UNIVERSITY OF TWENTE.

Master Thesis Business Administration

"A Restructuring Process"

"A case study on evaluating layout alternatives for an OEM"

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(S1495275)

May, 2016

Title
"A Restructuring Process: A case study on evaluating layout alternatives for an OEM"

Date
May 23, 2016

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A thesis submitted for the degree of:
Master of Science
Business Administration
Track: Financial management

Educational Institution
University of Twente

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"Teamwork is the ability to work together toward a common vision. The ability to direct individual accomplishment toward organisational objectives. It is the fuel that allows common people to attain uncommon results."

(Andrew Carnegie)

Management summary

Problem definition

In order to fulfil their ambition of becoming a more reliable original equipment manufacturer (OEM), the company has upgraded and optimised its production in recent years as much as possible given several restrictions. The company is producing what customers request, which aligns with the customer intimacy strategy. As their operations currently focus mainly on in-house production, their working methods correspondingly focus on engineer-to-order and make-to-stock. Both of these methods result in the proliferation of parts and focussing on one piece instead of the total costs of machines. The following other bottlenecks have been identified based on the company's current working method and two production sites:

- Transportation costs;
- Other costs due (such as inventory cost, possibly incorrect cost prices and the actual cost of phantom parts);
- Inefficiencies due to workflows within the existing layout; and
- The customer order decoupling point.

In order to tackle such problems, the company was planning to move to a new facility. This study is therefore a limited greenfield optimisation project concerning the retrofitting of a new facility. The company's management department also wished to increase the company's output.

Central research question

The company's target has been transformed into the following central research question for this thesis:

"How can the company's production process be optimised by establishing an effective workflow for a new production facility?"

In short, the goal of this study is to design and implement an effective workflow by optimising the production process for a new production facility in a way that meets the requirements of all stakeholders. These requirements are not just physical and technical; they are financial as well.

Methods

The methods used for this research were derived from the literature. We chose different models for different purposes; in brief:

- The action research approach was used to both guide the process of designing different layouts and implement the selected layout.
- A modified version of the systematic layout planning procedure was used to solve the layout problem and served as the structure for the theoretical framework.
- Because the company is an OEM with a high-variety and low-volume environment, a combination of the process and open-field layouts was identified as being best for routing the flow of materials.
- The most suitable layout was implemented within the timeframe of this thesis by using five control factors as guidance (namely time, money, quality, information and organisation).
- To determine the firm's core competency, we applied the value disciplines model of Treacy and Wiersema (1997).
- Different applicable key performance indicators (KPIs) were derived from the literature.
- We modified the analytical hierarchy process to judge the layouts individually and tried to improve on them by designing a new alternative.
- Different optimisation techniques (e.g, quick response manufacturing, lean management and agile) were analysed.

Results

The main conclusions of our research are as follows:

- Out of the 28 layout alternatives we designed, 4 led to the greatest changes. We then compared these four based on different criteria (e.g., ease of future expansion and material-handling effectiveness). As layout alternative 4 (figure A) satisfied more selection criteria than the other alternatives, it was selected for implementation.
- Before implementing the layout, we also designed a 3D model using the exact building and machine measurements.
- Within the timeframe of this thesis, we were able to implement the most suitable layout for the company. Implementing a layout involves many different issues and problems, and the master builder must react to changes or disruptions in progress appropriately. Remaining flexible is key. We performed several tasks to ensure that the move to the new production facility would go smoothly; in particular, we:
    - Explained the new layout to the company's employees and stakeholders;
    - Moved the actual production facilities to the new facility;
    - Undertook financial budgeting;
    - Engaged, selected and supervised different subcontractors; and
    - Started to introduce change management for further research and implementation.

  Implementation was successfully completed at the end of January 2016 and the production facility is currently fully operational. As the shareholders, managers and employees are all pleased with the new production facility, workflows and movement, we can conclude that the move (and thus the project) has been successfully implemented.
- With regard to the implementation of the chosen layout, it should be noted that human aspects had a major influence on the project, especially the move to the new production facility. We created support for the move by keeping stakeholders, managers and employees informed about the project. After all, while management <u>makes</u> the decisions, employees can <u>break</u> them.

Recommendations

Based on the results of this study, we offer the following recommendations:

- A balance between customer satisfaction and operational costs is always necessary. Instead of the current combined working methods, the company should apply the recommended make-to-order work method.
- When combined with modular design and the standardisation of the production process, the recommended work method will lead among other things to cost reduction, the prevention of obsolete parts, increased machinery utilisation, improved flexibility and shorter lead times.
- Daily activities should be monitored together with goals. We recommend using three KPIs to do so, namely: the rate of obsolete inventory, on-time production and supplier fill rate.
- The production process should be continuously improved by applying different optimisation methods (i.e., quick response manufacturing, lean management and agile).

Roadmap

To facilitate the achievement of the aforementioned improvements, we propose the following roadmap to guide the company.

Table A: Roadmap for achieving the improvements

Phase	Action	Actor
1	Apply the three recommended KPIs within the production process	Management
2	Standardise different parts	Engineering
3	Determine the actual core components	Engineering
4	Improve the costs for phantom parts	Operational manager
5	Apply the SCOR model to integrate the supply chain	Operational manager
6	Further research for reducing inefficient work methods	Operational manager
7	Further research on how to implement different optimisation techniques	Operational manager
8	Introduce modular design for the machines produced	Engineering

Figure: A: The most appropriate layout for the company

Preface

This thesis is written to satisfying a requirement for receiving my Master's in Business Administration from the University of Twente. The research was performed over the course of eight months at the company. The goal of this research was to create an effective workflow by optimising the production process for a new the company production facