are done due to deadline constraints during the concept planning stage.[92]

The implementation planning includes the following aspects:[93]

- Re-drafting of planning documents as defined by the joint decision made previously
- Development of construction work planning
- Detail planning of assets: formulation of performance specifications, gathering of quotes, and evaluation of collected quotes
- Creation of a detailed execution plan together with the chosen supplier
- Assembly schedule
- Construction and assembly management
- Acceptance inspection and start of operation

3.2.6 Start of operation

The start of operation step is the final step of a factory planning project and includes the construction of buildings, installation of the machinery, relocation of certain application areas and so on. This phase deals with the realization of the above in “Implementation planning” mentioned topics. The structure of this phase can be described as follows:[94]

1. Realization of the project
2. Delivery to the owner, after an acceptance inspection
3. Start of operation, starting with a pilot phase, ramp-up phase and ending with the normal operation state

[91] cf. H.-P. Wiendahl (2009), p. 482 ff.
[92] cf. C.-G. Grundig (2012), p. 217
[93] cf. B. Aggteleky (1981), p. 32
[94] cf. C.-G. Grundig (2012), p. 219

3.3 Rolling or cooperative factory planning

In most cases, the factor time plays an essential role during the development of a factory planning project. The dynamic of the market and shortened product life cycles may lead to a change in the planning goals or in the schedule of the project. The outcome of these is a need to shorten the factory planning cycle. This is done by means of rolling factory planning which means that some phases are carried out in simulations to others or that the whole system is broken down into less complex subsystems. Both principles lead to a shortened schedule and an increase in planning mistakes.[95]

The same concept is the basis for cooperative factory planning. The shortened schedule is achieved through synchronization and team-oriented processing with special planning tools in a shortened timeframe.[96]

In other words, the basis is a planning session with an interdisciplinary and flexible workshop character, which is held frequently. The team members from a wide variety of fields are encouraged to participate in these meetings, which leads to a fast and concentrated execution of the given tasks.[97]

It is advantageous to involve the employees concerned as early as possible in the planning process. On the one hand this will increase the planning quality, and on the other hand important undocumented potentials can be utilized. Furthermore, the acceptance for the planning result can also be increased. 2D or 3D planning tools, as described in section 3.5, are excellent tools to support such interdisciplinary meetings. These planning tools were specifically developed to assist in collaborative factory planning. Therefore, various layout plans can be developed at a single meeting and through consistent use of 3D planning tools potential conflicting elements and other mistakes can easily be detected.[98]

[95] cf. C.-G. Grundig (2012), p. 21
[96] cf. C.-G. Grundig (2012), p. 21
[97] cf. C.-G. Grundig (2012), p. 31
[98] cf. U. Bracht et al. (2011), p. 30 ff.

3.4 Adaptable factory planning

Because of globalization and dynamic of the markets, the technologies for the production of specific goods and demand are frequently changing, which leads in turn to the need for adaptable production facilities. The driving forces here can be company external factors, such as customer structural changes or product changes due to new technologies, or company internal, such as vertical integration of new products or shortages in the production processes. These forces make it necessary to implement an adaptability of the plant during the factory planning procedure in order to obtain a future-oriented concept over the full economic life of the planned facility.[99] The possibility to adapt production facilities is becoming a top priority for modern firms as well as is a perpetual task for the plant management.[100]

Two terms in connection with adaptable factory planning can be distinguished. First, flexibility is described as the ability to react on a change in demand in a certain predefined range in which the facility can be reversibly adapted. A predefined degree of flexibility should always be included in a planned facility that means; in case of a change in demand within this predefined range is reconstruction of the plant not necessary. Second, conversion capability is the ability to react rapidly to an adjustment, such as a significant change in quantity, with a low investment effort to adapt the planned facility. This prefigured reconstruction offers infinite possibilities to expand the planned facility; however, it is also possible to revert back to the original state.[101]

3.5 Computer-assisted factory planning

The need to shorten the planning schedule, the testing of different planning variants, the transformation ability and flexibility of a plant, assurance of the ramp-up phase and the requirement to have a consistent process from product development to production planning, make the use of innovative information technology hardware and software absolutely essential. Moreover, adjustment of the defined layout in the existing building structure is another important factor.[102]

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[99] cf. C.-G. Grundig (2012), p. 33
[100] cf. M. Schenk et al. (2010), p. 7
[101] cf. H.-P. Wiendahl (2009), p. 121 ff.
[102] cf. C.-G. Grundig (2012), p. 32

The areas of opportunity in which to use computer-assisted factory planning include the fields of data collection, processing and presentation. Databases provide the facility to store a large amount of information and offer fast access to this data. Due to databases, optimization techniques and statistics are possible. Moreover, three-dimensional presentations of layout plans and other graphical analysis are feasible. Current software packages have the objective to describe complete plants in a three-dimensional model. This model can be used as a basis for strategic planning or for production planning and monitoring.[103]

Such systems offer an interactive and integrated communication platform and due to that reason these systems are widely used as support tools in team-based factory planning. The basic input data for these systems can be described as follows:[104]

- Technology data (product or processes), such as product portfolio, quantities, bill of materials, work schedules or logistic elements
- Building data (room structure); this data is the foundation of all layout planning and is essential for the adjustment of defined logistic or production facilities in existing buildings

3.5.1 Factory planning tools

The increasing complexity and need to reduce the planning time makes the use of supportive software packages essential. Some important fields for supportive factory planning tools are described on the following pages.

3.5.1.1 Simulation

As described above, simulation can be a useful tool due to the increased complexity. In many cases, planning quality can be increased through a study of the dynamic behavior of a production facility, which is carried out using simulation software. A simulation is a proper tool to make a production process transparent and understandable. During a simulation, all quantifiable dimensions of a system are described and transformed in a simulation model. This model is used to describe the real system and its processes.

[103] cf. G. Pawellek (2008), p. 276 ff.
[104] cf. C.-G. Grundig (2012), p. 32

Various process variants can be simulated and the effect on the planned system can be observed while changing the input factors of the model.[105]

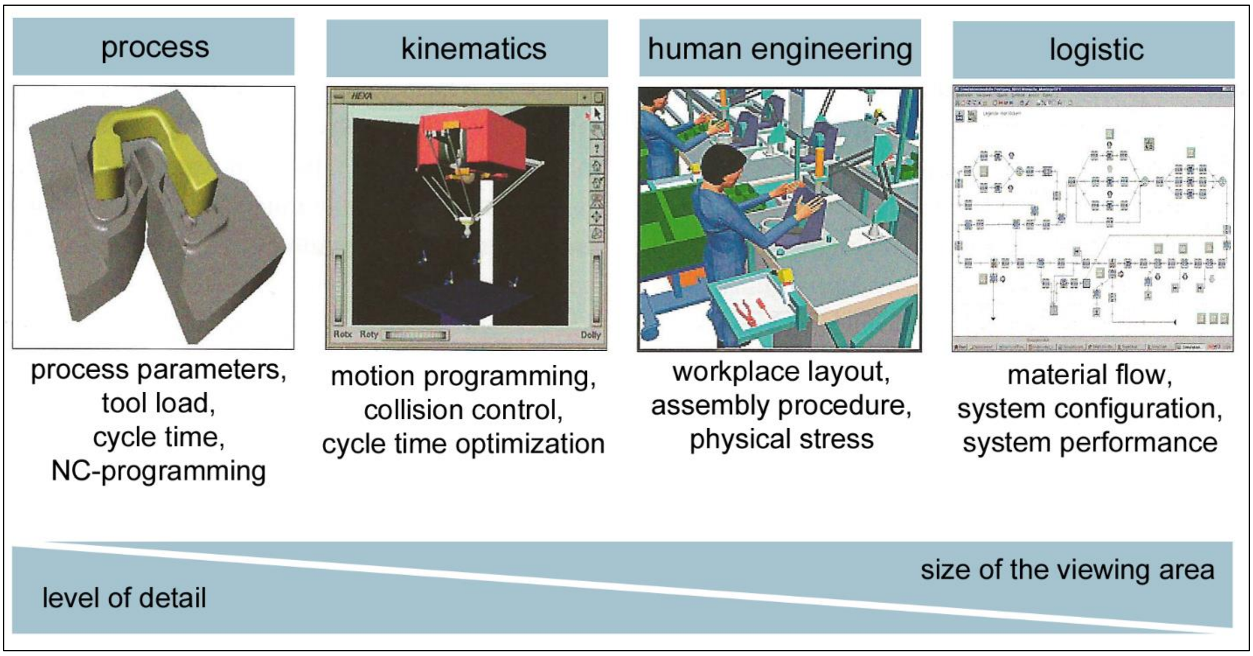

Figure 3-2: Exemplary applications of simulation in the manufacturing[106]

Figure 3-2 shows the main application fields of simulation software in production planning. These applications start at the process level of machinery and go right up to a global logistic concept of the whole plant. Furthermore, there are various tools for building technologies to simulate the air movement, temperature distribution or lighting conditions inside a production facility.[107]

The general process of simulation can be divided into the following steps, as shown in figure 3-3.

During the data collecting step all relevant information is gathered. The correctness of the simulation results has a sizeable impact on the collected data. The model design step describes the creating process from reality or current planning layout to a simulation model on the computer. This model has to be proven in regard to its correctness. The interpretation of the simulation results lead to extensive knowledge of the simulated

[105] cf. G. Pawellek (2008), p. 293
[106] cf. H.-P. Wiendahl (2009), p. 520
[107] cf. H.-P. Wiendahl (2009), p. 520

system. Simulation systems are not automatically optimized systems. The optimization process of the system has to be done by the planner.[108]

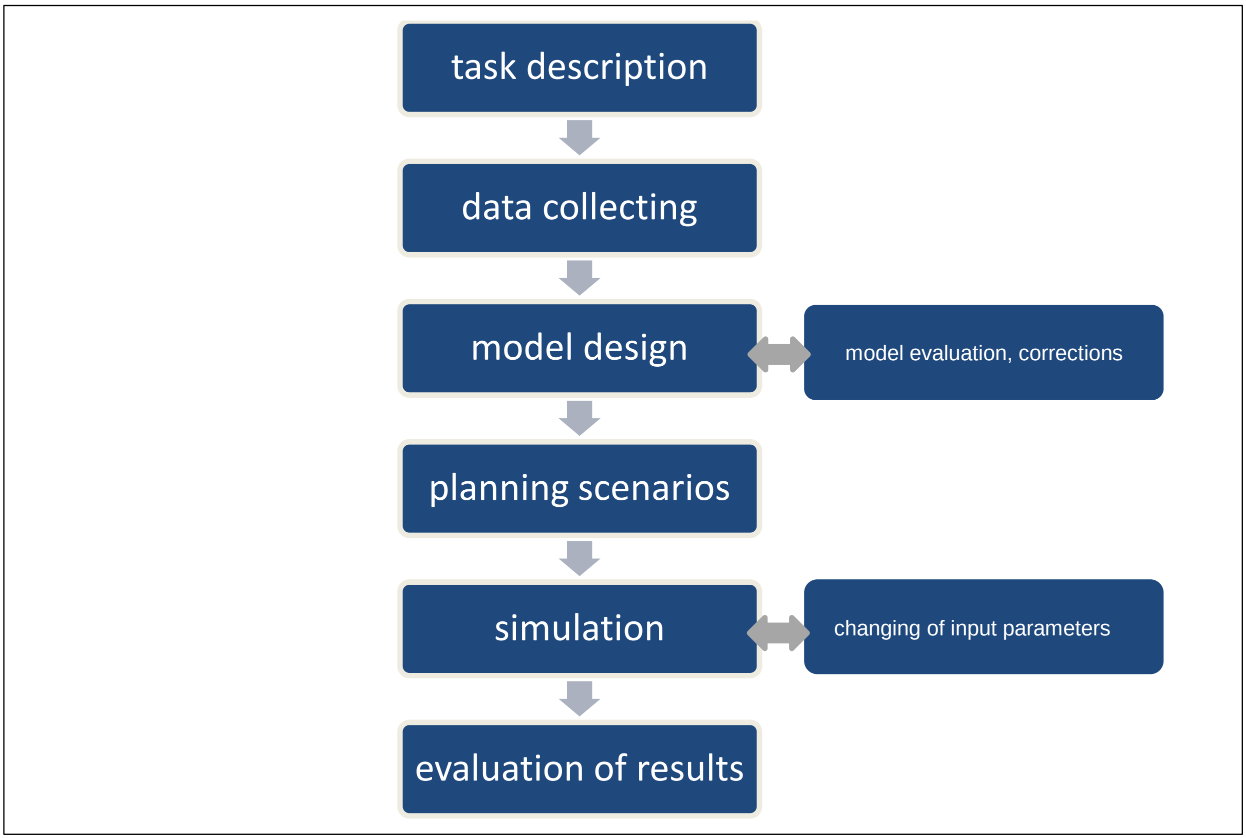

Figure 3-3: Simulation process[109]

During concept planning, the use of simulation is a good method to evaluate different variants. The main goal is to generate operational figures which can be used as objective assessment criteria. These operational figures offer an overview of further productivity and make bottlenecks of the production or transportation system visible. Another advantage of the simulation is that random order structures or quantities can be simulated with the same model. System parameters, such as the speed of the conveyor system or the number of employees, can easily be adjusted and the result can be evaluated within minutes.[110]

Typical results of a simulation can be described as follows:[111]

- Evaluation of plant layouts

[108] cf. G. Pawellek (2008), p. 294
[109] cf. G. Pawellek (2008), p.294
[110] cf. G. Pawellek (2008), p. 299
[111] cf. G. Pawellek (2008), p. 299

- Comparison of manual, semi-automatic or fully automatic assembly or production systems
- Approval of capacity limits for assembly or production lines
- Appraisal and dimensioning of a suitable storage layout
- Determination of an ideal entire process
- Verification of door-to-door time
- Quantification of operational cost
- Observation of cooperation between different work steps and detection of bottlenecks

3.5.1.2 Facility management

The term facility management describes the internal service which has the technical and economic responsibility for all the equipment of a plant. Facility management has four main functions: factory planning, realization, management and controlling. By the use of a computer integrated facility management (CIF) it is possible to collect, present and store all the data in connection with a specific facility.[112]

3.5.1.3 Virtual reality

Virtual reality is a human-machine interface, which provides the opportunity to immerse into a computer-generated, three-dimensional world. As a part of the computer-generated world, it is possible to change positions and viewing angles. Moreover, it is also possible to change the virtual world.[113]

Due to the extensive development of computer hardware and software, most two dimensional computer-aided design (CAD) systems are replaced with three-dimensional systems. Nonetheless, most companies use two-dimensional CAD systems for factory planning. The main reason is the huge amount of additional work required to design a precise, three-dimensional model of the building structure, conveyor system or machinery.[114]

In the context of factory planning, virtual reality offers the possibility to make a virtual walk-through in order to check spatial conditions of the plant building, the future human

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[112] cf. G. Pawellek (2008), p. 306 ff.
[113] cf. VDI (2009), p. 3
[114] cf. G. Pawellek (2008), p. 309

working conditions or the ambient light.[115] Furthermore, an intuitive access to the complex factory planning task is created. In addition, it is also easier to discover different variations and earlier error detection can be implemented, which leads in turn to a significant reduction in planning effort and cost.[116]

The use of modern planning tools, such as virtual reality, gives the planner a variety of potential benefits. The most important are listed below:[117]

- Shortening of planning schedule with the use of computer-aided tools and databases which contain information on the facility and factory models.
- Increase in planning accuracy as a result of the spatial representation of complex systems. Furthermore, a reduction of planning errors is possible.
- Abandonment of time-consuming prototypes and models
- Integration of the people concerned due to collaborative planning principles

3.5.1.4 Digital factory

The term "digital factory" describes a wide network of digital models, methods and tools, such as simulation software or software for three-dimensional visualization, which are integrated in a data management system. The goal is a holistic view of the planning process, evaluation and improvements of all important structures or processes in an existing factory.[118]

This approach is based on an integrated product, process and resource model, which means that the whole production process of a certain product and involved employees are included while the uniform understanding of the production is increased. Modern software packages include every step of the product life cycle starting with product development.[119]

The most common characteristics of a digital factory can be described as follows:[120]

- Strong connection between product development and production engineering
- Early study of critical dimensions and assembly schedule
- Quick communication between construction, prototyping, service and planning

[115] cf. U. Bracht (2011), p. 138
[116] cf. U. Bracht (2011), p. 318
[117] cf. G. Pawellek (2008), p. 310
[118] cf. VDI (2008), p. 3
[119] cf. G. Pawellek (2008), p. 312
[120] cf. G. Pawellek (2008), p. 313

- Support for factory planning and shortening of the time frame, such as structure or layout planning
- Transfer of data required for the production processes, such as assembly instructions or program codes for machine tools or robots

In practice, factory planning is frequently used as a part of the digital factory. The aim of these digitally planned layouts is to identify the most efficient material flow, which leads to low material handling cost. In addition, a comprehensive planning of factory layout provides the possibility to attain higher production efficiency and a shorter production ramp-up period (time-to-volume). Moreover, problems can be visualized at an early stage.[121]

3.6 Further perspectives and current trends of factory planning

Terms, such as digital factory, show the direction to a complete computer assisted production process which is for sure a major trend in the future.[122]

Additionally, the synonym lean production should also be mentioned. Lean production is a procedure that tries to avoid waste of various types, such as overproduction, long door-to-door times or faulty products, in order to make a company more effective and competitive. This production procedure originates from the Toyota production system in the 1950s and became quite popular in industrialized countries from the 1980s. Lean production is characterized by its lean operations, such as low inventories, error prevention due to quality management, small production runs, just-in-time production, employee commitment and close cooperation with suppliers.[123]

Furthermore, there is a tendency for virtual products or prototypes, which is also known as digital mock-up (DMU). These digital mock-ups are used to detect errors at an early stage of the product development process and to reduce the need to build physical prototypes. The automobile industry for example uses digital mock-ups to verify the harmony of entire vehicles or to detect dynamic and static collisions.[124]

[121] cf. P. Hehenberger (2011), p. 191
[122] cf. G. Pawellek (2008), p. 335
[123] cf. P. Hehenberger (2011),p 192 ff.
[124] cf. P. Hehenberger (2011), p. 193

4 Investment appraisal

The following section describes the principal methods of static and dynamic investment analysis. The main goal of these methods is to evaluate the benefits of an investment project.

An investment is typically defined by the following three factors:[125]

- Use of funds
- Actions for targeted use of assets
- Transformation of available funds in other types of assets and liabilities

A characteristic example of an investment is the acquisition and use of a machine to produce goods. During the acquisition phase, the company spends money on the initial investment, which is paid at a future date. During the useful life of the new machine, a company earns income and pays outgoings in connection with selling and producing goods. The use of the machine needs inputs of certain production factors such as employees, raw materials or other means of production. These production factors lead to payments and the income results by selling goods.[126]

An investment can have an absolute return, a relative return or a negative return. A venture is absolute profitable when it is a stand-alone project and has a positive feedback on the company's targets. When more than one project are compared with each other and one of them has the biggest and most positive impact on the company's targets, the chosen investment is deemed to be relatively profitable.[127]

Investments can be separated into real investments, such as machines, buildings or cars, and financial investments, such as shares or bonds. Due to the fact that a new production facility is a real investment, this section focuses only on this type of investment.

[125] cf. A. Greyer et al. (2009), p. 75
[126] cf. A. Greyer (2009), p. 75 ff.
[127] cf. A. Greyer (2009), p. 76

4.1 Static investment appraisal methods

The difference between dynamic and static investment appraisal methods is that the static methods are not payment-related. Payment-related implies that the method is based on average values from cost accounting. This means that each payment or income is not related to a certain time. In addition, static methods do not take the impact of interest into account. Due to this fact, a financial mathematical consideration is not possible.[128]

Static capital budgeting methods are not used in practice. These methods are only used for comparing different variants theoretically with each other.[129]

For these reasons, this thesis is focusing on dynamic investment appraisal methods.

4.2 Dynamic investment appraisal methods

The characteristic of the dynamic investment method in comparison to the static method is that all payments or incomes are related to a certain time and that these payments are assessed with an adequate interest rate. This means that the dynamic methods describe the reality of an investment.[130]

Dynamic methods rely on financial mathematical considerations and require an adequate target rate. This adequate target rate has major importance in the evaluation of a profitable investment, which is shown later in more detail in this section.[131]

The main disadvantage of dynamic investment appraisal methods is the general rate of interest, because in reality different activities have different rates of interest, for instance, equity has a different rate to committed assets and within this group, many different interest rates exist due to the various grace periods, collaterals or creditor bases.[132]

In order to describe the complex reality in a model of a functional dynamic investment appraisal, it is important to state six assumptions. These statements are used within all methods which are described in the following section:[133]

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[128] cf. A. Greyer (2009), p. 79 ff.
[129] cf. B. Heesen (2012), p. 6
[130] cf. K. Poggensee (2011), p. 108
[131] cf. A. Greyer (2009), p. 84
[132] cf. K. Poggensee (2011), p. 108
[133] cf. K. Poggensee (2011), p. 110 ff.

1. All calculation elements are known with certainty. However, many input values are assumptions and that is why the investment appraisal reflects an unsubstantiated objectivity.
2. All calculation elements of one year are paid at the end of the year. In other words, this assumption postpones all continuously accumulating payments and receipts within one year at the end of this period. The beneficial of this supposition is a faster calculation with one general interest rate.
3. Payments can be transferred over time. Based on this statement an investment appraisal completely ignores the liquidity planning of a company.
4. Only one rate of interest is used. This assumption is important for evaluating the investment project itself and not the funding opportunities.
5. All calculation elements are payments. Only monetary factors are taken into account, other influencing factors, such as environmental issues, are not considered within an investment appraisal.
6. Dynamic investment appraisal methods provide only meaningful results with the assumption of profit maximization.

4.2.1 Net present value method

The net present value is the sum of the present values which are connected to an investment project. In other words, a present value is the amount of money that a discounted future payment has if it existed today.[134]

For example, € 100 in one year is less than € 100 today and the difference has to be calculated with a discount. This discounted value, the present value, is described in equation 4-1. The interest rate used is calculated in years.[135]

$$present\ value = \frac{value}{(1 + interest\ rate)^{time\ span}}$$

Equation 4-1: Present value calculation[136]

[134] cf. U. Ermschel et al. (2013), p. 50
[135] cf. E. Depner (2012), p. 73 ff.
[136] cf. E. Depner (2012), p. 74

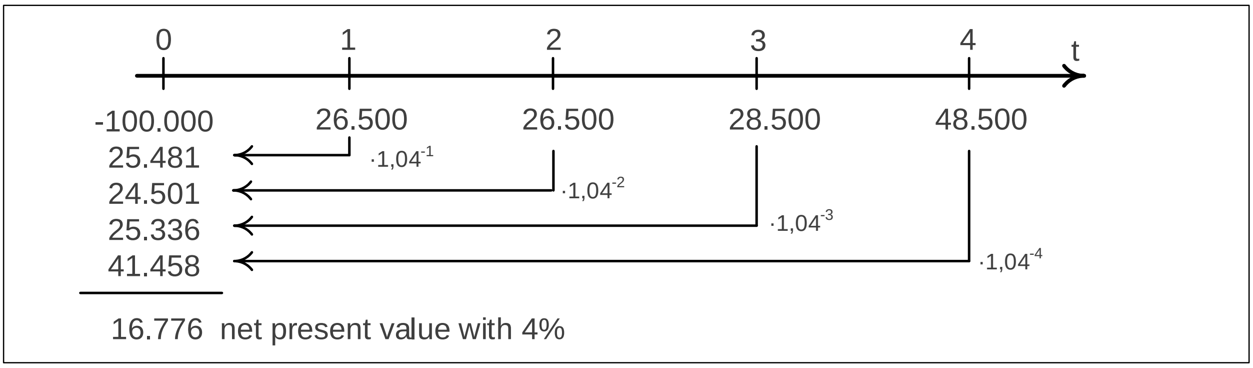

Figure 4-1: Calculation scheme of net present value[137]

Figure 4-1 shows the principle of the net present value method. In this example an adequate target rate of interest of 4% is used. The net present value is positive which means that the realization of the project creates a positive effect for the company's value. Furthermore, the net present value is the present value of the additional earnings which are generated through the realized project. The net present value is also an indicator for the maximum possible withdrawals during the time span of an investment, by which the company's asset is not less than an assessment in the financial markets. Overall, an investment with a positive net present value has a positive effect on the company's targets. If a decision between two projects is needed, it is always beneficial to choose the project with the higher net present value.[138]

To maximize the amount of net present value the amount of payments has to be increased, the payments have to be timed sooner and the adequate rate of interest has to be decreased.[139]

In literature concerning this field, the net present value method is the most popular and widely accepted method of dynamic investment appraisal. Furthermore, it is a qualified method in regard to the calculation of effort, the determination and gathering of relevant data, and overall model assumptions. The calculation effort is because of the easy-to-use operations very low. In contrast, the determining and gathering of relevant data is difficult. This is because the net present value method needs several assumptions for data input, such as initial net investment, the amount of future payments, useful economic life, liquidation proceeds at the end of the useful economic life and the adequate target rate of interest. The model of the net present value focuses on different periods which brings it closer to reality than a static investment appraisal method.[140]

[137] cf. A. Greyer (2009), p. 89
[138] cf. A. Greyer (2009), p. 85 ff.
[139] cf. P. Carstensen (2008), p. 35
[140] cf. U. Götze (2008), p. 80 ff.

Furthermore, variable interest rate structures can also be used. In the case of a non-constant adequate target rate of interest, a spot rate must be used for each present value in the calculation, which corresponds to the target rate at a certain point in time. The net present value can be interpreted as mentioned before.[141]

Generally, risk should be included in every investment appraisal. Additionally, this is done within the net present value method. There are two different approaches to include project risk in this method. In the first scenario, a security equivalent to the risk of an investment and discounting with a risk free interest rate is used. The second scenario, uses the expectation value and discounting with a risk-adjusted interest rate.[142]

4.2.2 Annuity method

The annuity method is an extension of the net present value method. It has its main difference in the useful economic life of an investment. The annuity method offers the possibility to distinguish between the time span of a project and the useful life of the asset. In addition, it is possible to determine the maximal amount of constant payment at any point during operation in such a way that the net present value has a non-negative outcome. An annuity is equated to a transformation of irregular and unstructured sequence of numbers in a sequence of numbers with equal amounts. This amount can be defined as the financial mathematical mean of the net present value, which is achieved each year and is calculated as shown in equation 4-2. This method relies on the net present value method, and due to this fact a positive equivalent annual cost leads to an absolute beneficial investment.[143]

$$annuity = present\ value \cdot \frac{(adequate\ target\ rate - 1) \cdot adequate\ target\ rate^{time\ span}}{adequate\ target\ rate^{time\ span} - 1}$$

Equation 4-2: Calculation of annuity[144]

[141] cf. A. Greyer (2009), p. 125
[142] cf. A. Greyer (2009),p. 119 ff.
[143] cf. A. Greyer (2009), p. 94 ff.
[144] cf. A. Greyer (2009), p. 94

The qualification of this method is similar to the net present method. The assumptions of the model are the same and the calculation effort is only slightly higher. In many cases it is possible to set the calculation of the equivalent annual cost aside, because the net present method delivers the same results. It is important to use this method within a never-ending investment chain to calculate the net present value.[145]

In addition, the annuity method is used in the case of assessing identical reinvestments, to verify if a single investment is beneficial or not. The useful economic life of each single project is used to calculate the required annuities, although payments of the project are received after this period.[146]

4.2.3 Dynamic payback period calculation

Like the methods that were mentioned before, the dynamic payback calculation determines the absolute beneficial of an investment with the help of one criterion; the payback period.[147]

This method is often used in practice. It determines the time span within an investment that has been amortized; the payback period. When this payback period (t^*) is reached, the discounted net cash flow achieved has exactly the same amount as the initial net investment, as seen in equation 4-3.[148]

$$present\ value = -investment + \sum_{t=1}^{t^*} cash\ flow_t \cdot interest\ rate^{-t} = 0$$

Equation 4-3: Calculation of dynamic payback period[149]

An investment project is absolute profitable if the payback period is shorter than the defined maximum permissible value. An investment project is relatively profitable if the payback period is shorter than comparable projects. The dynamic payback period can be

145 cf. U. Götze (2008), p. 96
146 cf. A. Greyer (2009), p. 99
147 cf. K. Poggensee (2011), p. 108
148 cf. U. Ermschel (2013), p. 70
149 cf. U. Ermschel (2013), p. 70

determined by step-wise calculation of the cumulated present value of each period. This cumulated present value equates to the net present value of a certain useful period. While this value is negative, the payback period is not finished. In contrast, a positive value means that the payback period is reached.[150]

A dynamic payback period, which is lower than the predefined maximum permission value, means:[151]

- A complete recovery of net investment
- Interest on all open amounts with the defined rate of interests is paid
- Profit of an unspecified amount is earned

The dynamic payback calculation takes only payments into account until the payback period of an investment is reached. In contrast, the net present value method considers all payments even though the payback period has been reached. This is a big disadvantage of the payback calculation method because possible losses of assets can go undetected. This leads the author of "Grundlagen der Finanzierung"[152] to reject this method and to prefer the net present value calculation instead.[153]

For this reason, the dynamic payback calculation should only be used as an additional method.[154]

4.2.4 Internal rate of return method

The internal rate of return also refers to the net present value and is based on the same model. In comparison, though, this method includes the investment of freed-up resources and the equation of tied-up capital and useful economic life. It focuses on the internal rate of return. While evaluating the profitability of an investment project, a comparison is made between the rate of interest and the financial costs, which is represented by the internal rate of return.[155]

The internal rate of return describes the interest rate in which the net present value is zero. This means that an investment has reached break even.[156]

[150] cf. U. Götze (2008), p. 108
[151] cf. K. Poggensee (2011), p. 167
[152] cf. A. Greyer (2009)
[153] cf. A. Greyer (2009), p. 102
[154] cf. U. Götze (2008), p. 110
[155] cf. U. Götze (2008), p. 96 ff.
[156] cf. P. Carstensen (2008), p. 72

In other words, the internal rate of return is the effective interest rate of the tied-up capital of an investment. The return of an investment states the percentage rate of the assets which can be taken from the invested capital at the end of each period without endangering the amortization of the project. This definition gives the possibility to formulate decision rules. An investment is profitable when the internal rate of return is higher than an effective rate of interest which is used for calculating alternative estimated future cash receipts and payments over the expected life of the financial instruments. The internal rate of return can also be interpreted as the critical rate of interests which marks the boundary between an profitable and an unprofitable investment. Nevertheless, the internal rate of return method has some drawbacks. The main drawback is the precondition that the reinvestment of available capital with a defined and calculated interest rate is possible. This precondition does not match with the real fluctuating financial market.[157]

4.3 Economic value added (EVA)

Economic value added, short for EVA or in German “Geschäftsbeiwert (GWB)”, is used for the evaluation of companies or business units. This concept was developed by the well-known consulting company Stern Stewart & Co and is very frequently used by the German companies Metro, Telkom and in particular Siemens. Siemens employs this method to assess the performance of its business units. The EVA method fosters the integrated view at the operative level of financial and investment actions. Simultaneously, the calculated figures can be used as an incentive system for certain business units. The economic value added is a figure which is primary focused on the concerns of the financier and not on the risk-averse outside creditor. This approach includes a performance measure of the business activities, financing and investments.[158]

Many management decisions in regard to budgeting, investments and acquisitions are based on this concept. The economic value added method establishes a uniform base for budgeting decisions and quantifies the performance of a business unit. In addition, it

[157] cf. A. Greyer (2009), p. 108 ff.
[158] cf. B. Zirkler (2002)

gives the possibility to detect the added-value potential of strategic actions and includes the project risks.[159]

$$EVA = NOPAT - (GK \cdot WACC)$$

Equation 4-4: Calculation of economic value added[160]

As shown in equation 4-4 the EVA is the difference between the net operating profit after tax and capital costs per period.

- NOPAT: The net operating profit after tax contains all earnings before interest and tax multiplied by the tax rate.[161]
- GK: Business Assets is an addition of net working capital and noncurrent assets. The net working capital includes cash, accounts receivables, inventories and other current assets, but accounts payables and other current liabilities have to be excluded. The non-current assets include intangible assets, tangible assets and other assets which are held longer than one year within the business unit.[162]
- WACC: Weighted average cost of capital can be seen as a return expectation of a unit. The WACC is the sum of the equity ratio multiplied by the cost of equity and debt ratio multiplied by the cost of debt. The WACC can include a possible project risk of a specific business unit.[163]

4.4 Compound annual growth rate (CAGR)

The compound annual growth rate is an important factor within investment appraisal. It shows the average percentage return per period after receivables, such as interest on investments or dividends to equity investors, and original investment expenditures before tax. As shown in equation 4-5 below.[164]

[159] cf. C. Schawel and F. Billing (2012), p. 86 ff.
[160] cf. C. Schawel (2012), p. 87
[161] cf. C. Schawel (2012), p. 87
[162] cf. C. Schawel (2012), p. 87
[163] cf. B. Zirkler (2002)
[164] cf. B. Heesen (2012), p. 92 ff.

$$CAGR_{\%} = \left(\sqrt[time\ span]{1 + \frac{net\ present\ value}{investment}} - 1 \right) \cdot 100$$

Equation 4-5: Calculation of compound annual growth rate[165]

An investment which has a life span of 5 years is financially rewarding when the CAGR has a value of around 10% and the dynamic payback period is reached after the half of the life span. Furthermore, if the CAGR has a value of around 12%, the payback time can be reached after around 60% of the life span. The dynamic payback calculation cannot always deliver clearly determined values for a profitable or unprofitable investment, which is why the CAGR is an even more important factor during the investment appraisal.[166]

[165] cf. B. Heesen (2012), p. 92
[166] cf. B. Heesen (2012), p. 217 ff.

5 Target planning of a production line for axle boxes

The target planning and the task, as described in section 3.2.1 and 3.2.2, are the first steps in the factory planning procedure and can be combined. The following section gives an analysis of the initial situation, a clarification of the production program, a specification of the working direction, a process analysis and a first outline schedule for the production ramp-up.

The evaluation of the initial situation, the recognition of the problem and the definition of the suitable target concept, are the most important management tasks within this planning phase. However generally the possible target is set by the marketing department, accounting department or plant management, but has to be evaluated from the perspective of an entrepreneur and an optimal combination of the operational equipment has to be defined. Moreover, the specification of the production portfolio has a major influence on the planned assets and structures. It is important to analyze the long-term sales planning on the basis of evaluation of market developments and the production policy of the company.[167]

5.1 Task definition

The plant management of the factory location Graz Eggenbergerstraße wishes to clarify the technical and commercial possibility of insourcing axle boxes. A new production line has to be planned which will be used specifically to produce axle boxes out of raw castings. In addition, a specification of the required machinery is needed and possible suppliers must be chosen.

The corporate buildings - object 470, as described under 5.5 - can be used for the new production facility.

Furthermore, a workshop floor plan has to be created and the different raw material and products have to be analyzed.

[167] cf. B. Aggteleky (1981), p. 233

Finally, a step-wise implementation and recommended investment plan has to be prepared, which will form the basis for a further execution plan.

5.2 Target definition

Entrepreneurial objectives consisted of various short-term, medium-term or long-term components. These components can be summed up in a harmonized target system, which includes the entrepreneurial master plan and corporate culture.[168]

The planning objectives of factory planning include long-term or medium-term targets. These gradations are done in practical use based on different expansion stages. The first expansion step is the medium-term objective and further expansion steps or development potentialities can be viewed as long-term goals. The target definition should cover the complete operational life of the production facility.[169]

The further planning steps are done based on the medium-term objectives. The long-term objects are the expansion possibilities or reorganization of the production facility.

Medium-term objectives

- Construction of a new production facility specifically for axle boxes to increase the added-value depth in the bogie production. This new production line should cope with an annual production of 8500 pieces.
- Decrease in production cost
- Shortening of door-to-door time for axle boxes
- Lose dependency on certain suppliers
- Simplification of logistics and reduction of inventory cost
- Establishment of “one-roof” concept for the production of wheel sets
- To ensure the future competitiveness, state-of-the-art technologies should be used; the level of automation should be adjusted to the max possible capacity
- Increase of supply stability
- Increase of process reliability and product quality

[168] cf. B. Aggteleky (1981), p. 149
[169] cf. B. Aggteleky (1981), p. 266

Long-term objectives

- Increase the potential for innovation; development, production and quality control are located on the same site
- Decrease the number of different raw castings; currently each bogie has four axle boxes; two for the right side and two for the left side. The future situation could be one raw casting for both sides and the differences between the right side and left side are given during the machining process.
- Due to the know-how gained in the production of axle boxes, further improvement of the existing production procedures are possible
- The utilization ratio and the added-value depth is further increased due to the production of other casted housings

5.3 Situation analysis

Each situation analysis consists of three steps which are described in the following paragraph. These steps can be summed up as follows.[170]

1st step: Gathering of current situation

As described in section 1.1, the Siemens plant located in Graz Eggenbergerstraße is the world competence center for manufacturing and development of bogies. The bogies are mainly used within the Siemens railway systems for locomotives, passenger coaches, metros or high-speed trains. The planned production line should only be suitable for axle boxes for those bogies. The axle box is the only connection between the wheel set and the frame of the bogie. In the event of a failure of the axle box, the train will lose the track and will inevitably derail, that is why axle boxes have to fulfil different safety standards. The main function of an axle box is to transfer half of the wheel set load. Furthermore, additional functions are the bearing of the axle and as a holder of attachment parts such as temperature sensors or dampers. Each bogie has four axle boxes. The planned production line should be able to cope with the total production output within one year. Axle boxes are casting parts which are made from two different materials, as seen in table 5-1.

[170] cf. B. Aggteleky (1981), p. 235

	%OF TOTAL PRODUCTION 2013-2018	AMOUNT OF PRODUCTS
Aluminum silicium alloy AC-AlSi7Mg0,3-S-T6	**5,1%**	**2**
Spheroidal graphite cast iron EN-GJS-400-18-LT	**94,9%**	**15**

Table 5-1: Overview of different raw materials[171]

Due to the fact that a foundry is not a part of the Siemens plant in Graz and because of environmental restrictions imposed by the Graz city authorities, the basis for further research is the procurement of raw castings.

Various companies currently supply the plant with axle boxes as a ready-for-assembly part. However, some axle boxes are developed in-house and some are designed externally, as shown in figure 5-1.

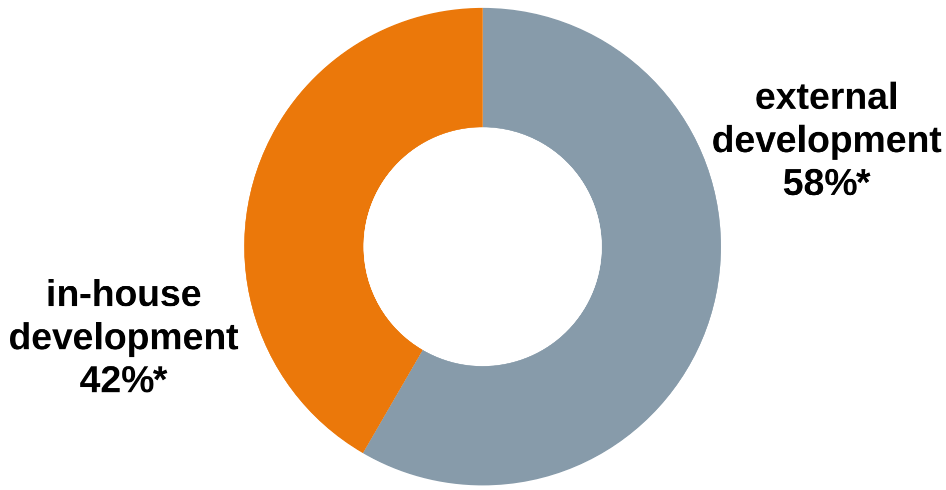

Figure 5-1: External or internal development (* in percentage of total production 2013-2016)[172]

Currently there are four different suppliers. A reference company is a supplier in Slovenia. This company is specialist in the production of axle boxes. In addition to the machining, checking and painting production steps, the company also runs a foundry. The company regards itself as the market leader in the production of axle boxes and brake disks.

[171] based on Siemens plant internal production planning
[172] based on Siemens plant internal production planning

2nd step: Review

Since 2011, a new factory building for wheel set assembly (RASMO) has been added to the Siemens plant in Graz. This new production facility has a huge impact on the availability of certain assembly parts and shortens the door-to-door time. The axle box production can be included in this new facility. With the introduction of the in-house production of axle boxes, a further reduction of the door-to-door time and a further increase of the availability of certain parts is guaranteed.

In the past, the in-house development of axle boxes was not common within the development process of new bogies at the Siemens plant in Graz.

3rd step: Outlook

Due to an in-house production of axle boxes, a shortening of the order-to-assembly time is possible. The strategic procurement department at Siemens appraises an order-to-assembly time for the finished product of 16 weeks and the raw material has a period stipulated for delivery of four weeks. Including the door-to-door time of a planned axle box production, which is estimated with one week, a shortening of the whole buying process of 11 weeks is possible. This gap between the existing situation and a possible outlook offers various possibilities and benefits in terms of product development and material availability. Moreover, the fixed capital costs are reduced.[173]

In addition, an in-house production can increase the share of in-house developed axle boxes. This fact will provide two development opportunities. First, a production and development at the same site will increase the product innovation potential. It is easier to design cheaper to manufacture products, if the production department is involved in the development process, as mentioned in section 2.2. Second, the dependence on certain suppliers will decrease. If the development of an axle box is outsourced, it is very hard to change the supplier at a later stage in the production, as mentioned in section 2.2.2.

Another influencing factor is the reduction of inventory cost. Raw material can be stored in boxes and does not have to be handled with special care in comparison with finished parts.

The production of axle boxes also fits in the planning perspective of the “one-roof” concept for the production of wheel sets. The “one-roof” concept means that every major part which is needed for the production of wheel sets, is produced in the same factory

[173] Diviak Thomas, 26.08.2013, IC RL SCM SPR AT

building. After RASMO was introduced, immense efforts have been made to insource various assembly parts of a wheel set. Axle boxes are a part of this concept.

5.4 Production program

The maximum capacity of the new production line is stated as 8500 axle boxes per year. Production of these 8500 pieces shall run in a three-shift model, which at Siemens, means 5280 working hours per year, excluding vacation and holidays.[174]

The production program must consider the amount of products to be produced in the next three to five years at the planned site.[175]

Based on the production planning and schedule of Siemens Graz, the stated capacity of 8500 pieces per year can be utilized with the forecasted projects, as shown in the following figure 5-2.

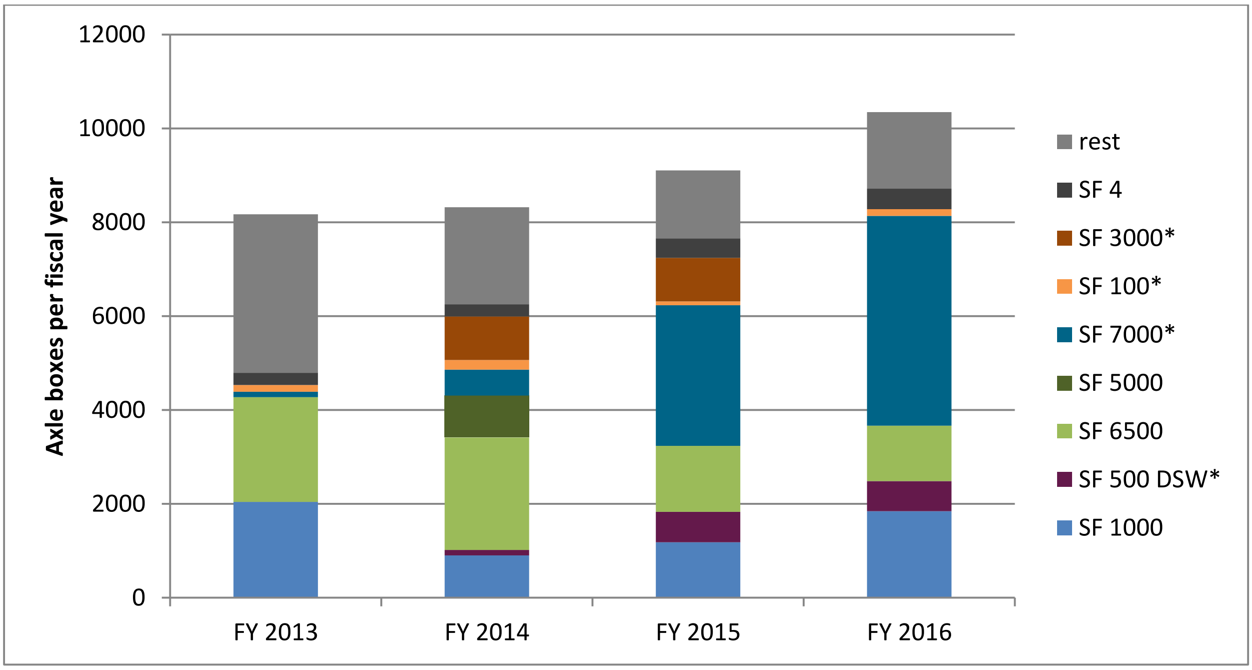

Figure 5-2: Production program in fiscal years (* in-house development)[176]

[174] Siemens plant management, IC RL LOC BG MF-GRZ
[175] cf. H.-P. Wiendahl (2009), p. 451
[176] based on Siemens plant internal production planning

These products can be broken down by group with the percentages of total production from 2013 to 2018 based on the type of the axle box, as shown in figure 5-3.

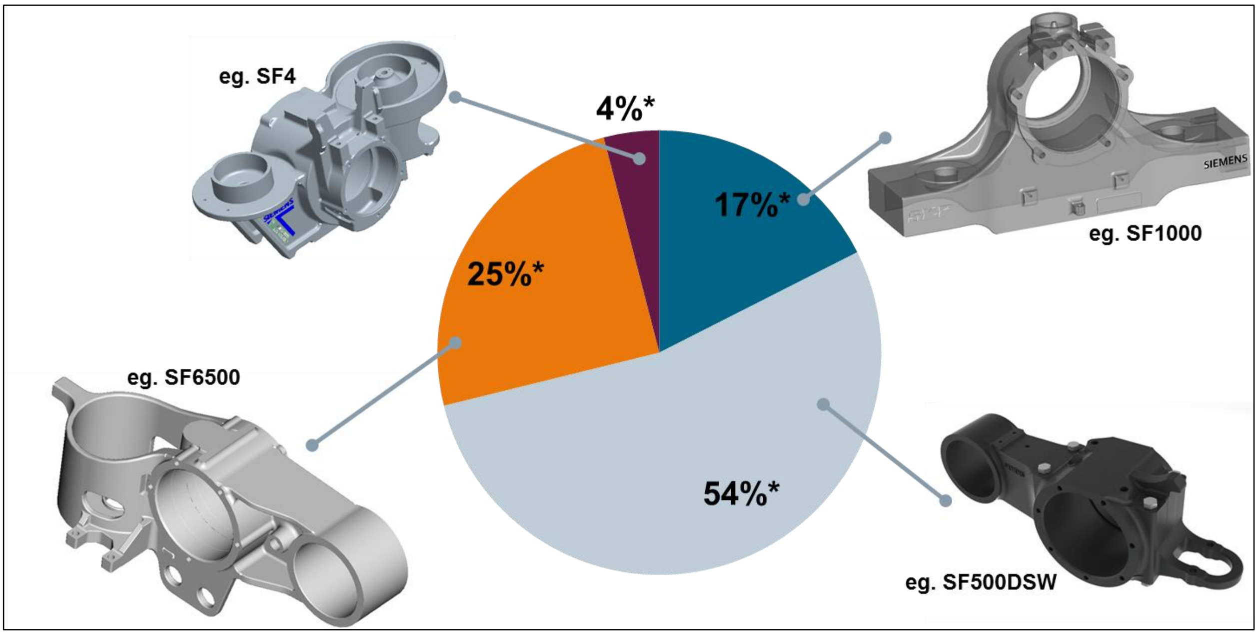

Figure 5-3: Products spilt up in dimensions (* in percentage of total production 2013-2018)

To sum up, in the next few years a total production of 8500 axle boxes per year is probable. The portfolio currently includes 17 different products which can be grouped into four product categories as shown in figure 5-3. These 17 products are made from two different raw materials as shown in table 5-1.

Overall, table 5-2 gives an overview of the maximum and minimum object dimensions of the axle boxes, including the maximum and minimum weight, of the current portfolio at the Siemens plant in Graz.

	LENGTH	WIDTH	HEIGHT	WEIGHT
MAXIMUM	972 mm	505 mm	418 mm	135 kg
MINIMUM	350 mm	250 mm	165 mm	26 kg
AVERAGE	867 mm	373 mm	315 mm	88 kg

Table 5-2: Overview of maximum, minimum and average part dimensions based on the current axle box portfolio at the Siemens plant in Graz

5.5 Operational structure

The Siemens plant in Graz Eggenbergerstraße is an old factory location which has existed since 1854. For that reason, the buildings are not perfectly arranged for a continuous material flow, and free space is limited. The plant is located near the center of Graz which is why an extension of the factory location is not possible. New production lines can only replace existing ones. Figure 5-4 shows the current layout of the entire factory location. The management has chosen object 470 as the target area for further research. This object is a hall with dimensions of 45m length and 18m width and with a height of 9.5m. The foundations are designed to cope with a load of 8t/m². As this object is currently used for assembly work, all necessary safety regulation requirements are fulfilled. There are two overhead cranes installed which can carry a load of 12.5t and 8t respectively. Both cranes are currently in operational use. In addition, as seen in figure 5-5, there is a walkway in the middle of the hall that is used to reach an office area which is located at the opposite side of the entrance door. The whole production hall is built with a basement which is not currently in use. In addition, basic connections to both electricity and natural gas exist.

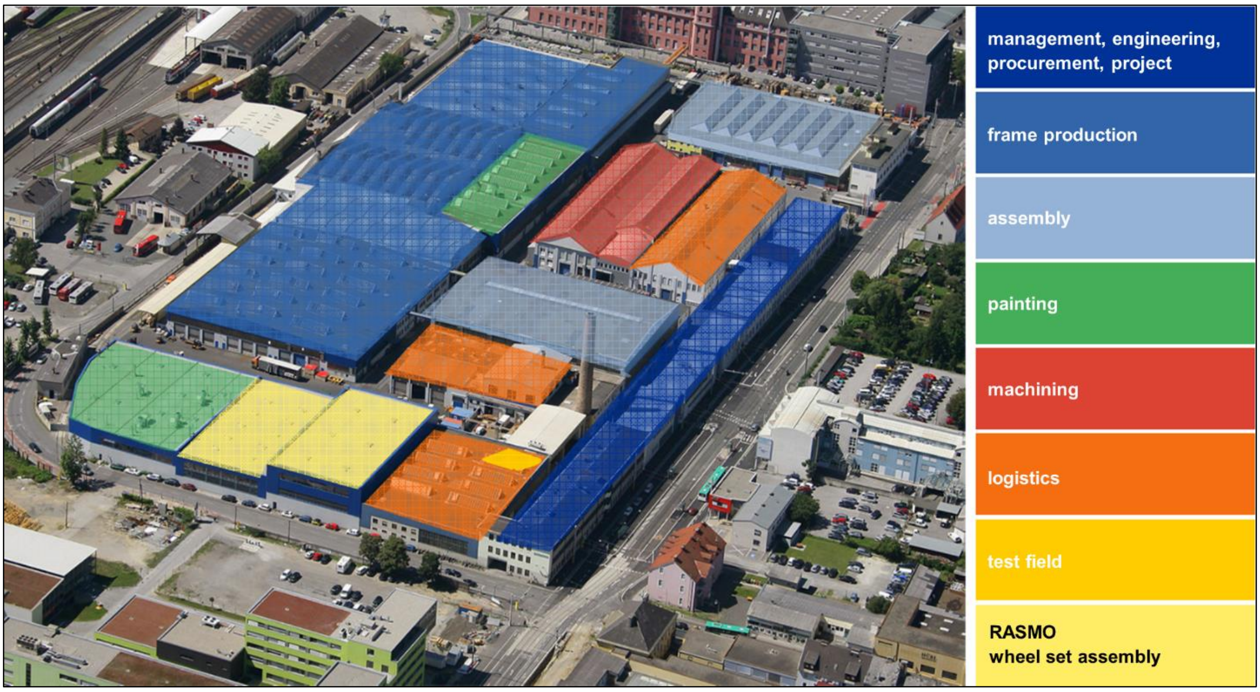

Figure 5-4: Factory location of Siemens Graz[177]

[177] cf. Siemens (2013a)

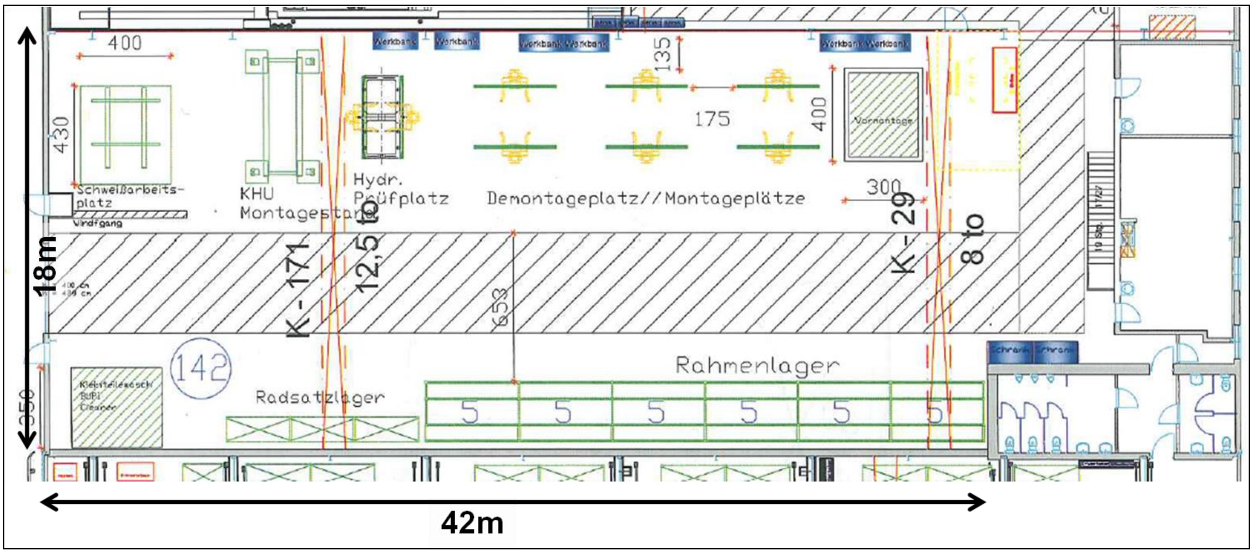

Figure 5-5: Chosen corporate building, object 470

5.6 Process analysis

The aim of the process analysis is the description of the business processes, material flow, communication and value streams. The value stream diagrams are a simple graphical representation which is easy to understand and enables possible weaknesses to be seen.[178]

Figure 5-6 shows the initial value stream in terms of an axle box production. As described above, more than half of axle boxes are developed externally. When the development is finished the drawings are given to the foundry. The foundry builds molds and then produces the raw castings. The raw castings undergo a sandblasting treatment to remove the casting sand and other dirt. The next production steps are machining, checking and painting. In most cases this procedure is not done at the same factory site as the casting. Finally, the finished parts are delivered to the Siemens plant in Graz and mounted in the wheel sets assembly facility. The various departments at Siemens have to invest some effort to ensure the quality of the axle boxes and the predefined scope of supplies and service. As seen in figure 5-6, the average door-to-door time for the whole production is 16 weeks.

[178] cf. H.-P. Wiendahl (2009), p. 454 ff.

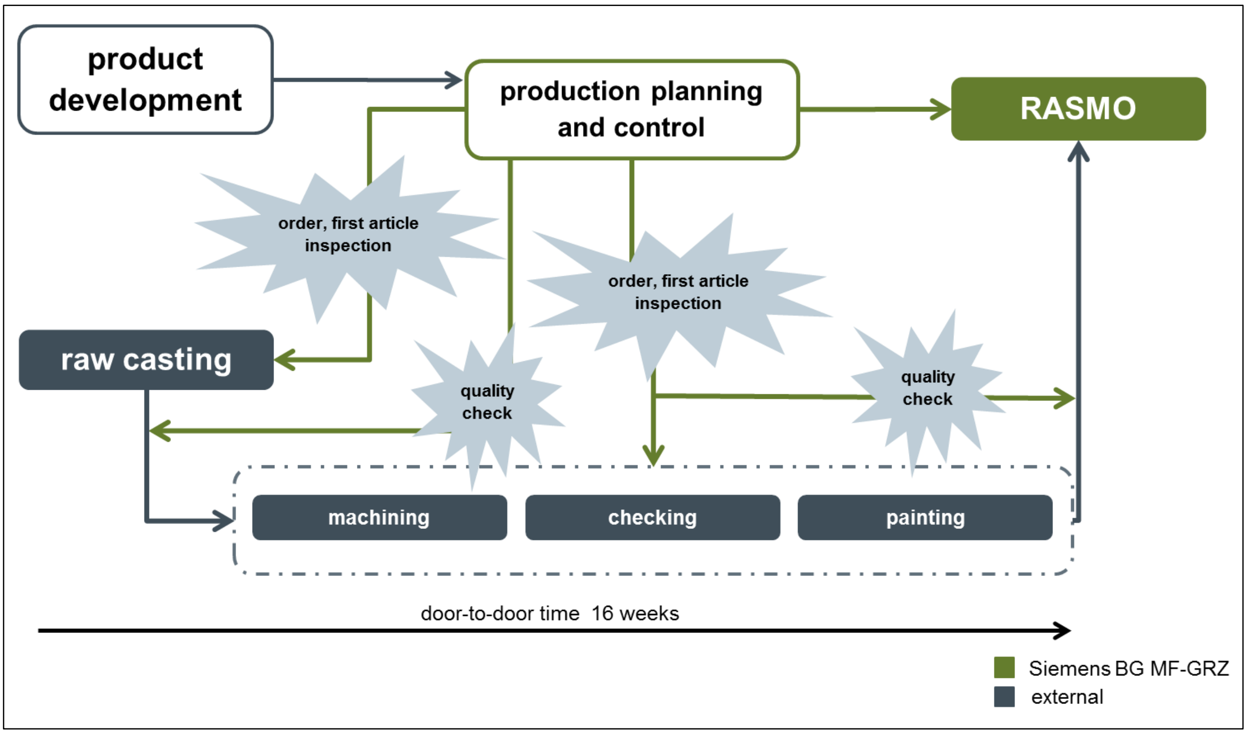

Figure 5-6: Rough value stream analysis - initial situation

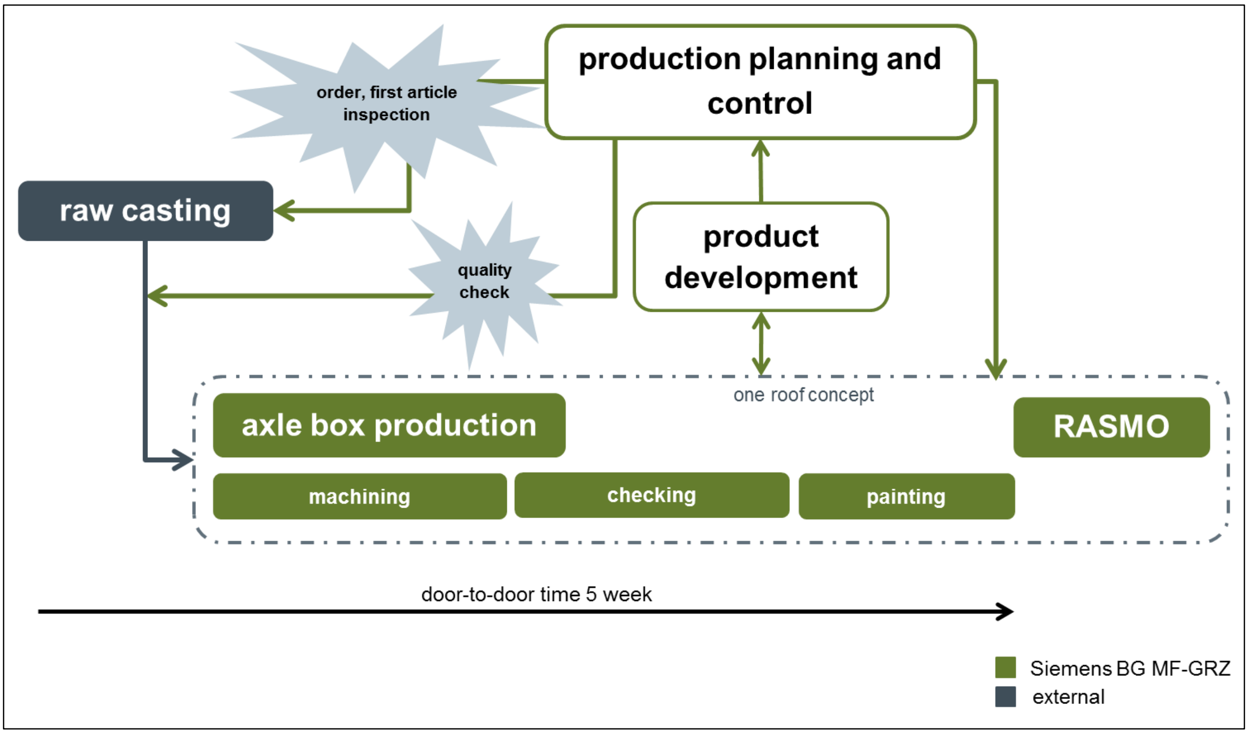

Figure 5-7: Rough value stream analysis - target situation

Figure 5-7 shows the target situation of an in-house axle box production. The product development is done internally. For this reason, the development of new products is carried out in teams from the engineering department and production engineering to ensure product designs in such a way that they are easier to manufacture and thus lead to a more cost efficient manufacturing. Moreover, the door-to-door time can be reduced to one week. In addition, the production of axle boxes is located at the same site as the wheel set assembly, the so-called “one-roof” concept.

5.7 Outline schedule - production ramp-up

Figure 5-8, provides an overview of the outline schedule for the planned factory. The concept-planning phase will be finished in mid-October and the point-of-no-return decision will be made in November. The implementation-planning phase will then follow. At 2014 year-end, most of the machinery will have been delivered and a pilot series will be produced. Estimated production in the year 2015 is for 3000 axle boxes and 6000 axle boxes in 2016. At the beginning of 2017, the new production line should run at its standard capacity of 8500 axle boxes per year.

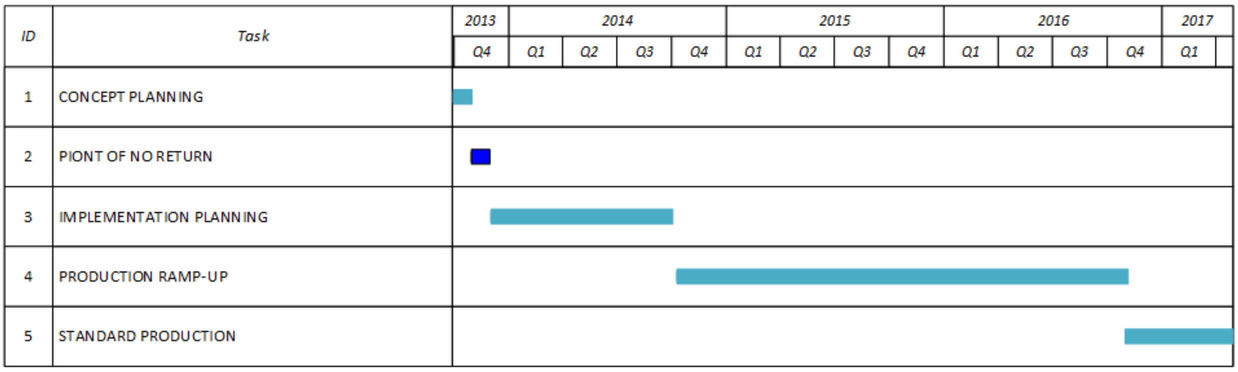

Figure 5-8: Ramp-up plan of an axle box production

6 Concept planning of a production line for axle boxes

All the data that is collected in the previous step is used within the concept planning stage. As mentioned in section 3.2.3, the aim of this stage is to take the information of the target planning and to adjust this to fit in the real structure. This is done within a feasibility study, which is the core element of the factory planning process.

A feasibility study includes a system and structure planning, a global planning as well as an investment appraisal. The structure planning mainly deals with a detail analysis of the manufacturing steps required. Furthermore, the global planning concentrates on a material flow analysis supported by simulation software and layout planning. Finally, an investment appraisal is created, which will include the information collected for each variant and all alternatives are then studied from a commercial perspective.

6.1 System and structure planning

On the basis of the production portfolio, the framework for the definition of operational function determines all necessary production steps and the needed equipment. This operating scheme of a planned factory describes all the required operational units and provides a graphical representation of the interconnections between each operational unit, regardless of the given building structures.[179]

[179] cf. C.-G. Grundig (2012), p. 80

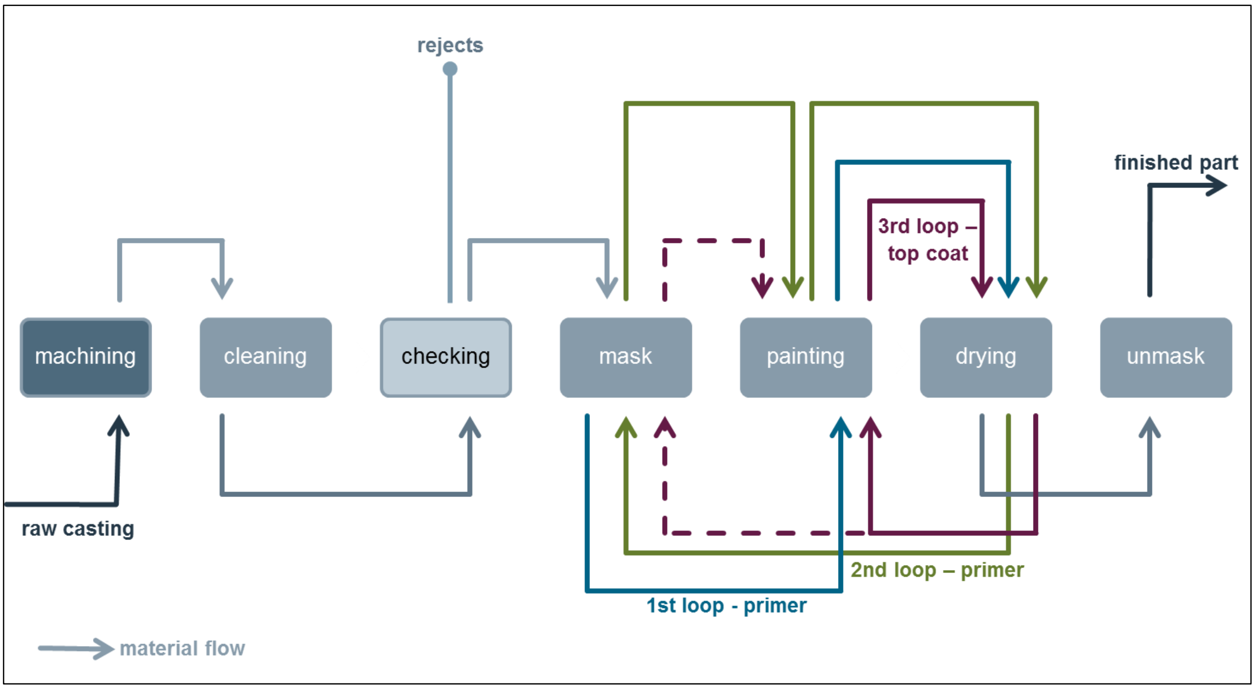

Figure 6-1: Operational scheme of a production line for axle boxes

Figure 6-1 shows the operational scheme of the planned production line with the arrows referring to the flow of the work through the various stages. The first step in the planned production facility is goods intake and inspection. Next comes machining of the raw castings. Each axle box must undergo a dimensional inspection, but due to the very tight tolerances of axle boxes, a satisfactory dimensional inspection is only possible on cleaned parts. That is why every part has to be cleaned after milling and before checking. In addition, cleaning is also very important for the paint application. The painting procedure has three main areas: masking, painting and drying. Due to the fact that some surface areas of an axle box need a thinner dry coat thickness than other areas and in order to achieve a satisfactory painting quality, every part has to undergo this painting procedure three times. The final step is the unmasking and a final optical inspection by an employee. All seven manufacturing steps are necessary to produce an axle box from a raw casting.

In contrast to the production cycle mentioned above, research shows that it is also feasible to paint the axle boxes before the milling production step and checking are performed. This procedure will reduce the masking effort, which leads to a faster door-to-door time, but on the other hand, damages and quality issues due to the milling process on the top coat can occur and refinishing work, such as the painting of fastening flange surfaces, will be necessary.

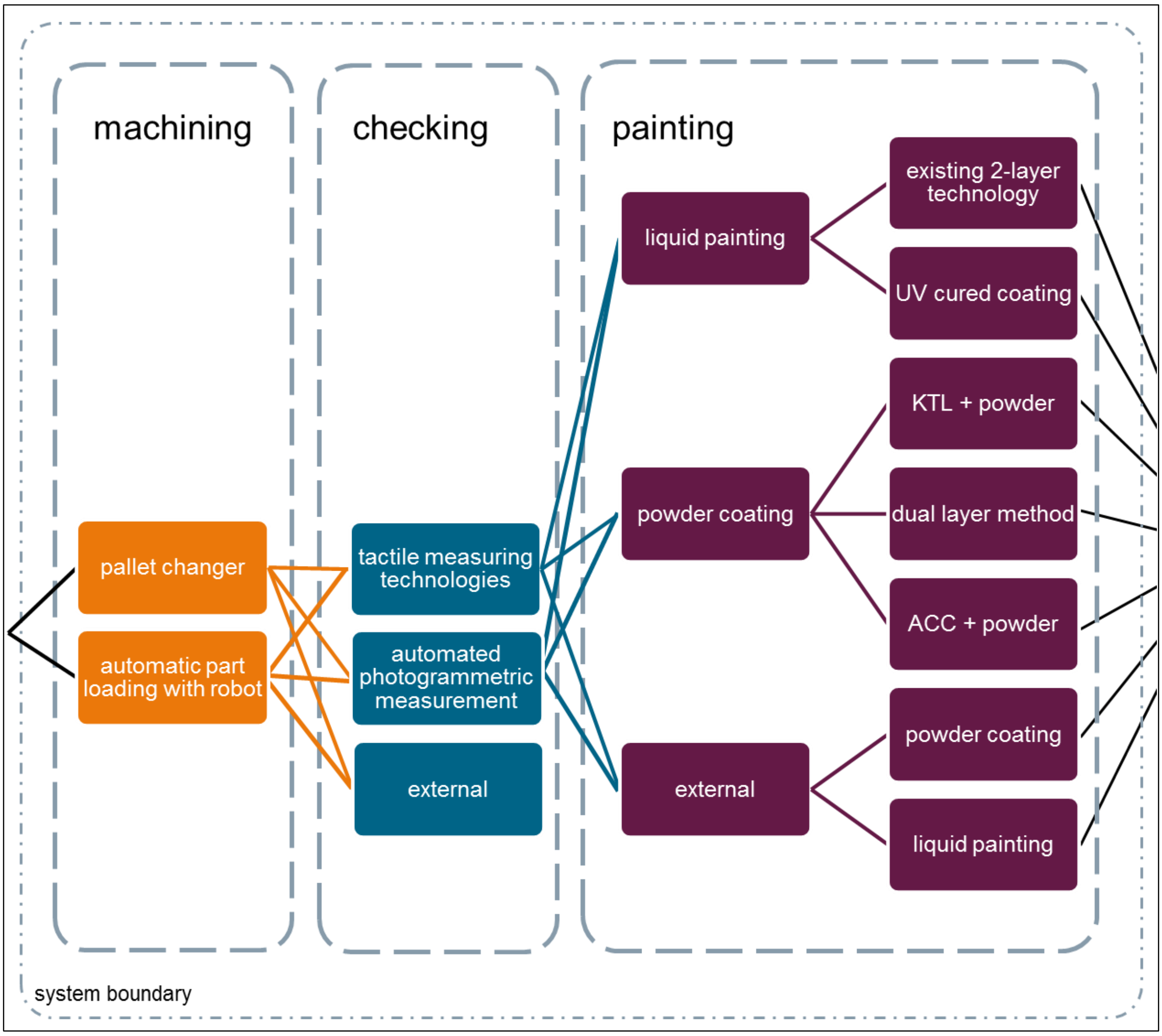

Figure 6-2: Variant tree of possible operational technologies

The variant tree, shown in figure 6-2, shows the possible operational technologies and their combinations between each production step. The following pages describe each operational technology in detail and weigh up the pro and cons. In addition, some improvements of the process are outlined.

6.1.1 Machining

Due to the fact that machining adds the highest useful value to the product, it is the most important process step of the whole production line. Moreover, a suitable machining center adds a significant investment cost to the production facility. For this reason, it is very important to obtain a high utilization of the machine, otherwise it is not possible to achieve a competitive product price. To generate more knowledge about the machining time of an axle box, two representative products were chosen and detailed machining time studies were done.

	Two-piece axle boxes	One-piece axle boxes
Raw material	**Spheroidal cast iron**	**Spheroidal cast iron**
Product	**SF100**	**SF500DSW**
Percentage of total production from 2013-2018	**16%**	**84%**
Time study author	**TCM**[180]	**DMG Mori Seiki**[181]
Number of repeated clamping	**3**	**2**
Process time (main & auxiliary process time)	**76.40min**	**41.57min**

Table 6-1: Overview of machining time studies

Based on the time studies of table 6-1 the average machining time for an axle box can be calculated as follows:

$$average\ machining\ time = (76.40 \cdot 0.155) + (41.57 \cdot 0.845) = 46.97\ {}^{min}/_{part}$$

Adding 20% extra time as a safety margin:

$$average\ machining\ time_{+20\%} = 46.97 \cdot 1.20 = 56.36\ {}^{min}/_{part}$$

Multiplied by the capacity required for one year:

$$machining\ time\ per\ year = 56.36\ {}^{min}/_{part} \cdot 8\,500 parts = 479\,094\ {}^{min}/_{year}$$
$$\triangleq 7\,985\ {}^{h}/_{year}$$

This calculation shows that the planned capacity of 8500 axle boxes per year can only be reached with two machining centers. One machining center in a 3-shift model, which is common at the Siemens plant in Graz, has 5280h/year productive hours (5 working days per week, 44 weeks per year)[182]. Moreover, two machining centers have enough capacity for further productivity increases or to cope with increased demand.

[180] based on a time study of SF100 (A6Z99000064615) axle box by TCM, 06.11.2012
[181] based on a time study of SF500DSW (A2V00002165118) axle box by DMG Mori Seiki, 12.08.2013
[182] based on plant service department, IC RL LOC BG MF-GRZ PS

A machining center is a CNC-milling or drilling machine, which is equipped with an automatic tool changer and a tool magazine. This offers the possibility to finish machining without any direct manual intervention. In addition, some machining centers are equipped with a pallet changer, which gives the possibility to clamp a new work piece while another part is machined. Furthermore, using a five-axis machine reduces position deviation as the necessity for repeated clamping is avoided. It is obvious that manual activities decrease with the use of automation, but on the other hand, the quality of the work pieces increases and trouble-free operation is likely. The aim of automatic machining centers is to increase the machine utility rate. This is based on increased daily time-of-use through unmanned production shifts and shortening of changing times through automatic tool and pallet changers.[183]

In general, two different groups of machining centers, as shown in figure 6-2, can be characterized and used in the planned axle box production. The following list gives some benefits of each concept.

Machining center with pallet changer

- A pallet changer makes the set up possible while another part is machined
- Parts are transferred to and from the machining center by human action
- Higher flexibility because handling is done by humans
- Lower probability of failures because the machines are operating independently of each other

Machining center with automatic part loading through a handling robot

- Work piece change with handling robot leads to faster changing time
- Productivity around the clock, no breaks are made during the shifts
- Unmanned production in the night shift
- Higher operational safety because the employee clamps the parts behind a safety fence

Practical industry experiences by way of reference examples of how to use automated part handling show that an unmanned production is possible. The STIWA group for instance has a spindle running time at their machining centers of 134h/week with just two manned shifts. Moreover, the company's manager mentioned that it is only possible to

[183] cf. J. Dilinger et al. (2007), p. 351

stay competitive in Europe if the machining is optimized and automated. In this context, automated does not mean reducing the number of employees, but rather an increase in machine utilization[184]

6.1.2 Checking

In regard to the product specification, various sections have to undergo a dimensional check after machining. The most accurate measure to be tested according to DIN ISO 1101 is a roundness to 0.015mm of a 250mm diameter. Another important factor is that the check station should be placed in the production flow. Moreover, no additional building structures should be required, such as an air-conditioned containment for the measuring device.

The basic idea behind a dimension measuring system is to set a finite amount of measuring points on the surface of the work piece and to generate from these a statement of the quality and dimensional tolerances of the measured part. In principle, tactile and optical measuring systems can be distinguished.[185]

Research shows that two groups of measuring systems should be focused on in more detail, as shown in figure 6-2. On the following pages, both methods are discussed.

Tactile measuring technologies

The advantage of this measuring technology is that a touching system can operate independent of ambient lighting and shiny work piece surfaces. A negative aspect of this technology is that data generation is very time consuming. In addition, the outer shell of the part itself is not detected; these machines measure the center point of a ball tip. This leads to the generation of measuring errors.[186]

Overall, practical experience shows that:

- Testing time for a typical axle box is around 20min
- Fully-automatic measuring machines exist on the market
- Minimal space for the measuring system is needed
- No air-conditioned measuring containment and no foundation is required
- Very high accuracy (0.001mm)

[184] cf. R. Fraunberger (2012)
[185] cf. P. Hehenberger (2011), p. 231
[186] cf. P. Hehenberger (2011), p. 232 ff.

Automated photogrammetric measurement

Photogrammetric measuring means the recognition and dimensional reconstruction of the part's shape with the use of photographic figures. An advantage of the optical measuring methods is that the data collection, in comparison to the tactile systems, is very fast and the work piece surface is directly detected. The disadvantage of this method is the dependence on ambient light.[187]

The pros and cons of photogrammetric measuring systems can be summed up as follows:

- Fully automatic unmanned measuring machines exist on the market
- The short cycle time allows the possibility to include this system in addition to the incoming goods inspection
- Detection problems on shiny surfaces
- Lower accuracy in comparison to tactile systems (0.01mm)

Further research and discussions with possible suppliers show that this measuring system does not fulfil the given specifications due to its lower accuracy. It is not possible to measure a roundness to 0.015mm of a 250mm diameter. In addition, it is difficult to measure machined planes because of their shiny surfaces.[188] For that reason, all further assumptions are made on the basis of using a tactile measuring system.

6.1.3 Cleaning

Each work piece has to be cleaned before paint can be applied with a satisfactory quality. The current state-of-the-art process is wet chemical cleaning, but this technology generates high maintenance costs which is why the CO_2-blasting method can be an alternative.

[187] cf. P. Hehenberger (2011), p. 235 ff.
[188] based on discusses with WESTCAM Datentechnik GmbH, 25.07.2013, and AICON 3D Systems, 26.07.2013

Wet chemical process

In regard to practical use, the following steps are required for the painting pre-treatment of a casting part:[189]

1. Alkaline cleaning (grease removal) at 80°C, 5min
2. Purging
3. In event of a subsequent galvanic coating process: electrolytic cleaning (anodic 1 to 2min)
4. Purging
5. Etching (pickling) for 10 to 15sec
6. Purging
7. Adhesion promoting layer

In event of bad casting quality, repetition of step 3 to 6 may be necessary.

The aim of the alkaline cleaning process is to remove firmly adhered soiling of various types, such as adhesive residues, grease, oil, cuttings and flash rust. In most cases, water-based chemicals are used which on the one hand increase the exposure time, but on the other hand provide the possibility to clean at a lower temperature. It is obligatory that natural oxide layers must be removed before a reaction with an adhesion-promoting layer can take place, and that is why etching is an important step. When special chemicals are used, it is also possible to combine etching with the alkaline cleaning. After purging, a short drying period is needed. This is important because otherwise problems can occur during the drying process of paint, which results in quality issues.[190]

CO_2 (dry ice) blasting

During the CO_2-blasting process, a blasting abrasive is accelerated with pneumatic forces and is applied to the surface of the work piece. In comparison to conventional blasting abrasive, like shot peening, the final quality of the work piece surface is not only the result of a mechanical abrasive action. As seen in figure 6-3 in addition the thermal effect and sublimation effect are used. The thermal effect has an impact on the cleaning of a part. The low temperature (-78.5°C) of the blasting abrasive leads to an embrittlement of the contamination and breaks up this layer through different thermal expansion. CO_2-blasting does not have a negative influence on the greenhouse effect because the used CO_2 is a waste product from chemical and industrial applications.[191]

[189] cf. J. Pietschmann (2010), p. 252
[190] cf. J. Pietschmann (2010), p. 255 ff.
[191] cf. M. Bilz et al. (2012)

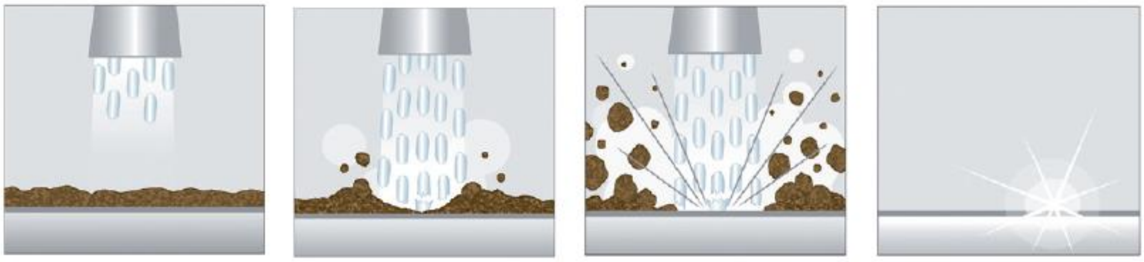

Figure 6-3: CO_2-blasting process steps[192]

There are two different methods of CO_2-blasting: First, dry ice blasting. This method uses pellets about the size of a rice corn, which are made out of liquid CO_2. Second, CO_2 snow cleaning process, which uses liquid CO_2. The liquid CO_2 can be stored in tanks and is expanded directly in the jet nozzle of the CO_2 snow cleaner. This process is used for cleaning fine structures and plastic parts.[193]

Benefits of CO_2-blasting:[194]

- Residue-free cleaning
- Non-destructive process even with sensitive surfaces
- Energy efficient due to discarding of the energy-intensive drying process and additional after-treatment processes
- Can be used directly in the painting box with the same robot
- Non-abrasive, non-flammable and non-conductive cleaning method without any solvents that leads to a reduction in maintenance costs

In connection with this thesis, two tests with different products from different companies were conducted. Both tests show the general possibility to use this principle as a pre-treatment method prior to the painting procedure. It is important to use small particles in the range of 1-2.5mm, otherwise a satisfactory result on a harsh casting surface is not achievable. Automation of this procedure is possible. It is also practicable to use the same robot for cleaning and painting. The only negative effect is the enormous noise level of up to 120dB(A). However, a reduction of the operational costs and cycle time is feasible.

[192] cf. D. Juchmes (2010)
[193] cf. M. Bilz (2012)
[194] cf. M. Bilz (2012); D. Juchmes (2010)

Because of the good results, CO_2-blasting is included instead of the traditional wet chemical cleaning process in all further appraisals.

6.1.4 Masking

The masking workstation is a manned operational unit where an employee applies a foil on various areas of an axle box. This is important due to the painting specification of these parts. Some surfaces have to be blank, other zones such as fastening flange surfaces, need a thinner thickness of the coat and all other surface areas have to be top coated.

Overall, research shows that two approaches exist to reduce the work activities within this production step. First, painting of the work pieces assisted by a robot without masking. In this approach, the robot paints only those surface areas which need a top coat and leaves the other areas blank. Based on statements of the engineering department, this method is likely to fail because of the tight tolerance at some specific areas that are currently not reachable by a robot without a correct masking procedure. Second, no paint on fasting flange surfaces which reduces the work activities during this production step to a minimum because masking of areas which need a thinner thickness of top coat is avoided. The engineering department of the plant is currently running a field test on this issue, which should clarify the usability of this approach.

6.1.5 Painting

Metal coating is a very complicated process step because quality issues can be detected immediately. Selecting and implementing a suitable production process, which also decreases production costs and maintenance effort, is a difficult issue. As stated in the paint specification of axle boxes, a two-layer two-component epoxy resin primer and top coat with a total layer thickness of 260µm to 280µm has to be used.[195]

The painting of bogies is subject to special requirements in terms of corrosion and protection against highly abrasive exposures and so less effort is therefore required in

[195] cf. Siemens (2013b)

connection with a perfect appearance of the painted part compared to the automobile industry.[196]

The Siemens plant in Graz is located in a high wage country, and thus full or semi-automatic production is an acceptable development. Important factors in automatic painting systems are the optimal trajectory of the coating robot and clearly defined process parameters within the painting procedure. Today, it is not so difficult to find an optimal trajectory due to the increased use of simulations, industrial process and control as well as flexible robot systems. In addition, the part identification, paint supply systems, tone changing techniques and conveyor systems are very important for a successful automatic coating system.[197]

The biggest motivations for using and aims of an automatic system can be concluded in the following points:[198]

- Use of more effective electrostatic painting system, which uses a higher electric voltage
- Decrease of painting costs based on an automatic system that produces less waste
- Reduction of energy costs because of a reduction of air speed intake
- Reduction of labor expanses due to reduced number of qualified employees
- Improvement of painting quality
- Decrease of monitoring effort and easier supervision
- Higher level of utilization and higher production capacity
- Unmanned shift operation is feasible

Industrial spray-painting (wet-coating procedure)

Due to environmental reasons, Siemens Graz is focusing on water-based wet paint within all production lines. For this reason, this sub-section only focuses on water-based paint. Moreover, Siemens in Graz is presently using this technique as its standard painting procedure.

Water-based paint has some special restrictions during application, supply and drying in comparison to solvent-based paint. For instance, water-based painting does not dry as fast as solvent-based paint at high humidity and it is very hard to reach a stepwise and consistent evaporative emission. Since the industry uses water-based wet paint with a

[196] H.-J. Streitberger and H. Kittel (2008), p. 345
[197] cf. M. Obst (2002), p. 63
[198] cf. M. Obst (2002), p. 64

very small portion of organic solvents, a thermal air treatment at the dryer has to be clarified.[199]

Industrial spray painting is an established process that has been in use since 1923. In principle, two procedures can be distinguished: one method uses electrostatic spray and the other one does not use electrostatic charge. Both methods have their advantages and disadvantages. The method without electrostatic charge has lower investment cost and lower requirements on system engineering, paint and substrate. Another benefit is the reduction of painting quality issues on hollow parts or parts with sharp edges. Nevertheless, on the other hand, the major disadvantage is high paint overspray losses. The atomizer without electrostatic charge only relies on mechanical forces. These methods use, for example, the velocity of the air jet to atomize the paint. The electrostatic spray is based on the electrostatic rejection between two same-polarity charged elements. In other words, the paint is charged in an electric field and the combination of attraction to the opposite pol and internal rejection based on the same polarity causes a drift apart of the paint.[200]

Powder coating

In comparison to the wet-coating procedure, the powder coating procedure is more environmentally friendly because it does not use any solvents, produces hardly any waste and reduces the energy demand due to a closed air circuit of the painting box.

Powder coating is a good option if limited tones and temperature resistant material are used. A fast hardening cycle is feasible and the thickness of dry paint is the same than in the wet-coating procedure.[201] Figure 6-4 shows the necessary equipment of a powder coating system.

Two main types of powder coating can be distinguished:[202]

1. **Powder sintering process**
   In this method, a work piece is preheated before the coating procedure takes place. The preheating temperature is above the melting temperature of the powder. After that, the powder is applied on the hot work piece surface and melts.

[199] cf. M. Obst (2002), p. 79
[200] cf. T. Brock et al. (2009), p. 303 ff.
[201] cf. M. Obst (2002), p. 79
[202] cf. T. Brock (2009), p. 303 ff.

2. **Electrostatic powder coating**

Electrostatic powder coating is similar to the previously mentioned electrostatic spray procedure. The electric charged powder particles are guided through an electric field to the work piece surface where they adhere due to Coulomb forces. Then the particles have been fired in an oven.

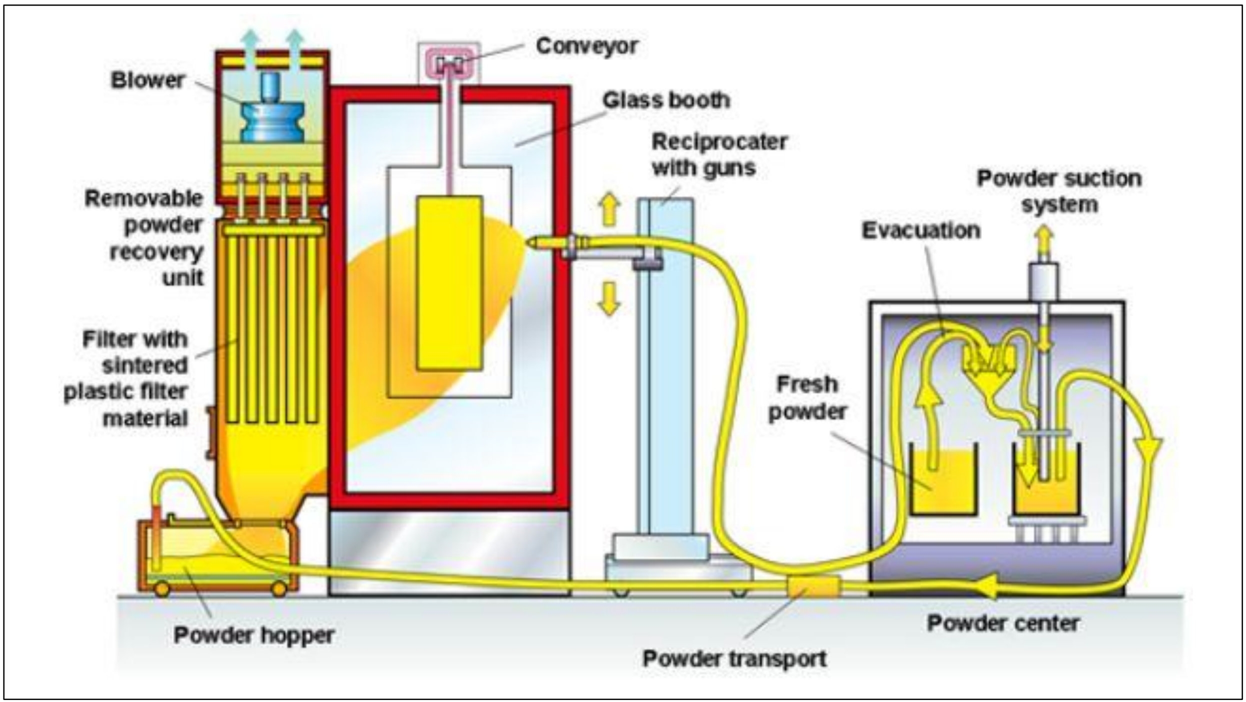

Figure 6-4: Diagram of equipment required for a powder coating procedure[203]

The positive effects of powder coating in comparison with industrial spray painting are listed below:[204]

- High application efficiency between 90% and 98% in a closed circuit use including a powder recovery of the overspray
- High layer thickness of up to 150µm is possible, without drip off
- Cleanness of painting box
- Low emissions and low paint losses during the process
- Energy savings while drying due to a high temperature but low air flow
- Not toxic and not a hazardous product

[203] cf. Eisenmann (2013), retrieved 14.10.2013
[204] cf. T. Brock (2009), p. 303 ff.

The negative effects of powder coating can be described as follows:[205]

- The recovery of the overspray is a difficult process and that is why it is very important to search for the highest possible application efficiency
- Changing the tone is normally a time-consuming process. If possible, every painting box should use just one color tone or a loss of the overspray can be accepted. This fact influences the planning phase of a new facility
- The powder hardening process is also a difficult step. It is essential to talk to the supplier of the powder and to carry out a study of the hardening temperature and time

As mentioned previously, powder coating is currently not used at the Siemens plant in Graz, but this method should be taken into consideration in regard to this research.

Cathodic dip coating

Cathodic dip coating is an electrophoretic dip coating procedure. This procedure is characterized by the electric flow between the work piece and the dipping bath. All electrophoretic dip coats are water-based with a low amount of solvent (less than 4%). Cathodic dip painting is a high quality priming procedure and well established for practical use, especially in the automobile industry.[206]

The main benefits of cathodic dip coating:[207]

- Even coating of work piece surfaces and hollow spaces with uniform coating thicknesses
- Well-suited for automated coating and designed to run 24/7
- No formation of drops
- Hardly any paint loss
- Good possibility to control the procedure and the process quality
- High corrosion protection

The main disadvantages of this procedure are the high investment cost, high material cost and the higher effort needed to maintain the quality of the dipping bath to ensure a consistent painting process.[208] Due to the high investment cost and a low utilization ratio,

[205] cf. M. Obst (2002), p. 82 ff.
[206] cf. D. Ondratschenk (2007), p. 199 ff.
[207] cf. D. Ondratschenk (2007), p. 199 ff.; T. Brock (2009), p. 297
[208] cf. D. Ondratschenk (2007), p. 199 ff.

and based on the parameters of the planned project, the cathodic dip coating method is over-engineered for the described use.[209] In view of this, this coating procedure is not feasible for the stated use in an axle box production line.

Autophoretic coating chemicals (ACC)

The autophorectic coating system is a special variant of the dip coating procedures. In this method, the parts are dipped in the same way as mentioned in the cathodic dip painting procedure in a dipping bath. In contrast to the cathodic dip painting, this method does not rely on the flow of electric current. In this process, the substances in the dipping bath are chemical transformed to adhere to the metal surfaces. The use of this method is therefore only possible for cleaned ferrous substrate materials, such as steel.[210]

ACC is becoming increasingly popular today as the process avoids inorganic pre-treatment, which is usual in the dip coating procedure, and give rise to an improvement of the chemical substances as well as the avoidance of the electric current, which all lead to reduced investment costs. Another benefit is the reduced drying temperature compared to the cathodic dip method. However, the corrosive protection is weaker.[211]

A supplier of ACC dipping baths stated that the used chemical substances are only stable at temperatures up to 120°C, which makes powder coating after this priming procedure not possible. In light of this and the fact that this procedure is not usable for aluminum castings, this technique is not feasible for the specified use.

6.1.6 Drying

To form a satisfactory paint film drying and curing systems are used in the industrial painting procedure. These systems accelerate the physical drying cycle. The following methods were select, because they fulfil the described specifications in the most satisfactory way.

[209] based on a discuss with TIGER Coatings GmbH & Co. KG, 27.08.2013
[210] cf. D. Ondratschenk (2007), p. 207 ff.
[211] cf. A. Goldschmidt and H.-J. Streitberger (2002), p. 520

Convection furnace

The evaporation of the liquid elements of the paint is an important process step of the drying procedure of the paint film, especially when using wet-coating systems. This is a critical process step for primarily water-based paint which is influenced by different factors such as time, temperature and humidity.[212]

The cycle of the hot airflow of a convention furnace can be described as follows. First, the airflow is guided over the painted parts in the drying chamber, and then it is extracted by suction. The next step is reheating the ambient air in a heat exchanger and finally the hot airflow is guided back from the heat exchanger in the drying chamber. During this process, a heat transfer from the hot air flow to the painted parts takes place.[213]

Drying in a convection furnace is the standard procedure at the Siemens plant in Graz.

Infrared drying

Infrared technology has been established in industrial use for a while and is known as a fast drying and hardening technology. It is popular in paper, plastic foils and the textile industry. This technology uses high performance lights which generate shortwave infrared radiation with a very high energy density.[214] Moreover, infrared drying is more energy efficient than drying in a standard convection furnace.

Dark radiation convection is a new technology on the market which is used for the firing of powder coating or for cathodic dip coating, and in addition it is also possible to dry wet paint. This technology allows faster drying of work pieces with widely differing wall thicknesses of 2 to 200mm. Furthermore, a reduction of the oven size is possible on the basis of a 60% shorter drying time. In comparison to a standard convection furnace, energy savings and higher process reliability are achievable as a result of reduced airflow.[215]

Based on research and a discussion with Klaus Wiesinger form Tiger coatings GmbH & Co. KG, dark radiation convection technology is a future-orientated concept, but high investment costs are probable.

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[212] cf. M. Obst (2002), p. 86
[213] cf. M. Obst (2002), p. 86
[214] cf. M. Obst (2002), p. 79
[215] cf. Anon (2013)

Curing by UV exposure

UV-cured coating works as follows: UV-curable coatings are polymeric coatings, which are applied as a liquid at room temperature. The UV light energy triggers and powers an appropriate chemical reaction that converts instantaneously the liquid UV coating into a solid state. The absence of volatile solvents in the coating formulation eliminates the need for traditional evaporation to form a dry film, which decreases drying time and conversion of wet coating into a dry finish. This results in a significant increase of production speed. When correctly designed, installed and used, UV lamps are not a serious hazard in workplaces.[216]

Solvent-free UV-cured coatings are widely used in the furniture and wood industries. These products are based on water and applied through spraying technology. According to the author of “Lackierereien planen und optimieren”[217] the UV-cured coating is not yet ready to be used for metal parts, but there have already been some tests with three-dimensional plastic components in the automobile industry. It very hard though to verify the perfection of paint hardening on a three-dimensional part.[218] However, modern computer simulations and the use of robots enable the possibility to achieve a satisfactory paint hardening, due to this reason interest in this environmentally friendly and economically beneficial curing method is increasing.[219]

Benefits of UV cured coating:[220]

- High mechanical and chemical resistance
- Satisfactory optical film-forming properties
- Better recycling properties than in standard wet painting procedures
- Painted parts are instantly ready for packing after the hardening

Further research and discussions with possible suppliers show that this technology is not yet ready for the described usage. Achieving the right thickness of the dry layer is still a problem due to draining of the wet paint. In addition, it is difficult to arrange the UV lamps correctly to cover the complete three-dimensional shape of a casting part. Because of these reasons, the UV-cured coating is not covered in further appraisals.

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[216] cf. A. a. Sokol (2010)
[217] cf. M. Obst (2002)
[218] cf. M. Obst (2002), p. 92
[219] cf. A. Goldschmidt (2002), p. 641
[220] cf. M. Obst (2002), p. 92

6.2 Global planning

As stated in section 3.2.3, the global planning step is central within the feasibility study of a project. The following section describes a material flow analysis, specifies the area required for operations, gives several variants for the layout and describes the required modification to the chosen production building with an industrial building design.

6.2.1 Material flow analysis

This section only focuses on the internal material flow and takes into account the basic processes, which are also described in in section 3.2.3.1, such as manufacturing, handling and storage.

The term material flow, in practice, can be described as a flowing process. This means that goods are continuously swapping between the states of manufacturing, handling and storing. Manufacturing processes are value-adding processes in contrast to handling and storage processes. Moreover, handling and storage processes add significantly to both the production costs and the door-to-door time, and thus should be kept to a minimum.[221]

The material flow analysis is carried out with the software Tecnomatix Plant Simulation 10.1 developed by Siemens PLM Software. The procedure to obtain the best simulation results follows the principle of the simulation process as described in section 3.5.1.1 and the manual which is described in the book “Praxishandbuch and the manual which is described in the book “Praxishandbuch Plant Simulation und SimTalk“[222].

Setting objectives

The main objective of this simulation and analysis is to improve the efficiency of the new production line.

Minor targets are the data generation of door-to-door times for axle boxes and an estimation of the employees required for the production process. Another important aspect is to verify the need for automation devices. Moreover, the machine utilization of each workstation should be recorded and a bottleneck analysis should be carried out.

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[221] cf. C.-G. Grundig (2012), p. 116 ff.
[222] cf. S. Bangsow (2011), p. 2 ff.

Situation analysis

The aim is to create and design a new production line for axle boxes at the Siemens plant in Graz. This new production line is planned in an empty production hall and should cover only the production of axle boxes, as described in section 5.

In regard to the production mix, the new production line should be able to manufacture an annual capacity of 8500 axle boxes.

The planned production line should cover machining, varnishing and checking as discussed in the section before.

The main parameters for the simulation model are the size of the new production hall and the employment of a three-shift model. The most important aspects in specification were a beneficial set of all necessary parameters between the parameters model, the defined workstations including their interdependency and a complete reproduction of the interfaces with the environment.

The three-shift model can be defined as five full days a week and 44 weeks per year, which gives 5280 working hours per year.[223]

Draft of the material flow model

The draft for the simulation model is generated in line with the top-down approach and is shown in figure 6-5. Each step is described in detail in section 6.1. In addition, it includes the calculated process times[224].

[223] based on information from the department, IC RL LOC BG MF-GRZ PS

[224] the machining time is based on two time studies carried out by different companies; the checking time is stated by a real test on a tactile measuring system; the process times for the cleaning, masking, painting and drying are Siemens' internal assumptions based on the existing production processes.

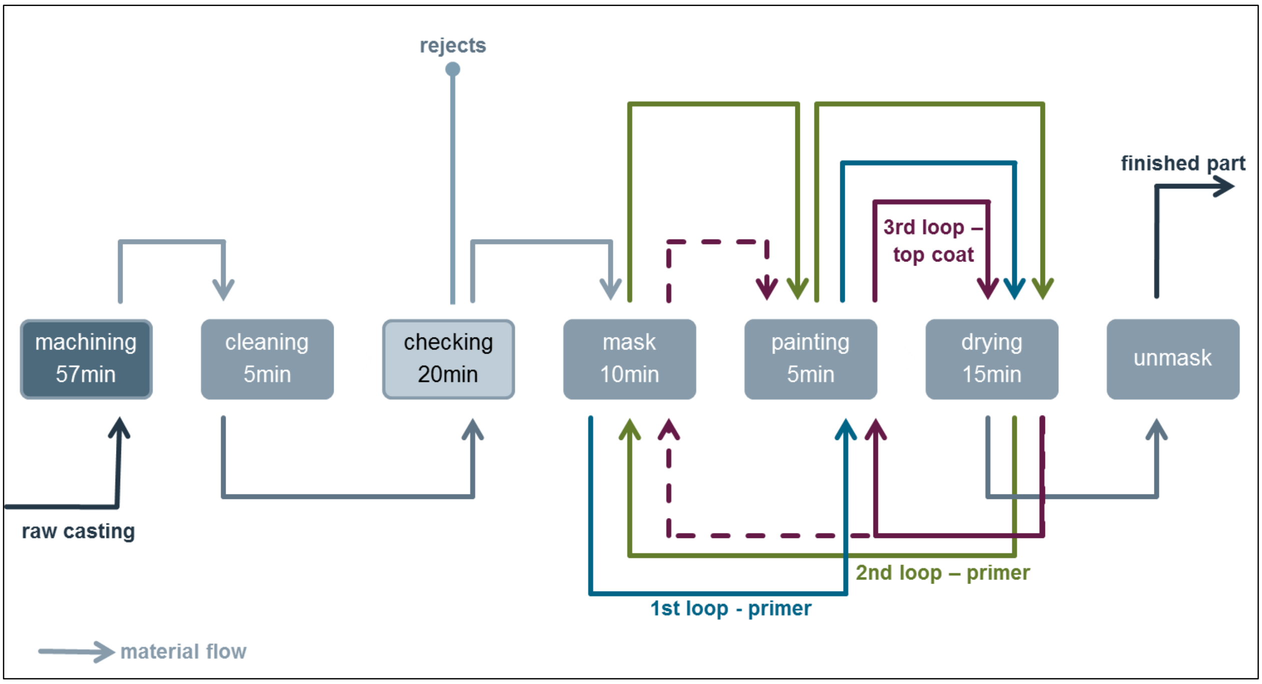

Figure 6-5: Operational diagram of an axle box production including process times

Model implementation and verification

The basic module “Einzelstation” is used to simulate most of the work steps. Different production steps can be illustrated using the option to define various parameters such as process time, setting-up time or machine malfunctions. The objects “Quelle” and “Senke” define the parameters of the system. The “PickandPlace” element defines the handling robots next to the machining centers. A crossover, which is used for deciding how many loops each work piece has to pass through, is simulated through the element “Flusssteuerung”. Another workstation, where an employee clamps the raw materials to a fixture, is located before the machining centers. The handling robot lifts these fixtures into one of the two machining centers and if they are occupied, the parts are stored in a rack. The Plant Simulation element “Puffer” with the capacity of 14 items simulates this rack.

The machinery in operation includes two five axis machining centers, one handling robot, a cleaning and checking station as well as a paint shop. The dimension check is done by a tactile measuring system. The “rejects” element simulates rejected goods with 2% of the production after the dimensional check. The paint shop consists of a masking zone, a painting box and a dryer. An automated conveyor system is the connection between each zone. This conveyor system simulates the motion time between every single workstation.

The system boundary for incoming goods can be described as an interface between the transportation process of goods receipt location and production. Investigations show that the incoming goods department, which operates on a three-shift model, is always able to supply the production process with enough raw materials. There are different casting suppliers, and thus an associated requirement for storage locations, but these are not modelled. Incoming goods is described as a source in the simulation model.

The “outgoing goods” parameter can be defined as an interface between manufacturing and outgoing goods. All axle boxes which exit the production system are transferred to a warehouse or used just in time in another assembly line. That is why no storage is needed for finished products. Outgoing goods is outlined as a sink in the simulation model.

The model verification is carried out by means of a static calculation of machine occupancy rate and through two different approaches:

1. **Verification in smaller elements:**
   The defined methods and elements are checked one after another in the debugger mode to see whether the results of each element match exactly with practical experiences.
2. **Walk-through-approach and animation:**
   In this approach, the material flow of the products is checked when the goods pass each operational unit.

Experimentation

Various models were generated to test different combinations of the workstations. The model, which is presented below, fulfils the given targets in the most convincing way. Figure 6-6 shows this final model. During the optimization, values such as the storage capacity for the clamped parts or the shift calendar of the manned workstations were adjusted. Furthermore, the “dryer” workstation is a parallel station. This adjustment is necessary because of the bottleneck analysis.

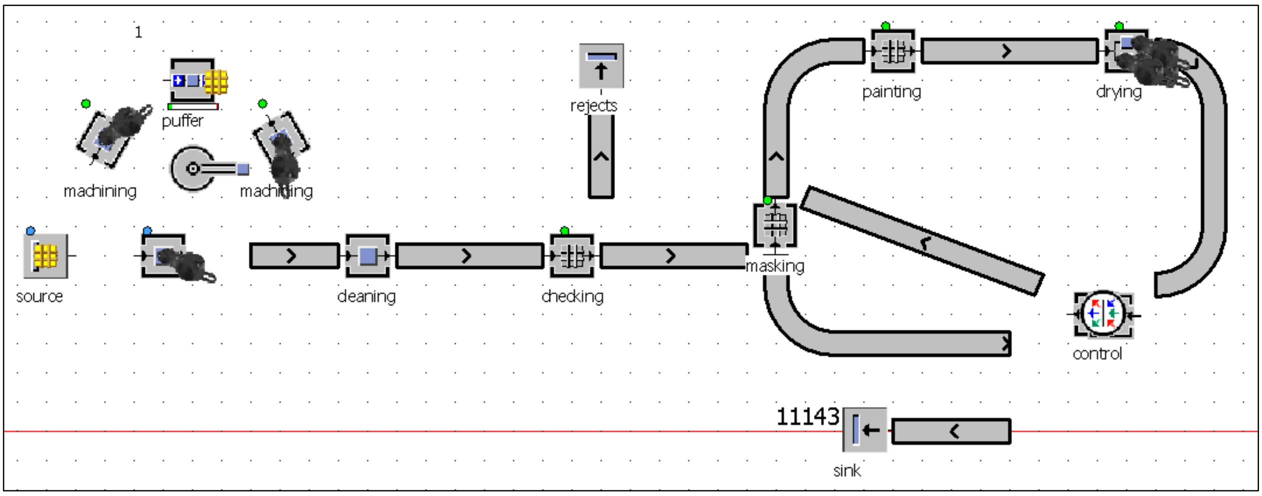

Figure 6-6: Overview of simulation elements by Tecnomatix Plant Simulation 10.1

In figure 6-7 the different machine utilization rates can be seen. “Working” means that the workstation is working without any problems. “Waiting” can be interpreted as the state in which the workstation is ready for working but does not have any work pieces to start operations. This part should be reduced to a minimum. The status “blocked” means that the workstation has finished its operation, but is still loaded with the part and is waiting for its removal. “Malfunction” this is based on a 95% availability of the machine. Due to the shift calendar, every employee has forty minutes break during his shift; this is marked as “paused”. In this model, only two employees are planned within the whole production line. One employee is located next to the machine centers and the other one works at the masking station. “Unplanned” means that the production facility is shut down based on the shift calendar, such as on weekends.

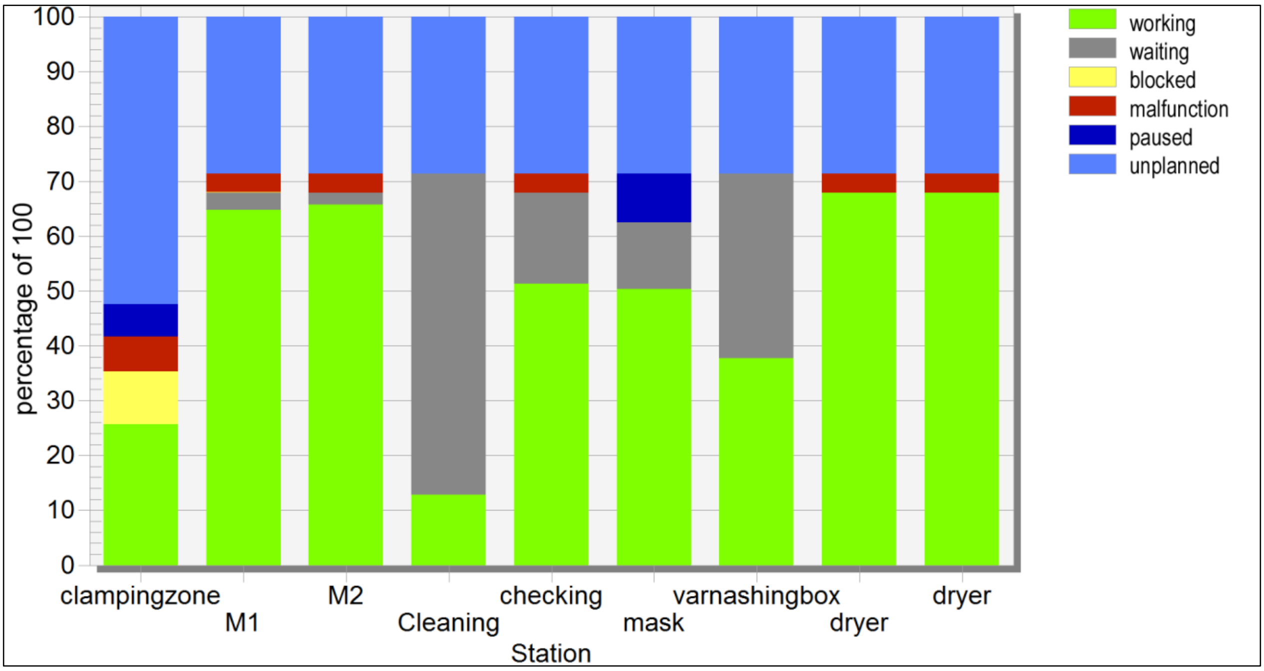

Figure 6-7: Different machine utilization rates for various operational elements

Interpretation of the results

The simulation and optimization of the planned production line demonstrates that the target capacity of 8500 axle boxes per year is possible. Including the given process times and all boundaries an output of 11 143 items can be reached.

After eliminating all bottlenecks in the production flow, the final variant fulfils all given targets. There are two bottlenecks in the production: the output of the machining centers and the dryer after the painting procedure. Optimizations show that the workstation "clamping zone" can be run in a two-shift system without reducing the production output. A puffer between the clamping zone and the machine centers supports this. The puffer is managed by the handling robot, which automatically decides between loading the machines and storing the work piece for later use. Moreover, the "cleaning" workstation has a very low machine utilization rate. Research show that this rate can be increased by using the cleaning system for additional parts such as wheel sets. If an employee is needed for the "cleaning" and "checking" workstations, this can easily be accommodated in a three-shift model.

The material flow analysis shows that the planned production facility has enough capacity reserves to cope with a further increased demand.

6.2.1 Land use planning

As described in section 3.2.3.3 land use planning is the initial step for each layout planning. Table 6-2 describes all workstations for various variants and their required area. The area of use does not include any handling zone.

Area	Area of use	Employees needed	Height of the facility
Machining with robot handling	128,8 m²	1	3,20 m
Machining with pallett changer	103,8 m²	1	3,50 m
Tactile measuring system	12,8 m²	1	3,10 m
Manual painting procedure	221,0 m²	2	5,00 m
Automatic painting procedure	170,0 m²	1	5,00 m
Powder coating process	150,0 m²	1	5,00 m
Storage for raw material	48,0 m²	0	6,00 m

Table 6-2: Land use planning for an axle box production

6.2.2 Layout planning

A layout is the correct spatial positioning of all necessary operational structures. An important point in layout planning is the adaptability and expandability of the planned facility.[225]

Moreover, a perfectly designed layout reduces cost. Depending on the industrial segment and the product, the intra-plant logistics are responsible for 15% to 60% of the production costs. It is advantageous when the spatial positioning follows the material flow. In other words, the chronology of each production step should fit to the step before. If this principle is carried through, it is possible to achieve a minimization of the door-to-door time, a transparency of the material flow procedure and a minimization of transportation cost.[226]

[225] cf. H.-P. Wiendahl (2009), p. 471
[226] cf. C.-G. Grundig (2012), p. 114

6.2.2.1 Ideal layout

As described in section 3.2.3.3, an ideal layout is the production flow-aligned, area-related ideal spatial positioning of all necessary operational structure.[227]

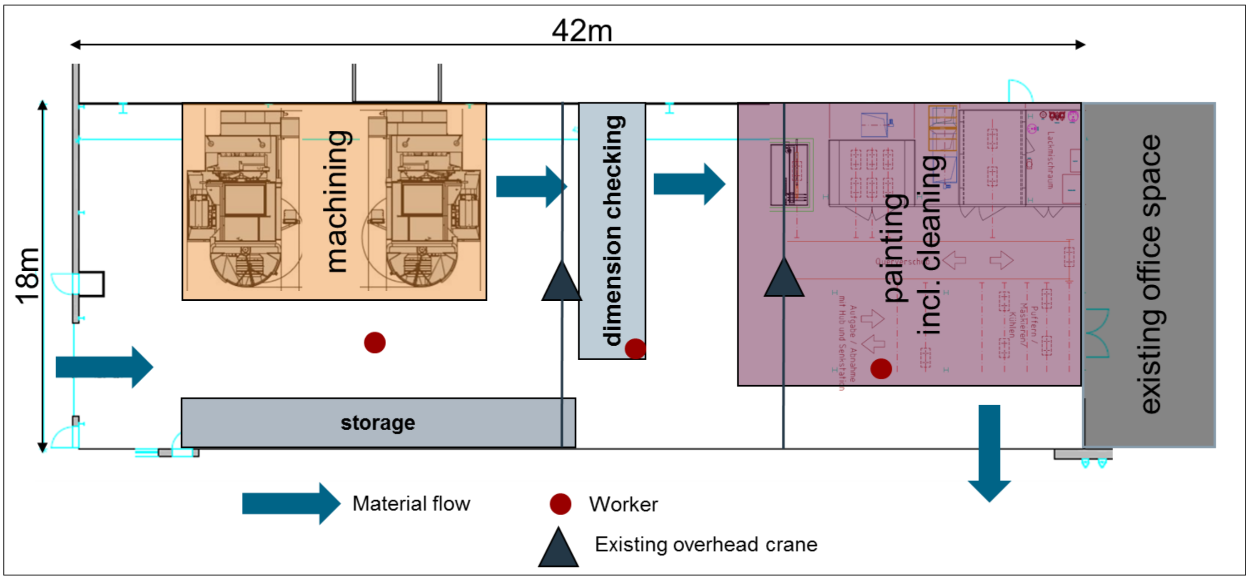

Figure 6-8: Ideal layout, conventional design

Figure 6-8 shows a full-scale ideal layout for a marginal automated production line. The material flow is marked with blue arrows. The orange area is the machining zone, which includes two machining centers as described previously. The light grey part is for dimensional checking. Purple indicates the paint shop. This ideal layout also includes existing facilities, such as two overhead cranes and an existing office area, which should not been relocated during the reorganization of this factory hall. This layout can easily be adapted. If demand increases, it will be possible to include a third machining center. On the other hand, if the demand falls, a machining center can easily be removed too as the machines do not need a bed. Moreover, due to the positioning of the office area at the rear of the building, the supervisor will frequently cross the production line which ensures a direct communication link between management staff and production staff. This layout concept is very flexible and can cope with various products not only axle boxes. Furthermore, it can easily be adjusted to portfolio changes.

[227] cf. C.-G. Grundig (2012), p. 446

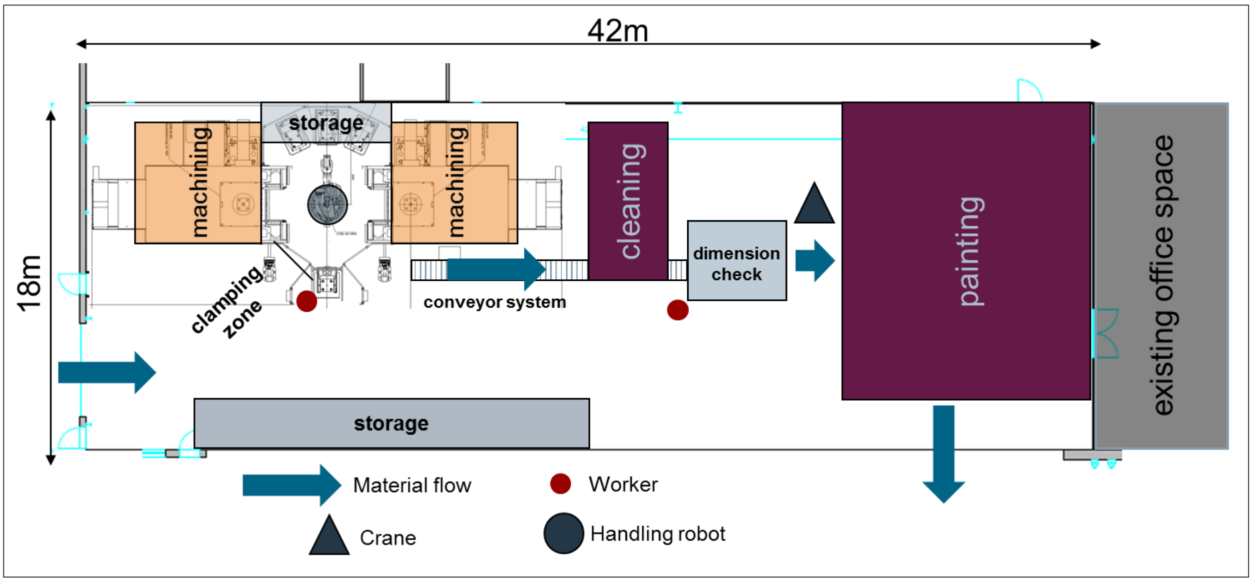

Figure 6-9: Ideal layout, with high level of automation

Figure 6-9 shows a different full-scale ideal layout of a production line with a high degree of automation. As mentioned previously, the blue arrows indicate the material flow. The first production step is machining, marked in orange. In this layout, a handling robot does the part handling. After machining, all work pieces are put on a conveyor system, then automatic part cleaning and dimensional checking follow. The last production step is painting, marked in purple. This production step is supported by a painting robot . It is more difficult to adapt this layout to a change in demand, because the robots are not as flexible as employees are. However, a third machining center can be added to this layout and the handling robot can be mounted on rails so that it can reach all three machining centers. As described in the previous section, the checking and painting zone are not the capacity limiting factors.

6.2.2.2 Real layout planning

A real layout planning is a practicable spatial arrangement among all operational units including functional, material flow, areal-related, practice-related and regulatory influencing factors. As described in section 3.2.3.3 the aim of real layout planning is to transform the ideal layout into the real world including all operational constraints.[228]

[228] cf. M. Schenk (2004), p. 284

Operational specific constraints can be described as flow:

- The existing building structures of the chosen production hall should not be modified
- The painting system must be located next to a fire-proof wall
- The painting booth must be located next to the cleaning box, because they can use the same robot in the event of an automated painting system
- The measuring system should be located as far away as possible from doors or other environmental influences to ensure a satisfactory measuring quality
- A walkway from the door to the office area should be kept free
- The existing office area should not be repositioned
- The masking zone should provide as much space as possible, which allows a longer drying time and a better painting quality
- A tool crib is not needed as it can be included in an existing facility
- The painting zone needs fire protection
- The cleaning zone needs noise protection in the event of CO_2 cleaning

Real layouts are generated on the basis of the ideal layouts and taking all constraints into consideration. All layouts include CO_2 cleaning technology as a pre-treatment before the painting procedure. In addition, most layouts are mirrored on the opposite side of the production hall due to fire protection regulations. Various real layouts were created in teamwork; on the following pages, only the most suitable layouts are presented.

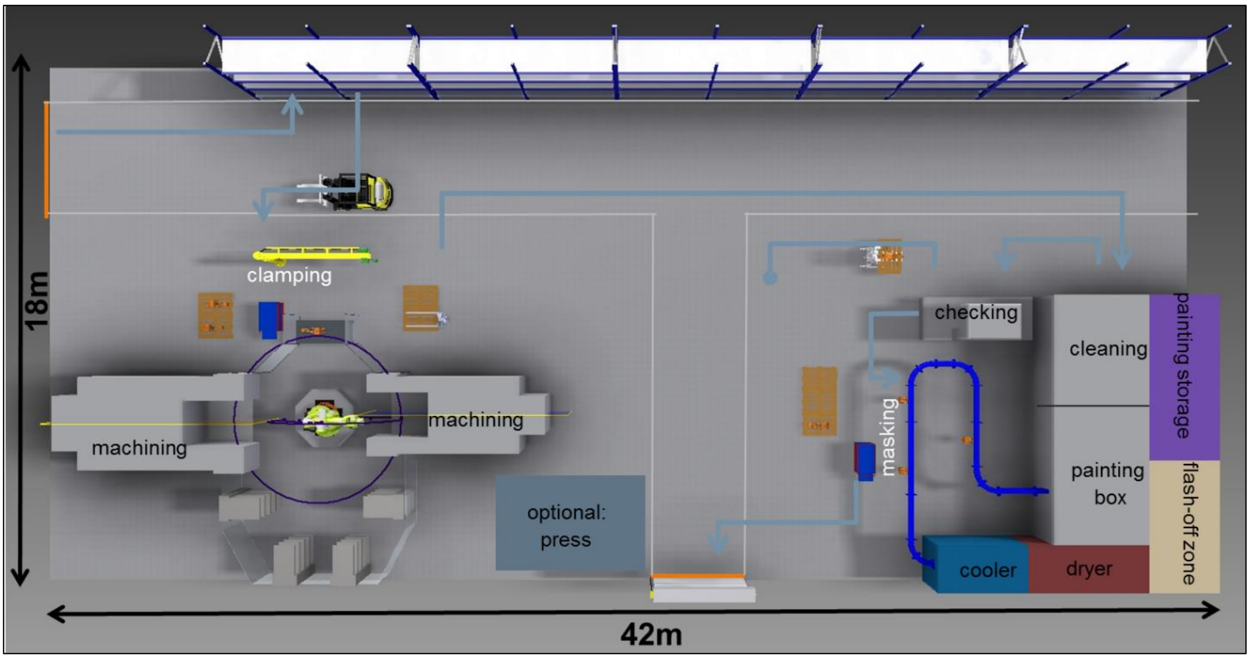

Figure 6-10: Real layout, variant: handling robot including automated painting procedure

Figure 6-10 shows the layout variant with a high degree of automation. The part handling of the machining centers is carried out by a robot, which also has the possibility to store raw clamped parts or finished parts in a rack, in the case of an unmanned clamping station. When the machining process is finished, all parts are then transferred to the cleaning box. The same robot is installed in the cleaning and painting booth. As mentioned in section 6.2.1, the capacity of the cleaning and painting booth is high enough to deal with both operations. That is why the painting robot is mounted on rails and moves from one booth to the other one. Checking is then carried out by an automatic tactile measuring station. One employee is required to load and unload the machine. The next step is masking. This is a manned workstation. The employee has to transfer the work items from the checking station to the masking zone where the parts are fixed on a hanging conveyor system. The following production processes run automatically. After the last loop, the employee places the finished parts on pallets and a forklift transfers the parts from the production hall.

The machining centers with the handling robot and the clamping zone can easily be replaced by two machining centers with a pallet changer without affecting any constraints or changing the material flow.

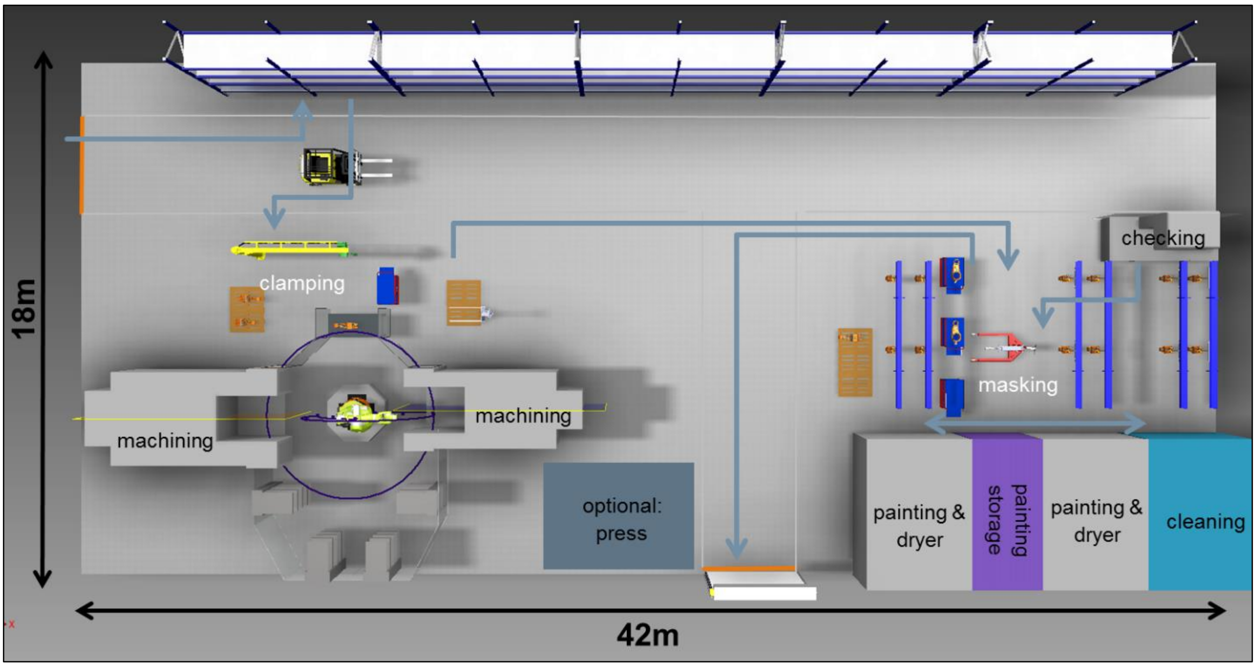

Figure 6-11: Real layout, variant: handling robot including manual painting procedure

Another layout concept is presented in figure 6-11. In addition to the layout mentioned previously, a handling robot with two machining centers is used. It is possible to replace these machining centers with two machining centers with a pallet changer. After the machining steps the semi-finished parts are transferred to the painting-checking zone. The parts are fixed on a rail system to access the cleaning box, checking station or painting box. The work pieces are stored on this rail system between each production step, and meanwhile the masking operation can be carried out. Finally, the finished parts are put on pallets and a forklift transfers the finished axle boxes just in time to an assembly line.

Figure 6-12 shows a third layout concept. A powder coating system instead of the industrial spray painting characterizes this concept. Before the powder can be applied, the machined parts have to be cleaned and checked. After the checking step, the axle boxes are fixed on a "power&free" conveyor system and the first layer of the powder coat is applied in the painting booth, and then the part is transferred into a dryer. Because the dryer runs at 160°C, a long loop of the conveyor system is installed after the dryer to cool the axle boxes. Then a second layer of the powder coat is applied. After drying and cooling of the finished axle boxes, they are put on pallets and a forklift transfers the parts to the next production step. In this layout, the painting booth is not located next to the fire-protection wall, because the powder has a lower hazard than the wet paint.

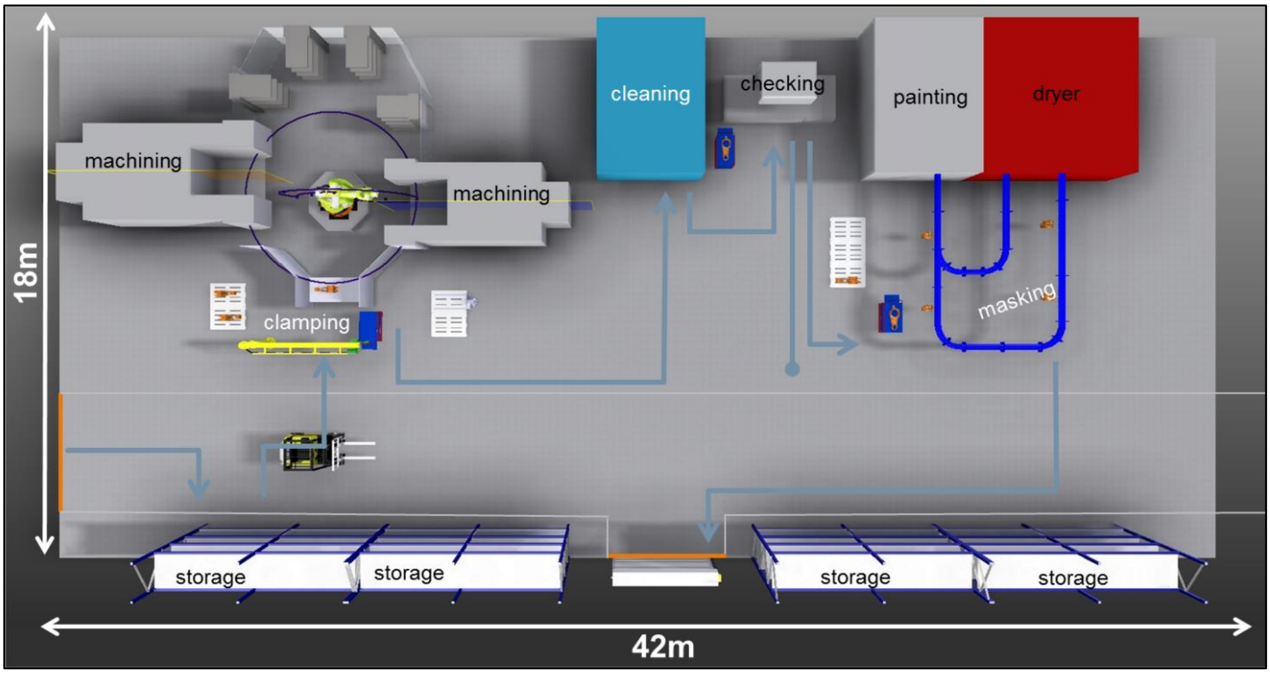

Figure 6-12: Real layout, variant: handling robot including powder coating system

6.2.2.3 Optimization and evaluation of the real layouts

The main difference between the variants mentioned is the degree of automation. In total, six variants are described with a degree of automation ranging from high, as shown in figure 6-10, to low as seen in figure 6-11. In addition to the mentioned variants, three options with machining centers with a pallet changer instead of the machining centers with a handling robot exist. The investment costs also vary depending on the degree of automation.

To gain a better understanding of the different variants, a value benefit analysis was carried out. The stated criteria were defined and the evaluations of each variant were done in a teamwork at the Siemens Production Engineering department.

A value benefit analysis is a tool to support the systematic preparation of decisions between different project alternatives. In the first step, a criteria list is created, as seen in table 6-3. These criteria are duplicated in a matrix. The next step is the definition of the weight of each criteria. This is done by a pairwise comparison. If one criteria is more important than the other one, the number of the more important criteria is filled in in the matrix. If the criteria is less important than the other one, the number of the compared criteria is filled in in the matrix.[229]

These criteria from table 6-3 can be described as flow:

- “Area in use” describes the m² used in a layout variant. In this case, the optimum rating means that a low amount of square meters is used.
- The criteria “material flow efficiency” is characterized by the positioning of each operational unit and the connection between each other. If the positioning is satisfactory and distances between each operational unit are short, the rating is high.
- “Added cost for construction” includes for instance foundations or reconstruction of existing operational structures. A low amount of money is reflected in a high rating.
- “Workplace hazards” reflects the occupational safety and health of the planned facility. The optimum rating means that hardly any hazards exist.
- “Flexibility in capacity” is the ability to respond rapidly and flexibly to a changing demand. A high rating means that this ability is given.

[229] cf. H.-P. Wiendahl (2009), p. 479

- Expandability and adaptability is the possibility to adapt the planned facility in case of a portfolio change. If an expandability or an adaptability is not possible, the valuation is low.
- The "process reliability" criteria is very important due to the need to produce high-quality products all year round. If the process reliability is high, the rating is also high.
- The amount of lifting operations is reflected in the criteria "product handling". A lower amount means a higher rating.

		1	2	3	4	5	6	7	8	9	weighting
1	area in use	x	x	x	x	x	x	x	x	x	8,33%
2	material flow efficiency	2	x	x	x	x	x	x	x	x	8,33%
3	added cost for construction	1	2	x	x	x	x	x	x	x	0,00%
4	workplace hazards	4	4	4	x	x	x	x	x	x	19,44%
5	door-to-door time	5	5	5	4	x	x	x	x	x	16,67%
6	flexibility in capacity	1	2	6	4	5	x	x	x	x	5,56%
7	expandability, adaptability	1	7	7	4	5	6	x	x	x	8,33%
8	process reliability	8	8	8	8	8	8	8	x	x	22,22%
9	product handling	9	9	9	4	5	9	7	8	x	11,11%
	number of each criteria	**3**	**3**	**0**	**7**	**6**	**2**	**3**	**8**	**4**	100,00%

Table 6-3: Criteria of value benefit analysis

criteria	weighting	Automatic part loading + automated painting		Pallet changer + automated painting		Automatic part loading + manual painting	
area in use	8,3%	4	7%	4	7%	2	3%
material flow efficiency	8,3%	4	7%	4	7%	4	7%
added cost for construction	0,0%		0%		0%		0%
workplace hazards	19,4%	5	19%	4	16%	5	19%
door-to-door time	16,7%	5	17%	5	17%	4	13%
flexibility in capacity	5,6%	3	3%	4	4%	4	4%
expandability, adaptability	8,3%	3	5%	4	7%	4	7%
process reliability	22,2%	4	18%	4	18%	4	18%
product handling	11,1%	5	11%	4	9%	4	9%
	100%		**87%**		**83%**		**81%**

criteria	weighting	Pallet changer + manual painting		Pallet changer + powder coating		Automatic part loading + powder coating	
area in use	8,3%	3	5%	5	8%	4	7%
material flow efficiency	8,3%	3	5%	4	7%	4	7%
added cost for construction	0,0%		0%		0%		0%
workplace hazards	19,4%	4	16%	4	16%	5	19%
door-to-door time	16,7%	4	13%	4	13%	4	13%
flexibility in capacity	5,6%	5	6%	4	4%	4	4%
expandability, adaptability	8,3%	5	8%	5	8%	4	7%
process reliability	22,2%	5	22%	4	18%	4	18%
product handling	11,1%	3	7%	3	7%	4	9%
	100%		**82%**		**81%**		**84%**

Table 6-4: Results of value benefit analysis

For instance, in the first column the criteria “area in use” is compared to occupational safety in row 4. Based on the Siemens “Zero Harm” culture, occupational safety is very important, and for that reason, the field in column 1 and row 4 gets the value 4. The weighting is calculated on the basis of the total of each criteria that is filled in in the matrix.

During this pairwise comparison, the criterion “added cost for construction” has never been more important than another that leads to a 0% weighting. Consequently this criterion has no impact on the value benefit analysis.

The next step of the value benefit analysis is the evaluation of the six possible variants. A scale from one to five is used where one is the lowest rating which means that this criteria is not satisfactory fulfilled. In contrast five is the best rating which means that the requirements are met in an optimum case, as described before. The weighted rating is the product of the criteria weight and the relative rating. The sum of the individually weighted criteria is the value benefit of each variant.[230]

As seen in table 6-4 based on the value benefit analysis the best possible variant is automatic part loading with a robot-supported painting system. These values will be used in section 6.4.4 to elucidate the non-monetary benefits of each variant.

6.3 Industrial building design

As discussed in section 3.2.3.4, this section deals with the given building structure of the production hall. As described, the chosen building is currently used for assembly work and the refurbishment of bogies. Therefore it can be stated that the building structure is in good condition and can in principle be used for the production of axle boxes.

Figure 6-13 shows the complete current layout of the selected production facility. As seen in this diagram, an office area and a social room exist in the selected building. Therefore no further investment has to be planned for these facilities. In addition, the red line marks the existing fire protection wall. It was agreed with the fire protection officer that the painting center should be located next to the fire protection wall in order to save investment costs. In addition, the electricity and gas supply is also located at this wall. The new production line should not adversely affect the test field and the warehouse, which are located in the same building.

[230] cf. H.-P. Wiendahl (2009), p. 479

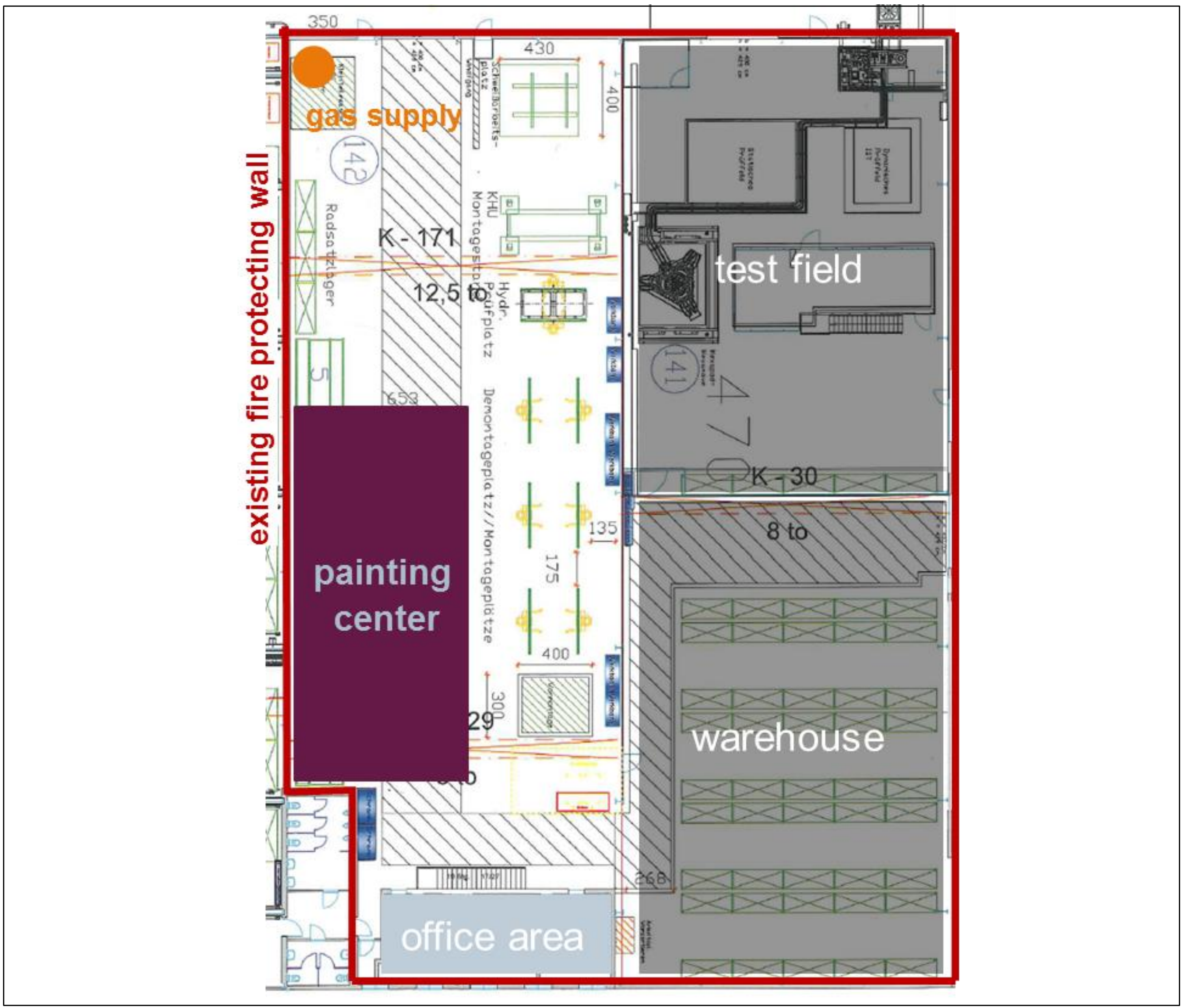

Figure 6-13: Current building structure including constraints

The foundation of the production hall is designed to cope with a load of 8t/m², which is enough for the stated use. This building also has an unused cellar. The building height is 9.5m, which is also suitable for the planned use. Overall, no major construction work or modifications of the building structure are necessary.

6.4 Investment and cost planning

The final part of a feasibility study is an investment appraisal as described in section 3.2.3. In addition, it is a central part of a factory planning because most decisions are made on the basis of the outcome of these calculations. The structure and the most important terms of an investment appraisal are laid out in section 4. The following section deals only with dynamic appraisal methods, due to a higher accuracy of these methods and a more realistic illustration of the investment projects.

6.4.1 Investment appraisal planning

Cost-conscious planning has an important role within the feasibility study because it defines the concept and the necessary technical requirements. The planner has to focus on the following principles:[231]

- Avoidance of quantitative and capacity oversizing
- Prevention of unnecessarily high quality requirements
- Aspiration to a high and constant workload
- Stepwise investment and no extensive upfront early-stage-investment
- Avoidance of disproportionate operating conveniences, such as area required or operational equipment

Based on these statements and on the research of different operational structures, which are described in section 6.1, a total of eight different investment variants were defined. Figure 6-14 shows these possible variants.

[231] cf. B. Aggteleky (1982), p. 671

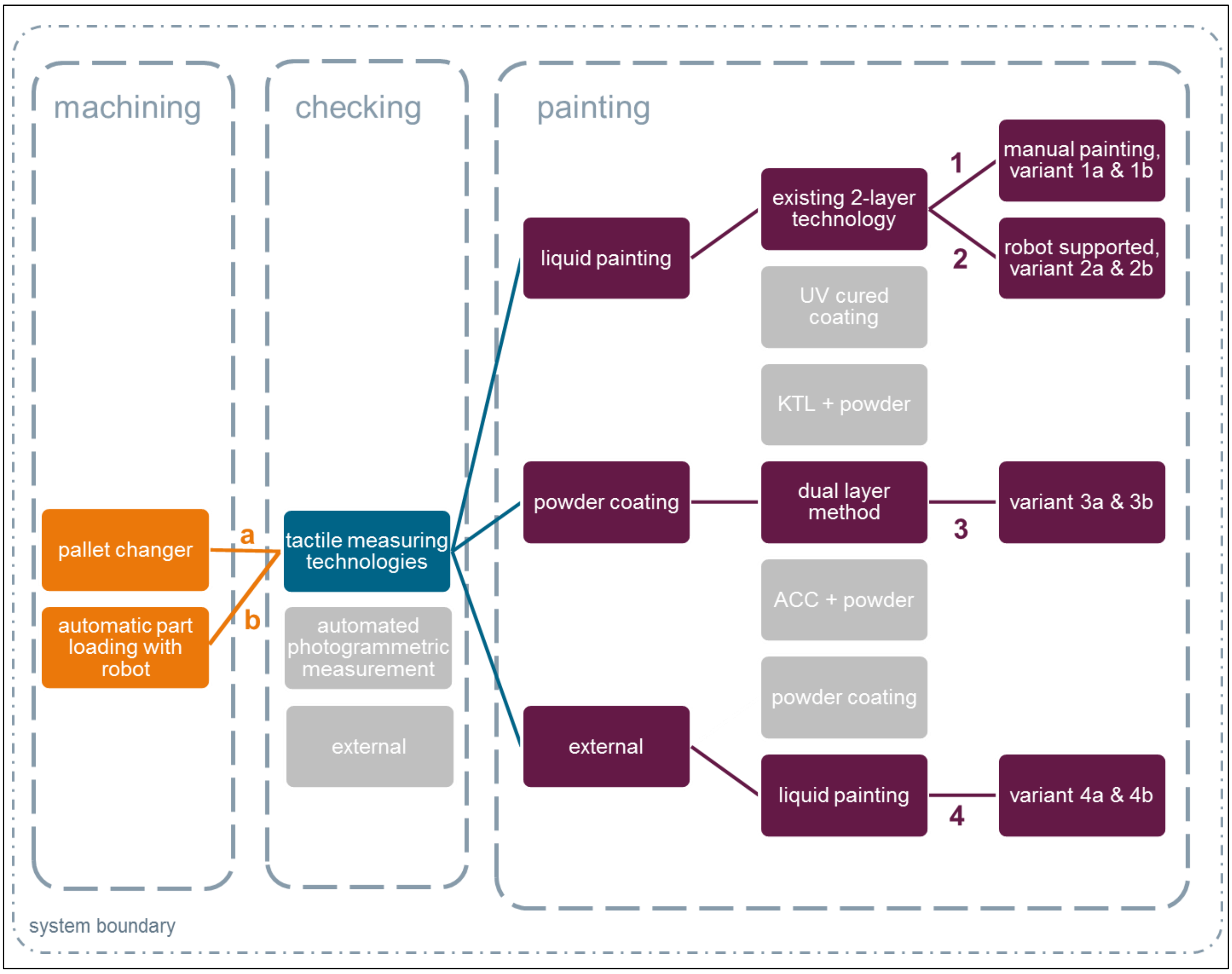

Figure 6-14: Overview of investment appraisal variants

As shown in the figure above, the eight investment variants are a combination of different manufacturing principles. For instance, variant 1a describes a production line including two machining centers with a tactile measuring system and a manual painting system as well as an industrial spray painting system. This is the variant with the lowest degree of automation. In contrast, variant 2b is stated as the option with the highest degree of automation and involves a handling robot for the part loading of two machining centers, a tactile measuring system and a fully-automated industrial spray painting procedure. Alternatively, variant 3a presents the two machining centers including a pallet changer, a tactile measuring device and a dual-layer powder coating system. Finally, variant 4a or 4b include only the machining and checking production steps. It is assumed that raw, not machined, but painted casting parts are procured. These options include only a partial in-house production of axle boxes because research shows that the painting production step is not profitable for the Siemens plant in Graz. This is explained in more detail in the following sections.

6.4.1 Investment planning

Based on the variants in figure 6-14, various discussions were held with companies which specialize in specific fields. The best possible suppliers for the machining, checking and painting production steps were selected on the basis of the information gained in these discussions. All suppliers were then asked to provide a cost estimate, which is the foundation of the investment appraisal and presented in the following section.

Variants 1a & 1b:

Machining, tactile measuring system and manual wet coating procedure

The machining production step can be distinguished between variant “a” with machining centers with a pallet changer, and variant “b” with machining centers with a handling robot for automatic part loading. Furthermore, this variant is based on a manual wet coating system, like the current painting system at the Siemens plant in Graz. The necessary investment for each production step is shown in table 6-5.

	VAR 1a **pallet changer + manual painting**	**VAR 1b** **automatic part loading + manual painting**
expenditure		
machining centers	€ 1 400 000	€ 1 500 000
checking	€ 250 000	€ 250 000
varnishing	€ 500 000	€ 500 000
miscellaneous	€ 60 000	€ 60 000
jib crane	€ 14 000	€ 14 000
one-off cost	€ 262 163	€ 260 163
jigs and fixtures	€ 114 724	€ 146 086

Table 6-5: Expenditures for variants 1a and 1b

The one-off cost row includes specific training courses for employees in the designated operational field, planning costs for the new production line, official qualification by customers as an approved production facility and productivity disadvantages in the ramp-up phase. The jigs and fixtures category has been determined in consultation with the production-engineering department of the Siemens plant in Graz.[232] Due to the storage rack and the automatic part loading system, as mentioned in section 6.1.1, more fixtures are needed than in the variants with pallet changers.

Variants 2a & 2b:

Machining, tactile measuring system and robot supported wet coating procedure

As in previous variants, the machining production step can be distinguished between variant “a” with machining centers with a pallet changer, and variant “b” with machining centers with a handling robot for automatic part loading. Moreover, these options are based on a robot- supported and automatic wet painting system. The investment required is shown in table 6-6.

	VAR 2a **pallet changer + robot supported painting**	**VAR 2b** **automatic part loading + robot supported painting**
expenditure		
machining centers	€ 1 400 000	€ 1 500 000
checking	€ 250 000	€ 250 000
varnishing	€ 1 220 000	€ 1 220 000
miscellaneous	€ 60 000	€ 60 000
jib crane	€ 14 000	€ 14 000
one-off cost	€ 262 163	€ 260 163
jigs and fixtures	€ 114 724	€ 146 086

Table 6-6: Expenditures for variants 2a and 2b

[232] based on department IC RL LOC BG MF-GRZ PE

Variants 3a & 3b:

Machining, tactile measuring system and manual power coating procedure

As mentioned variant “a” includes machining centers with a pallet changer and variant “b” includes machining centers with a handling robot for automatic part loading. Furthermore, these variants are based on a powder coating system. The powder coating system includes a manual powder coating booth which has two advantages. Firstly, a low investment is need and secondly it offers a high degree of flexibility. In addition, an oven and a CO_2-blasting system is included. The investment costs required are shown in table 6-7.

	VAR 3a **pallet changer + powder coating**	**VAR 3b** **automatic part loading + powder coating**
expenditure		
machining centers	€ 1 400 000	€ 1 500 000
checking	€ 250 000	€ 250 000
varnishing	€ 350 000	€ 350 000
miscellaneous	€ 60 000	€ 60 000
jib crane	€ 14 000	€ 14 000
one-off cost	€ 262 163	€ 260 163
jigs and fixtures	€ 114 724	€ 146 086

Table 6-7: Expenditures for variants 3a and 3b

Variants 4a & 4b:

Machining and tactile measuring system without any painting system

As stated before, the machining production step is distinguished in variant “a” and “b”. These variants do not include any painting system and it is assumed that not machined but painted axle boxes are procured. This variant is feasible because painted castings can be machined in machining centers without any major problems and research shows that suppliers can offer a cheaper purchase price for painted parts than an existing paint shop at the Siemens plant in Graz can. Moreover, the painting of axle boxes is not a complex and critical work step compared to machining. It does however entail a significant investment cost. The investment required for these variants is shown in table 6-8.

	VAR 4a **pallet changer + without painting**	**VAR 4b** **automatic part loading + without painting**
expenditure		
machining centers	€ 1 400 000	€ 1 500 000
checking	€ 250 000	€ 250 000
varnishing	€ 0	€ 0
miscellaneous	€ 30 000	€ 30 000
jib crane	€ 7 000	€ 7 000
one-off cost	€ 256 163	€ 254 163
jigs and fixtures	€ 114 724	€ 146 086

Table 6-8: Expenditures for variants 4a and 4b

6.4.2 Savings, due to an in-house production

The production of axle boxes at the Siemens plant in Graz gives five areas compared to the current situation to save cost. These four fields are described in more detail on the following pages.

Reduction of stockholding costs

The storage of goods is necessary for a continuous production of axle boxes, but it also increases the cost of goods. Stockholding costs are related to a fixed time unit and can be broken down into inventory cost, staff cost, operational cost, expenditure on buildings and other additional cost.[233]

[233] cf. H. Martin (2011), p. 343

As a result of a new axle box production facility, the inventory cost can be reduced compared to the present situation. The stocking of raw materials instead of finished parts gives the possibility to reduce the needed storage locations on the one hand, and on the other hand reduces the amount of fixed capital.

- **Inventory opportunity cost**

  Warehousing is an investment in the inventory of a company. Money tied up in inventory is money that cannot be put to work more profitably elsewhere, in the finance markets for example. This amount is reflected in the inventory opportunity cost. This key figure defines which interest rate the fixed capital has through the average inventory cost and the timeframe a product remains in the warehouse.[234]

$$interest\ rate_{stock} = interest\ rate\ p.a. \ \cdot \frac{average\ period\ spend\ in\ stock}{360\ days}$$

Equation 6-1: Storage interest rate

$$inventory\ opportunity\ cost = average\ amount\ in\ stock \cdot interest\ rate_{stock}$$

Equation 6-2: Inventory opportunity cost

Research shows that the average time in stock is four weeks and the amount of finished parts is approximately 700 axle boxes. The interest rate p.a. can be assumed as 8%. These two equations, equation 6-1 and equation 6-2, and including the procurement price of finished as well as raw axle boxes can be used to calculate the savings for one year:

$$inventory\ opportunity\ cost_{savings} = 8500 items \cdot 8\% \cdot \frac{28}{360} \cdot (453.94 - 215.38)$$
$$= \mathbf{12\ 617}\ {}^{\text{€}}\!/_{\boldsymbol{a}}$$

- **Increase of stock capacity**

  In addition to the savings related to inventory carrying costs, a reduction in the storage area needed is possible. Studies show that by storing raw materials instead of finished parts, the capacity within one storage location can be doubled.

[234] cf. K. Bichler et al. (2013), p. 5

At present, four finished axle boxes are stored in one storage location and a tighter packing is not possible due the top coat of these parts. A rearrangement of the raw materials within a storage location makes it possible to store up to eight raw axle boxes in one location.

Current situation, 20.07.2013: 748 axle boxes are stored in 227 pallet storage locations.

$$current\ stock\ cost = 11.7\ {}^{€}/_{loaction,\, month} \cdot 227\ locations = 2\ 656\ {}^{€}/_{month}$$

New storage concept: increased capacity per location and optimized storing

$$new\ stock\ cost = 11.7\ {}^{€}/_{loaction,\, month} \cdot 94\ location = 1\ 100\ {}^{€}/_{month}$$

Stock savings within one year

$$stock\ savings = \left(2\ 656\ {}^{€}/_{month} - 1\ 100\ {}^{€}/_{month}\right) \cdot 12 = \mathbf{18\ 672}\ {}^{€}/_{\boldsymbol{a}}$$

The calculation shows that € 18 672 per year can be saved by means of this improvement Moreover, it is assumed that all axle boxes, which were produced in the new production facility, are assembled just-in-time and no safety stock is built in.

Sale of scrap metal

With a maximum capacity of 8500 pieces per year and a scrap price for spheroidal graphite cast iron of € 0.18 per kg, an in-depth assessment for the earnings of scrap metal sale was done, as shown in table 6-9.

	Spheroidal graphite cast iron using the example of SF7000	Spheroidal graphite cast iron using the example of SF500 DSW
% of production	30.8%	13,6%
raw weight / item*	75,00 kg/item	102,00 kg/item
machined weight / item*	57,00 kg/item	73,33 kg/item
delta / item	18,00 kg/item	28,67 kg/item
proceeds of sale / item	3,24 €/piece	5,16 €/piece

Table 6-9: Scrap metal sale (*based on SAP product data)

For this calculation, two representative axle boxes were chosen and further research was carried out. The percentages of total production are based on the portfolio analysis from section 5.4. The data for raw part weight and machined part weight is gathered from the current versions of available drawings and CAD models. The delta between the raw and the machined part weight is the amount of scrap per work item. This amount is multiplied by the scrap price to obtain the potential sales revenue per item.

$$average_{scrapearnings} = 3.24\ {}^{€}/_{item} \cdot 0.308 + 5.16\ {}^{€}/_{item} \cdot 0.136\ +$$
$$\left(\frac{3.24 + 5.16}{2}\right) {}^{€}/_{item} \cdot 0.556 = 4.03€/item$$
$$sale\ of\ scrap\ metal_{year} = 8500\ {}^{itemes}/_{year} \cdot\ 4.03\ {}^{€}/_{items} = \mathbf{34\ 255}\ {}^{€}/_{\boldsymbol{a}}$$

As shown in the calculation above, it can be estimated that on average every work item adds earnings due to the sale of scrap metal of € 4.03.

In-house production

Additionally, savings in relation to the initial situation are achieved through an in-house production. The stated processing time from section 6.2.1 can be summarized to 111 min per axle box. An hourly rate was calculated for each variant based on Siemens' internal documentation and comparison with a cost center of similar size. These hourly rates varied between € 78.56 and € 86.64 per hour. The hourly rate includes the annual linear depreciation, staff costs, cost allocations, occupancy cost, auxiliary materials, maintenance costs, IT costs and additional services.

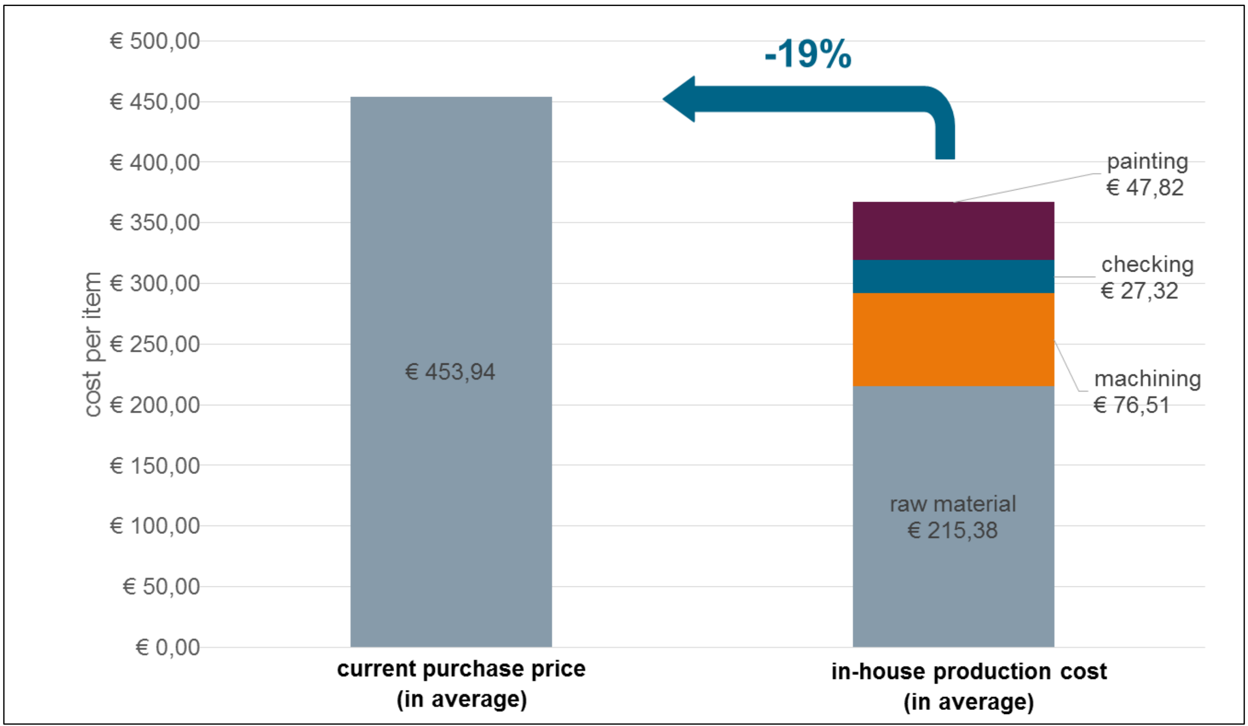

Figure 6-15: Comparison between in-house production cost and current purchase price[235]

The calculation example in figure 6-15 shows that an in-house production of axle boxes gives the possibility to produce axle boxes 19% cheaper than the current supplier offer.

6.4.3 Profitability and investment appraisal

In the final stage of an investment appraisal based on all the information collected, various figures for each variant are calculated. First, the EVA was for the timespan of five and ten years, as described in section 4.3 calculated. Second the dynamic payback period from section 4.2.3 and third, the compound annual growth rate, mentioned in section 4.4, were calculated.

All results gathered from the structure planning, material flow analysis, layout planning, investment planning and savings are included in the investment appraisals. The economic value added method, in German “GWB”, is the most important indicator for profitable business units within Siemens. However, a short payback period indicates a

[235] based on 81.97€/h hourly rate and 111minutes required processing time

lucrative project and the compound annual growth rate verifies that an investment is still profitable even at the end of the operational life of an asset.

In addition to the production employees required, each variant also includes two administrative staffs, who are necessary for supervision and administrative tasks.

Moreover, the linear depreciation of assets is linear is set at ten years and the WACC is stated due to Siemens internal regulations to 8%.

	VAR 1a **pallet changer + manual painting**	**VAR 1b** **automatic part loading + manual painting**
employees required	9	8
hourly rate	82.06 €/h	79.52 €/h
fixed assets in T€	**T€ 2 224**	**T€ 2 324**
GWB after 5 years	**T€ 1 428**	**T€ 1 480**
GWB after 10 years	**T€ 3 570**	**T€ 3 715**
dynamic payback period	**4.1 a**	**4.1 a**
CAGR	**12.9%**	**12.8%**

Table 6-10: Results of investment appraisal variants 1a and 1b

	VAR 2a **pallet changer + automated painting**	**VAR 2b** **automatic part loading + automated painting**
employees required	9	8
hourly rate	86.64 €/h	84.10 €/h
fixed assets in T€	**T€ 2 944**	**T€ 3 044**
GWB after 5 years	**T€ 1 071**	**T€ 1 123**
GWB after 10 years	**T€ 3 015**	**T€ 3 160**
dynamic payback period	**4.7 a**	**4.7 a**
CAGR	**9.7%**	**9.8%**

Table 6-11: Results of investment appraisal variants 2a and 2b

	VAR 3a **pallet changer + powder coating**	**VAR 3b** **automatic part loading + powder coating**
employees required	9	8
hourly rate	81.11 €/h	78.56 €/h
fixed assets in T€	**T€ 2 074**	**T€ 2 174**
GWB after 5 years	**T€ 1 502**	**T€ 1 554**
GWB after 10 years	**T€ 3 686**	**T€ 3 831**
dynamic payback period	**4.0 a**	**4.0 a**
CAGR	**13.6%**	**13.6%**

Table 6-12: Results of investment appraisal variants 3a and 3b

	VAR 4a **pallet changer + external painting**	**VAR 4b** **automatic part loading + external painting**
employees required	6	5
hourly rate	83.94 €/h	80.70 €/h
fixed assets in T€	**T€ 1 687**	**T€ 1 787**
GWB after 5 years	**T€ 1 394**	**T€ 1 446**
GWB after 10 years	**T€ 3 383**	**T€ 3 528**
dynamic payback period	**3.8 a**	**3.9 a**
CAGR	**14.6%**	**14.5%**

Table 6-13: Results of investment appraisal variants 4a and 4b

Table 6-10, table 6-11, table 6-12 and table 6-13 provide an overview of the results of the investment appraisals carried out.

6.4.4 Assessment of project alternatives

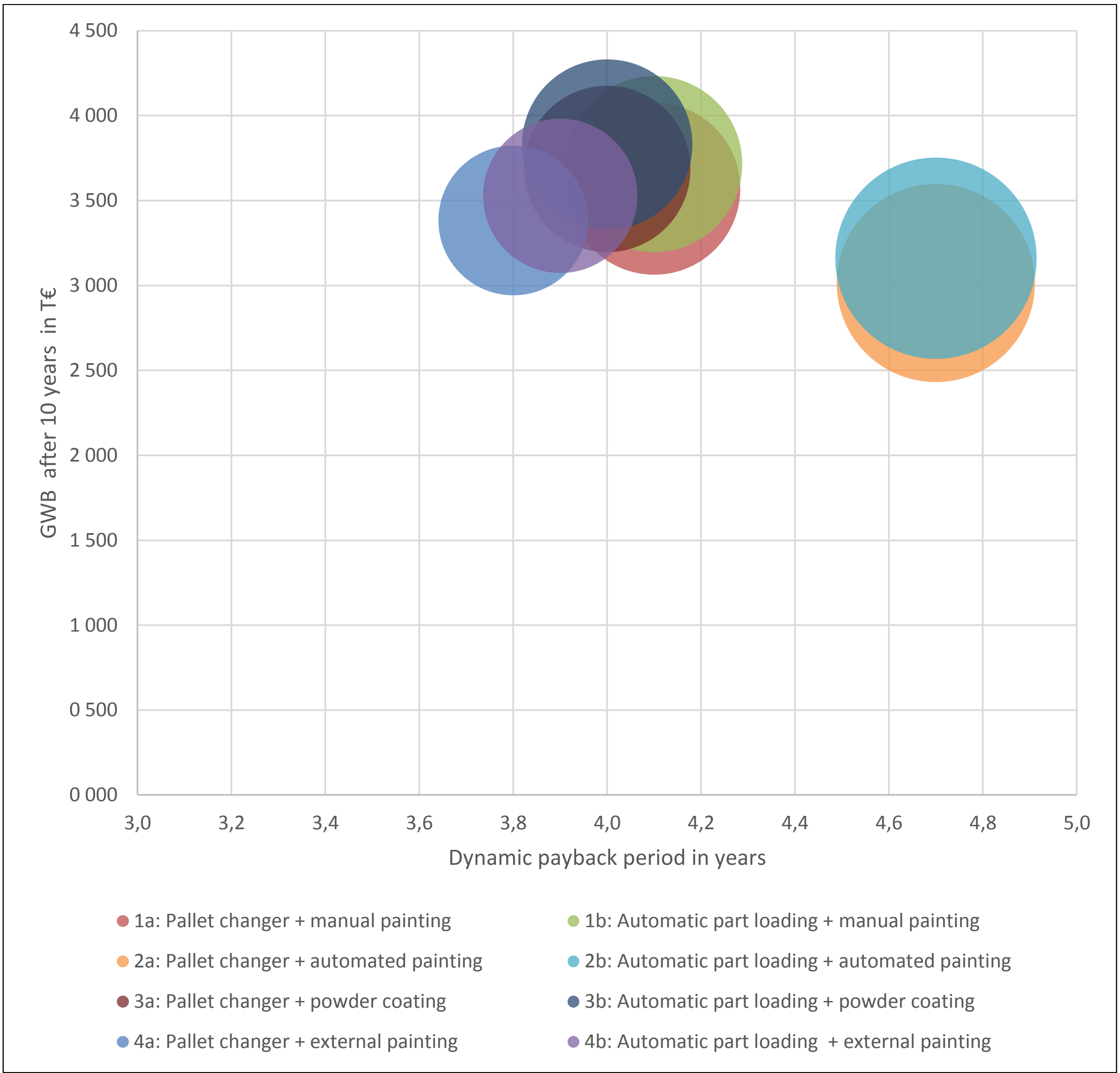

Figure 6-16: Overview of results of investment appraisal

The chart in figure 6-16 gives an overview of the results of the eight variants. The bubble size of each variant is an indicator of the investment costs required. As mentioned previously, variant 2a and 2b have the highest investment cost due to the higher capital expenditure for the automated painting system, and so their respective bubble size is larger. Furthermore, the horizontal axis shows the dynamic payback period. The variant 4a, machining centers with a pallet changer and external painting, has the shortest payback period of 3.0 years as it has the lowest investment cost. The variant 3b, machining centers with automatic part handling and powder coating system, has the highest EVA after ten years as well as after 5 years of operational use. This is shown on the vertical axis. The reason for this is the low hourly rate because of lower investment costs in comparison with the wet painting procedures. In addition, the number of employees required is lower compared to the machining centers with a pallet changer due to the unmanned night shifts.

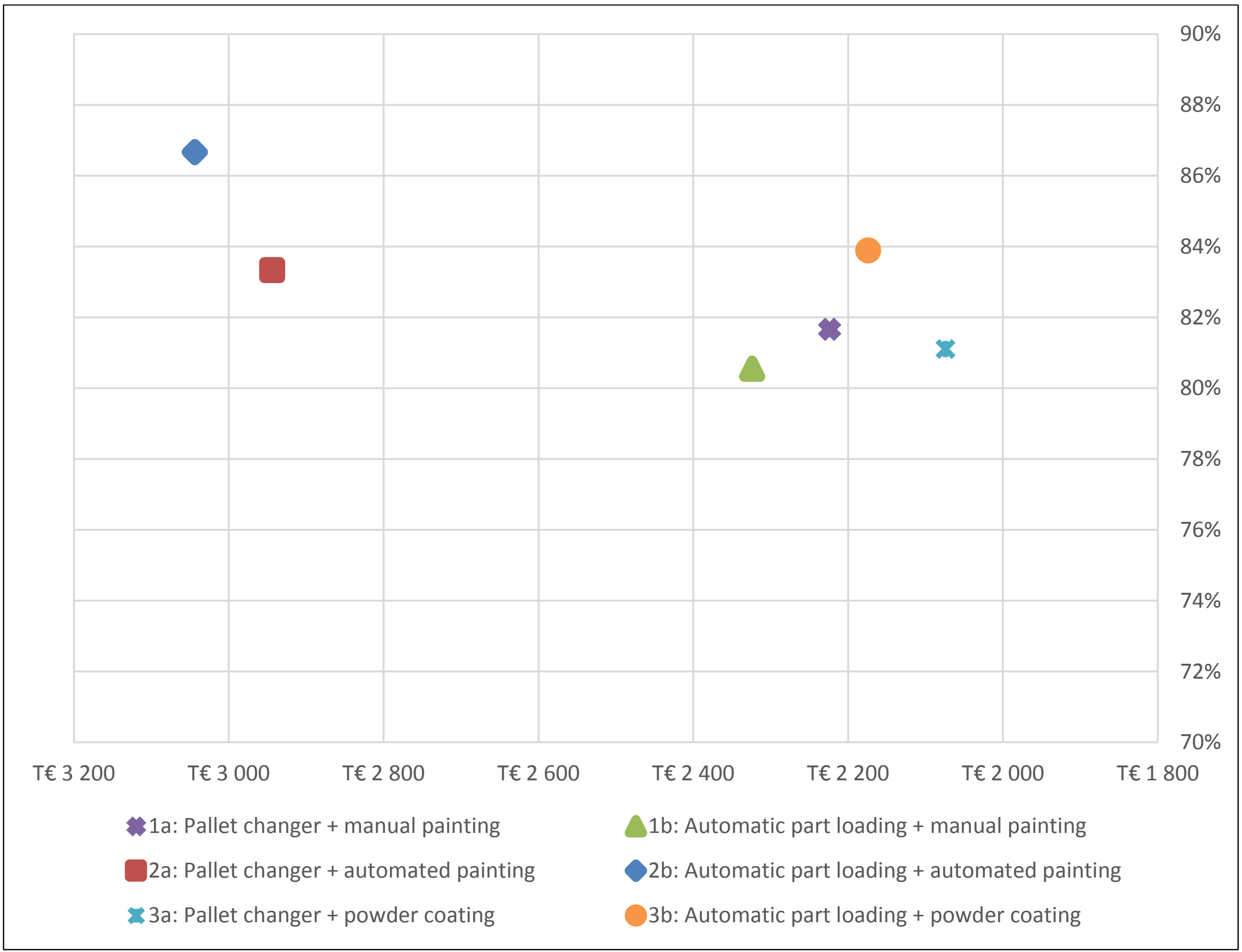

Figure 6-17: Results of value benefit analysis

It is also important to include non-monetary factors in an investment decision. As described in section 6.2.2.3, this is done within a value benefit analysis. Figure 6-17 shows the result of this analysis. The horizontal axis displays the required investment cost of each variant and the vertical axis shows the percentages that are received during the value benefit analysis. Variant 2b, machining centers with automatic part loading and automatic painting systems, has the highest ranking but has also the highest investment cost. In contrast, variant 4b has a slightly lower ranking in the value benefit analysis but a far lower investment is required for this option.

7 Conclusion and future perspectives

This thesis provides a feasibility study for strategic factory and technology planning at the Siemens plant in Graz. As stated in the beginning, the feasibility study is a supportive tool for the plant management which will help to make an important decision on whether or not to invest in an axle box production at the Siemens plant in Graz. This thesis is the basis for further investigations and shows possible options how such a production line could look like.

Other advantages than monetary factors of an in-house production are laid out in section 2. It is important to enhance the concept of “one-roof” production within the factory location. Because product development and manufacturing at the same site are a great combination in relation of product innovation and it helps a company to stay competitive, as the case of GE in section 2.2 shows. In addition, a simplification of the procurement process goes hand in hand with an in-house production of axle boxes. Based on information from the procurement department, the current procurement time to receive a machined and painted axle box is 16 working weeks. In contrast, the procurement time for a raw casting is four weeks. The material flow analysis shows that the door-to-door time for one axle box is always less than one working week. This means that the procurement time span can be reduced from 16 to five working weeks. Furthermore, an in-house production increases supply stability and process reliability as well as it reduces the inventory cost and shorten the procurement process.

The first stage in a factory planning project is the target planning. In case of an axle box production at the Siemens plant in Graz this stage includes a detailed task and target definition, an initial situation study, a portfolio analysis of the current production program, an overview of the existing operational structures, a rough value stream analysis as well as an outline schedule for a possible ramp-up scenario. The collected information shows that Siemens Graz has built up considerable knowledge over the last decade in the fields of milling and painting. Nevertheless, the examples discussed in section 6.1 show that improvements are possible, particularly in connection with the painting procedure, compared to the traditional procedure. These enhancements, such as CO_2 part cleaning, lead to quality improvements and cost savings. Moreover, the analysis of the current production portfolio shows that the stated capacity of 8500 axle boxes per year is feasible.

During this thesis, two tests were performed to verify that CO_2-blasting technology is a suitable cleaning method. These tests show the general possibility to use this principle to clean axle boxes after the machining step and before the painting procedure. Based on that all variants include this cleaning principle. The implementation of this technology will reduce the maintenance and operating costs in comparison to the established wet chemical process.

A material flow analysis is carried out with the use of a simulation software to optimize the planned production facility. Based on this simulation, possible door-to-door times, maximum output capacities and bottlenecks of the production are described. Furthermore, to obtain and collect all the necessary information for an investment appraisal, several meetings with potential suppliers were carried out during the project time and offers have been collected.

In total eight different variants of a new axle box production were generated during the work on this thesis and for each variant an investment appraisal is carried out. The key results are shown in table 7-1.

	VAR 1a	**VAR 1b**	**VAR 2a**	**VAR 2b**
value benefit analysis	81%	82%	83%	87%
total investment	T€ 2 601	T€ 2 730	T€ 3 321	T€ 3 450
dynamic payback period	4.1 a	4.1 a	4.7 a	4.7 a
CAGR	12.9%	12.8%	9.7%	9.8%
	VAR 3a	**VAR 3b**	**VAR 4a**	**VAR 4b**
value benefit analysis	81%	84%	-	-
total investment	T€ 2 451	T€ 2 580	T€ 2 058	T€ 2 187
dynamic payback period	4.0 a	4.0 a	3.8 a	3.9 a
CAGR	13.6%	13.6%	14.6%	14.5%

Table 7-1: Overview of results of investment appraisal

The best result in the performed value benefit analysis is achieved by the variant 2b. This variant includes an automatic part handling, a tactile measuring system and a robot supported painting system. In contrast, this variant has the highest investment cost. The research shows that the robot supported painting system is not working on its capacity limits and that is why this variant is not feasible.

As a consequence of this thesis, the implementation of variant 3b is recommended which entails the acquisition of two machining centers with a handling robot for automatic part loading, a tactile measuring system, a CO_2 part cleaning station, a manual powder coating booth as well as a dryer. In addition to a good rating in the value benefit analysis and satisfactory result in the investment appraisal, this variant includes the chance to use two technologies that are new to the factory location in Graz. However, the generated knowhow from these technologies - automatic part handling and powder coating - can offer various productivity improvements in other segments within the Siemens plant in Graz. In addition, the powder coating technology offers the possibility to reduce work activities within the masking step, which leads to a reduction in the door-to-door time and production cost. Current trials within Siemens Graz show high potentials for the usage of powder coating. Nevertheless, a customer acceptance has to be verified.

Another likely consequence of this thesis is the implementation of variant 4a. As shown in table 7-1, this variant has very low investment cost and a short payback period. The external painting presupposes that the parts are machined after the painting procedure and that the additional costs for logistics is relatively low. Due to the fact, that raw but painted axle boxes are stocked, a reduction of stockholding costs is not possible. Another negative aspect of this variant is the fact that possible casting errors are detected at a later stage in the production. In contrast, this variant offers a high degree of adaptability, which means that a painting system can be implemented in a later stage.

Overall, this master thesis shows that an axle box production is profitable at the Siemens plant in Graz. The output of this thesis is a detailed documentation of possible future scenarios. The results are a supportive tool that will help to make an essential decision on whether or not to invest in a new axle box production at the Siemens plant in Graz.

8 List of references

Abele, E., Meyer, T., Näher, U., Strube, G. and Sykes, R. (eds) *Global Production*, Berlin, Heidelberg (2008)

Aggteleky, B. *Fabrikplanung - Werksentwicklung und Betriebsrationalisierung, Band 1*, München (1981)

Aggteleky, B. *Fabrikplanung - Werksentwicklung und Betriebsrationalisierung, Band 2*, München (1982)

Anon ‘Lackierungen energiesparend und schnell einbrennen’, *JOT Journal für Oberflächentechnik* 53, (p. 20–21), February, 2013

Bacher, M. *Outsourcing als strategische Marketing-Entscheidung*, Wiesbaden (2000)

Bangsow, S. *Praxishandbuch Plant Simulation und SimTalk*, München (2011)

Bichler, K., Riedel, G. and Schöppach, F. *Kompakt Edition: Lagerwirtschaft*, Wiesbaden (2013)

Bilz, M., Motschmann, S. and Uhlmann, E. ‘Eiskalt sauber’, *JOT Journal für Oberflächentechnik* 52, (p. 74–79), February, 2012

Bracht, U., Geckler, D. and Wenzel, S. *Digitale Fabrik*, Berlin, Heidelberg (2011)

Bretzke, W.-R. *Logistische Netzwerke* (2. Auflage), Berlin, Heidelberg (2010)

Brock, T., Groteklaes, M. and Mischke, P. *Lehrbuch der Lacktechnologie* (3. Auflage), Hannover (2009)

Carstensen, P. *Investitionsrechnung kompakt*, Wiesbaden (2008)

Depner, E. *Excel für Fortgeschrittene am Beispiel der Darlehenskalkulation und Investitionsrechnung*, Wiesbaden (2012)

Dilinger, J., Dobler, H.-D., Doll, W., Escherich, W., Günter, W. and Heinzler, M. *Fachkunde Metall - mechanische Technologie* (55. Auflage), Haan-Gruiten (2007)

Dittrich, J. and Braun, M. *Business Process Outsourcing*, Stuttgart (2004)

Doig, S., Ritter, R., Speckhals, K. and Woolson, D. 'Has outsourcing gone too far?', *The McKinsey Quarterly* (p. 25–37), September, 2001

Ermschel, U., Möbius, C. and Wengert, H. *Investition und Finanzierung* (3. Auflage), Berlin, Heidelberg (2013)

Fishman, C. 'The Insourcing Boom', *The Atlantic* 310, (p. 45), December, 2012

Fraunberger, R. 'Teil 2 : Vollautomatisiert Fertigteile ernten', *x-technik* (p. 32–36), 2012

Goldschmidt, A. and Streitberger, H.-J. *BASF-Handbuch Lackiertechnik*, Hannover (2002)

Götze, U. *Investitionsrechnung*, Berlin, Heidelberg (2008)

Greyer, A., Hanke, M., Littich, E. and Nettekoven, M. *Grundlagen der Finanzierung* (3. Auflage), Wien (2009)

Grundig, C.-G. *Fabrikplanung* (4. Auflage), München (2012)

Heesen, B. *Investitionsrechnung für Praktiker*, Wiesbaden (2012)

Hehenberger, P. *Computerunterstützte Fertigung*, Berlin, Heidelberg (2011)

Jenster, P. V., Pedersen, H.S., Plackett, P. and Hussey, D. *Outsourcing -- Insourcing: Can vendors make money from the new relationship opportunities* (2005)

Juchmes, D. 'Kosten bei der Vorbehandlung von Lackiergut senken', *Besser lackieren!* 1, (p. 8), 2010

Koppelmann, U. (ed.) *Outsourcing*, Stuttgart (1996)

Koppelmann, U. (ed.) *Beschaffungsmarketing* (3. Auflage), Berlin, Heidelberg (2000)

Lang, M. 'Erfolgreiches Outsourcing', Technische Universität Graz (2007)

Martin, H. *Transport- und Lagerlogistik* (8. Auflage), Wiesbaden (2011)

Obst, M. *Lackiererein planen und optimieren*, Hannover (2002)

Ondratschenk, D. *besser lackieren! Jahrbuch 2008*, Hannover (2007)

Pawellek, G. *Ganzheitliche Fabrikplanung*, Berlin, Heidelberg (2008)

Pietschmann, J. *Industrielle Pulverbeschichtung* (3. Auflage), Wiesbaden (2010)

Poggensee, K. *Investitionsrechnung* (2. Auflage), Wiesbaden (2011)

Ramsauer, C. *Production strategy*, Graz (2009)

Schawel, C. and Billing, F. 'Top 100 Management Tools', (p. 86–88), 2012

Schenk, M. and Wirth, S. *Fabrikplanung und Fabrikbetrieb*, Berlin, Heidelberg (2004)

Schenk, M., Wirth, S. and Müller, E. *Factory Planning Manual*, Berlin, Heidelberg (2010)

Siemens AG *Produkte Siemens Graz, internal document A6Z0003415885*, Graz (2006)

Siemens AG *Weltkompetenzzentrum Fahrwerke, internal document AZ600034587839*, Graz (2013a)

Siemens AG *Painting specification, internal document AZ699000552005*, Graz (2013b)

Sokol, A. a. 'Ultraviolet (UV) cured coatings', *Metal Finishing* 108, (p. 196–204), December 2010

Streitberger, H.-J. and Kittel, H. (eds) *Anwendung von Lacken und sonstigen Beschichtungen* (2. Auflage), Stuttgart (2008)

Trage, S. 'Renaissance in Manufacturing', *Pictures of the Future, Spring 2013* (p. 36–37), 2013

VDI *VDI4499 Blatt1: Digitale Fabrik Grundlagen* (2008)

VDI *VDI 3633 Blatt11: Simulation von Logistik- , Materialfluss- Simulation und Visualisierung* (2009)

Venkatesan, R. 'Strategic Sourcing: To Make or Not To Make', *Harvard Business Review* (1992)

Wiendahl, H.-P., Reichardt, J. and Nyhuis, P. *Handbuch Fabrikplanung*, München (2009)

Wildemann, H. *Make or buy & insourcing* (18. Auflage), München (2010)

Womack, J.P., Jones, D.T. and Roos, D. *Die zweite Revolution in der Autoindustrie* (8. Auflage), Frankfurt, New York (1994)

Zirkler, B. 'Der Economic Value Added (EVAR®) als Konzept für den Mittelstand', *Controlling und Management* 46, (p. 98–104), August, 2002

9 Internet resources

Gabler Verlag (Publisher), Gabler Wirtschaftslexikon, Insourcing, internet: http://wirtschaftslexikon.gabler.de/Archiv/55838/insourcing-v4.html, retrieved 30.09.2013

Gabler Verlag (Publisher), Gabler Wirtschaftslexikon, Outsourcing, internet: http://wirtschaftslexikon.gabler.de/Archiv/54709/outsourcing-v8.html , retrieved 30.09.2013

Siemens AG, Press text “Infrastructure & Cities Sector“, internet: http://www.siemens.com/press/pool/de/events/2012/infrastructure-cities/2012-09-thecrystal/factsheet-ic-e.pdf , retrieved 30.09.2013

Siemens AG, Press text “Siemens - the company Infrastructure & Cities Sector “, internet: http://www.siemens.com/about/pool/business/infrastructure_cities/ic_2013_q1_update_en.pdf , retrieved 30.09.2013

EISENMANN Anlagenbau GmbH & Co. KG, Products & Service “Powder coating - diagram“, internet: http://www.eisenmann.com/en/products-and-services/application-and-robotics/paint-application/powder-coating.html, retrieved 14.10.2013

10 List of figures

11 List of tables

12 List of abbreviations

ACC	Autophoretic Coating Chemicals
CAD	Computer-Aided Design
CAGR	Compound Annual Growth Rate
CIF	Computer Integrated Facility Management
CNC	Computerized Numerical Control
DMU	Digital Mock Up
EVA	Economic Value Added
GDP	Gross Domestic Product
GWB	Geschäftswertbeitrag (Economic Value Added)
KTL	Cathodic Dip Coating (kathodische Tauchlackierung)
RASMO	Wheel set assembly (Radsatzmontage)
UV	Ultraviolet
VR	Virtual Reality
WACC	Weighted Average Cost of Capital

13 Formula directory

Appendix

Additional information – investment appraisal

Axle Box Production

Project title: axle box production; plant Graz

VAR1a: pallet changer + manual painting

Pos.	Investment appraisal (values in 1000 Euro)	Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
		1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers	2'224	0'791	1'433									
2													
	Operative result												
3													
4	Earnings before interest, tax and depreciation (EBITD)	11'585	-0'148	0'320	0'903	1'218	1'248	1'276	1'308	1'340	1'374	1'409	1'337
5	Tax depreciation	2'185	0'111	0'220	0'220	0'220	0'220	0'217	0'217	0'217	0'217	0'217	0'110
6	Earnings before interest and tax (EBIT) (Pos. 3 + Pos. 4 - Pos. 5)	9'400	-0'259	0'100	0'683	0'998	1'028	1'059	1'091	1'123	1'157	1'192	1'228
7	Net operating profit after taxes (NOPAT) tax rate: 25%	6'985	-0'259	0'075	0'513	0'748	0'771	0'794	0'818	0'843	0'868	0'894	0'921
8	in % of assets (Pos. 7 / Pos. 11)	-	-38,1%	4,1%	33,7%	60,6%	76,5%	101,3%	146,0%	250,8%	778,3%	k. A.	k. A.
	Revenue through tax loss compensation		0'065										
	Assets / cost of capital												
9	Fixed assets after depreciation (Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'679	1'893	1'673	1'453	1'234	1'017	0'800	0'583	0'366	0'149	0'039
10	Current operating assets	-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets (Pos. 9 + Pos. 10)	-	0'679	1'820	1'523	1'234	1'008	0'784	0'560	0'336	0'112	-0'113	-0'230
12	Weighted average cost of capita (WACC) rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes (Pos. 11 x Pos. 12)	0'617	0'054	0'146	0'122	0'099	0'081	0'063	0'045	0'027	0'009	-0'009	-0'018
	Economic Value Added												
14	Periodical economic value added (EVA) (Pos. 7 - Pos. 13)	6'433	-0'249	-0'071	0'391	0'650	0'690	0'731	0'773	0'816	0'859	0'903	0'939
15	**Economic value added** discount interest rate: 8%	**3'570**						**1'428**					
16	Series of payments (Pos. 7 + Pos. 8 - Δ Pos. 11)	7'280	-0'874	-1'066	0'810	1'037	0'997	1'018	1'042	1'067	1'092	1'119	1'038
	Accumulated		-0'874	-1'939	-1'130	-0'092	0'905	1'923	2'965	4'031	5'124	6'242	7'280

CAGR 12,9%

Payback period 49,1 months

4,1 years

Axle Box Production

Project title: axle box production; plant Graz

VAR1b: automatic part loading + manual painting

Pos.	Investment appraisal	values in 1000 Euro	Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
			1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers		2'324	0'824	1'500									
2														
	Operative result													
3														
4	Earnings before interest, tax and depreciation (EBITD)		12'088	-0'166	0'334	0'943	1'272	1'303	1'333	1'366	1'400	1'435	1'472	1'396
5	Tax depreciation		2'285	0'116	0'230	0'230	0'230	0'230	0'227	0'227	0'227	0'227	0'227	0'115
6	Earnings before interest and tax (EBIT)	(Pos. 3 + Pos. 4 - Pos. 5)	9'803	-0'282	0'104	0'714	1'042	1'073	1'106	1'139	1'173	1'208	1'245	1'282
7	Net operating profit after taxes (NOPAT)	tax rate: 25%	7'282	-0'282	0'078	0'535	0'782	0'805	0'829	0'854	0'880	0'906	0'933	0'961
8	in % of assets	(Pos. 7 / Pos. 11)	-	-39,9%	4,1%	33,5%	60,2%	75,7%	100,0%	143,5%	243,8%	716,3%	k. A.	k. A.
	Revenue through tax loss compensation			0'071										
	Assets / cost of capital													
9	Fixed assets after depreciation	(Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'708	1'978	1'748	1'518	1'289	1'062	0'835	0'608	0'381	0'154	0'039
10	Current operating assets		-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets	(Pos. 9 + Pos. 10)	-	0'708	1'905	1'598	1'299	1'063	0'829	0'595	0'361	0'127	-0'108	-0'230
12	Weighted average cost of capital (WACC)	rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes	(Pos. 11 x Pos. 12)	0'652	0'057	0'152	0'128	0'104	0'085	0'066	0'048	0'029	0'010	-0'009	-0'018
	Economic Value Added													
14	Periodical economic value added (EVA)	(Pos. 7 - Pos. 13)	6'701	-0'268	-0'075	0'407	0'678	0'720	0'763	0'807	0'851	0'896	0'942	0'980
15	**Economic value added**	discount interest rate: 8%	**3'715**						**1'480**					
16	Series of payments	(Pos. 7 + Pos. 8 - Δ Pos. 11)	7'583	-0'919	-1'120	0'842	1'080	1'041	1'063	1'088	1'114	1'141	1'168	1'084
	Accumulated			-0'919	-2'039	-1'197	-0'116	0'925	1'988	3'076	4'190	5'331	6'499	7'583

CAGR **12,8%** **Payback period** 49,3 months **4,1 years**

Axle Box Production

Project title: axle box production; plant Graz

VAR2a: pallet changer + automated painting

Pos.	Investment appraisal — values in 1000 Euro	Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
		1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers	2'944	1'031	1'913									
2													
	Operative result												
3													
4	Earnings before interest, tax and depreciation (EBITD)	11'481	-0'148	0'365	0'921	1'210	1'238	1'263	1'293	1'323	1'354	1'386	1'275
5	Tax depreciation	2'905	0'147	0'292	0'292	0'292	0'292	0'289	0'289	0'289	0'289	0'289	0'146
6	Earnings before interest and tax (EBIT) (Pos. 3 + Pos. 4 - Pos. 5)	8'576	-0'295	0'074	0'629	0'918	0'946	0'974	1'004	1'034	1'065	1'097	1'130
7	Net operating profit after taxes (NOPAT) tax rate: 25%	6'359	-0'295	0'055	0'472	0'689	0'710	0'731	0'753	0'775	0'799	0'823	0'847
8	in % of assets (Pos. 7 / Pos. 11)	-	-33,4%	2,3%	22,9%	40,5%	50,5%	66,0%	92,7%	150,3%	363,9%	k. A.	k. A.
	Revenue through tax loss compensation		0'074										
	Assets / cost of capital												
9	Fixed assets after depreciation (Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'883	2'505	2'213	1'921	1'630	1'341	1'052	0'763	0'474	0'185	0'039
10	Current operating assets	-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets (Pos. 9 + Pos. 10)	-	0'883	2'432	2'063	1'702	1'404	1'108	0'812	0'516	0'220	-0'077	-0'230
12	Weighted average cost of capital (WACC) rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes (Pos. 11 x Pos. 12)	0'867	0'071	0'195	0'165	0'136	0'112	0'089	0'065	0'041	0'018	-0'006	-0'018
	Economic Value Added												
14	Periodical economic value added (EVA) (Pos. 7 - Pos. 13)	5'566	-0'292	-0'139	0'307	0'553	0'597	0'642	0'688	0'734	0'781	0'829	0'866
15	**Economic value added** discount interest rate: 8%	**3'015**						**1'071**					
16	Series of payments (Pos. 7 + Pos. 8 - Δ Pos. 11)	6'663	-1'105	-1'493	0'841	1'050	1'008	1'027	1'049	1'072	1'095	1'119	1'001
	Accumulated		-1'105	-2'598	-1'757	-0'708	0'300	1'327	2'376	3'447	4'543	5'662	6'663

CAGR 9,7% **Payback period** 56,4 months **4,7 years**

Axle Box Production

Project title: axle box production; plant Graz

VAR2b: automatic part loading + automated painting

Pos.	Investment appraisal – values in 1000 Euro		Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
			1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers		3'044	1'064	1'980									
2														
	Operative result													
3														
4	Earnings before interest, tax and depreciation (EBITD)		11'985	-0'166	0'379	0'961	1'264	1'293	1'320	1'351	1'383	1'415	1'449	1'335
5	Tax depreciation		3'005	0'152	0'302	0'302	0'302	0'302	0'299	0'299	0'299	0'299	0'299	0'151
6	Earnings before interest and tax (EBIT)	(Pos. 3 + Pos. 4 - Pos. 5)	8'980	-0'318	0'077	0'659	0'963	0'992	1'021	1'052	1'084	1'116	1'150	1'184
7	Net operating profit after taxes (NOPAT)	tax rate: 25%	6'655	-0'318	0'058	0'494	0'722	0'744	0'766	0'789	0'813	0'837	0'862	0'888
8	in % of assets	(Pos. 7 / Pos. 11)	-	-34,9%	2,3%	23,1%	40,9%	51,0%	66,4%	93,1%	150,3%	357,0%	k. A.	k. A.
	Revenue through tax loss compensation			0'080										
	Assets / cost of capital													
9	Fixed assets after depreciation	(Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'912	2'590	2'288	1'986	1'685	1'386	1'087	0'788	0'489	0'190	0'039
10	Current operating assets		-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets	(Pos. 9 + Pos. 10)	-	0'912	2'517	2'138	1'767	1'459	1'153	0'847	0'541	0'235	-0'072	-0'230
12	Weighted average cost of capital (WACC)	rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes	(Pos. 11 x Pos. 12)	0'901	0'073	0'201	0'171	0'141	0'117	0'092	0'068	0'043	0'019	-0'006	-0'018
	Economic Value Added													
14	Periodical economic value added (EVA)	(Pos. 7 - Pos. 13)	5'833	-0'312	-0'143	0'323	0'581	0'627	0'674	0'721	0'769	0'818	0'868	0'907
15	**Economic value added**	discount interest rate: 8%	**3'160**						**1'123**					
16	Series of payments	(Pos. 7 + Pos. 8 - Δ Pos. 11)	6'965	-1'150	-1'547	0'873	1'093	1'052	1'072	1'095	1'119	1'144	1'169	1'047
	Accumulated			-1'150	-2'698	-1'824	-0'732	0'320	1'392	2'487	3'606	4'750	5'919	6'965

CAGR **9,8%**

Payback period 56,3 months **4,7 years**

Axle Box Production

Project title: axle box production; plant Graz

VAR3a: pallet changer + powder coating

Pos.	Investment appraisal – values in 1000 Euro		Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
			1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers		2'074	0'741	1'333									
2														
	Operative result													
3														
4	Earnings before interest, tax and depreciation (EBITD)		11'606	-0'148	0'310	0'900	1'219	1'250	1'278	1'311	1'344	1'378	1'414	1'350
5	Tax depreciation		2'035	0'104	0'205	0'205	0'205	0'205	0'202	0'202	0'202	0'202	0'202	0'102
6	Earnings before interest and tax (EBIT)	(Pos. 3 + Pos. 4 - Pos. 5)	9'571	-0'251	0'106	0'695	1'014	1'045	1'076	1'109	1'142	1'176	1'212	1'248
7	Net operating profit after taxes (NOPAT)	tax rate: 25%	7'116	-0'251	0'079	0'521	0'761	0'784	0'807	0'832	0'857	0'882	0'909	0'936
8	in % of assets	(Pos. 7 / Pos. 11)	-	-39,5%	4,7%	36,9%	66,9%	84,7%	112,7%	163,8%	287,0%	991,2%	k. A.	k. A.
	Revenue through tax loss compensation			0'063										
	Assets / cost of capital													
9	Fixed assets after depreciation	(Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'637	1'765	1'561	1'356	1'151	0'949	0'747	0'545	0'343	0'141	0'039
10	Current operating assets		-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets	(Pos. 9 + Pos. 10)	-	0'637	1'693	1'410	1'137	0'925	0'717	0'508	0'298	0'089	-0'121	-0'230
12	Weighted average cost of capital (WACC)	rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes	(Pos. 11 x Pos. 12)	0'565	0'051	0'135	0'113	0'091	0'074	0'057	0'041	0'024	0'007	-0'010	-0'018
	Economic Value Added													
14	Periodical economic value added (EVA)	(Pos. 7 - Pos. 13)	6'614	-0'240	-0'056	0'408	0'670	0'710	0'750	0'791	0'833	0'875	0'918	0'954
15	**Economic value added**	discount interest rate: 8%	**3'686**						**1'502**					
16	Series of payments	(Pos. 7 + Pos. 8 - Δ Pos. 11)	7'409	-0'825	-0'976	0'803	1'035	0'995	1'016	1'041	1'066	1'092	1'118	1'046
	Accumulated			-0'825	-1'802	-0'999	0'036	1'031	2'047	3'087	4'153	5'245	6'363	7'409

CAGR **13,6%**

Payback period 47,6 months **4,0 years**

Axle Box Production

Project title: axle box production; plant Graz

VAR3b: automatic part loading + powder coating

Pos.	Investment appraisal — values in 1000 Euro	Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
		1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers	2'174	0'774	1'400									
2													
	Operative result												
3													
4	Earnings before interest, tax and depreciation (EBITD)	12'110	-0'166	0'324	0'940	1'273	1'305	1'335	1'369	1'404	1'439	1'476	1'409
5	Tax depreciation	2'135	0'109	0'215	0'215	0'215	0'215	0'212	0'212	0'212	0'212	0'212	0'107
6	Earnings before interest and tax (EBIT) (Pos. 3 + Pos. 4 - Pos. 5)	9'975	-0'275	0'109	0'725	1'059	1'090	1'123	1'157	1'192	1'227	1'264	1'302
7	Net operating profit after taxes (NOPAT) tax rate: 25%	7'412	-0'275	0'082	0'544	0'794	0'818	0'842	0'868	0'894	0'921	0'948	0'977
8	in % of assets (Pos. 7 / Pos. 11)	-	-41,3%	4,6%	36,6%	66,1%	83,4%	110,6%	159,9%	276,4%	885,1%	k. A.	k. A.
	Revenue through tax loss compensation		0'069										
	Assets / cost of capital												
9	Fixed assets after depreciation (Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'665	1'850	1'636	1'421	1'206	0'994	0'782	0'570	0'358	0'146	0'039
10	Current operating assets	-		-0'073	-0'150	-0'219	-0'226	-0'232	-0'239	-0'247	-0'254	-0'262	-0'269
11	Assets (Pos. 9 + Pos. 10)	-	0'665	1'778	1'485	1'202	0'980	0'762	0'543	0'323	0'104	-0'116	-0'230
12	Weighted average cost of capital (WACC) rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes (Pos. 11 x Pos. 12)	0'600	0'053	0'142	0'119	0'096	0'078	0'061	0'043	0'026	0'008	-0'009	-0'018
	Economic Value Added												
14	Periodical economic value added (EVA) (Pos. 7 - Pos. 13)	6'881	-0'259	-0'060	0'425	0'698	0'739	0'781	0'824	0'868	0'912	0'958	0'995
15	**Economic value added** discount interest rate: 8%	**3'831**						**1'554**					
16	Series of payments (Pos. 7 + Pos. 8 - Δ Pos. 11)	7'711	-0'871	-1'030	0'836	1'078	1'039	1'061	1'087	1'113	1'140	1'168	1'092
	Accumulated		-0'871	-1'902	-1'066	0'012	1'051	2'112	3'199	4'312	5'452	6'620	7'711

CAGR 13,6%

Payback period 47,9 months
4,0 years

Axle Box Production

Project title: axle box production; plant Graz

VAR4a: pallet changer + external painting

Pos.	Investment appraisal – values in 1000 Euro		Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
			1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers		1'687	0'587	1'100									
2														
	Operative result													
3														
4	Earnings before interest, tax and depreciation (EBITD)		10'337	-0'148	0'248	0'798	1'088	1'116	1'143	1'172	1'203	1'234	1'266	1'216
5	Tax depreciation		1'668	0'084	0'167	0'167	0'167	0'167	0'166	0'166	0'166	0'166	0'166	0'084
6	Earnings before interest and tax (EBIT)	(Pos. 3 + Pos. 4 - Pos. 5)	8'669	-0'232	0'080	0'631	0'921	0'949	0'977	1'006	1'037	1'068	1'100	1'133
7	Net operating profit after taxes (NOPAT)	tax rate: 25%	6'444	-0'232	0'060	0'473	0'691	0'711	0'733	0'755	0'777	0'801	0'825	0'850
8	in % of assets	(Pos. 7 / Pos. 11)	-	-46,2%	4,4%	41,5%	75,8%	96,3%	129,3%	191,3%	349,6%	1600,2%	k. A.	k. A.
	Revenue through tax loss compensation			0'058										
	Assets / cost of capital													
9	Fixed assets after depreciation	(Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'503	1'435	1'268	1'100	0'933	0'767	0'601	0'435	0'269	0'103	0'019
10	Current operating assets		-		-0'063	-0'129	-0'189	-0'195	-0'200	-0'206	-0'213	-0'219	-0'226	-0'232
11	Assets	(Pos. 9 + Pos. 10)	-	0'503	1'372	1'138	0'912	0'738	0'567	0'395	0'222	0'050	-0'123	-0'213
12	Weighted average cost of capital (WACC)	rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes	(Pos. 11 x Pos. 12)	0'445	0'040	0'110	0'091	0'073	0'059	0'045	0'032	0'018	0'004	-0'010	-0'017
	Economic Value Added													
14	Periodical economic value added (EVA)	(Pos. 7 - Pos. 13)	6'057	-0'214	-0'049	0'382	0'618	0'652	0'687	0'723	0'760	0'797	0'835	0'867
15	**Economic value added**	discount interest rate: 8%	**3'383**						**1'394**					
16	Series of payments	(Pos. 7 + Pos. 8 - Δ Pos. 11)	6'715	-0'677	-0'809	0'707	0'917	0'884	0'905	0'927	0'950	0'973	0'997	0'940
	Accumulated			-0'677	-1'486	-0'779	0'138	1'023	1'927	2'854	3'804	4'777	5'775	6'715

CAGR **14,6%**

Payback period: 46,1 months **3,8 years**

Axle Box Production

Project title: axle box production; plant Graz

VAR4b: automatic part loading + external painting

Pos.	Investment appraisal — values in 1000 Euro		Total	Year 0 2014/15	Year 1 2015/16	Year 2 2016/17	Year 3 2017/18	Year 4 2018/19	Year 5 2019/20	Year 6 2020/21	Year 7 2021/22	Year 8 2022/23	Year 9 2023/24	Year 10 2024/25
			1	2	3	4	5	6	7	8	9	10	11	12
1	Investment based on offers		1'787	0'620	1'167									
2														
	Operative result													
3														
4	Earnings before interest, tax and depreciation (EBITD)		10'840	-0'166	0'262	0'838	1'142	1'171	1'200	1'231	1'262	1'295	1'329	1'276
5	Tax depreciation		1'768	0'089	0'177	0'177	0'177	0'177	0'176	0'176	0'176	0'176	0'176	0'089
6	Earnings before interest and tax (EBIT)	(Pos. 3 + Pos. 4 - Pos. 5)	9'072	-0'255	0'084	0'661	0'965	0'994	1'024	1'055	1'086	1'119	1'153	1'187
7	Net operating profit after taxes (NOPAT)	tax rate: 25%	6'740	-0'255	0'063	0'496	0'724	0'746	0'768	0'791	0'815	0'839	0'864	0'890
8	in % of assets	(Pos. 7 / Pos. 11)	-	-48,1%	4,3%	40,8%	74,1%	94,0%	125,6%	184,1%	329,3%	1290,2%	k. A.	k. A.
	Revenue through tax loss compensation			0'064										
	Assets / cost of capital													
9	Fixed assets after depreciation	(Pos. 1 - Pos. 5 + Δ Pos. 9)	-	0'531	1'520	1'343	1'165	0'988	0'812	0'636	0'460	0'284	0'108	0'019
10	Current operating assets		-		-0'063	-0'129	-0'189	-0'195	-0'200	-0'206	-0'213	-0'219	-0'226	-0'232
11	Assets	(Pos. 9 + Pos. 10)	-	0'531	1'457	1'213	0'977	0'793	0'612	0'430	0'247	0'065	-0'118	-0'213
12	Weighted average cost of capital (WACC)	rate: 8%	-	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%
13	Cost of capital after taxes	(Pos. 11 x Pos. 12)	0'480	0'042	0'117	0'097	0'078	0'063	0'049	0'034	0'020	0'005	-0'009	-0'017
	Economic Value Added													
14	Periodical economic value added (EVA)	(Pos. 7 - Pos. 13)	6'325	-0'234	-0'054	0'399	0'646	0'682	0'719	0'757	0'795	0'834	0'874	0'907
15	**Economic value added**	discount interest rate: 8%	**3'528**						**1'446**					
16	Series of payments	(Pos. 7 + Pos. 8 - Δ Pos. 11)	7'017	-0'722	-0'863	0'740	0'961	0'929	0'950	0'973	0'997	1'022	1'047	0'986
	Accumulated			-0'722	-1'586	-0'846	0'114	1'043	1'993	2'966	3'963	4'984	6'031	7'017

CAGR **14,5%** **Payback period** 46,5 months **3,9 years**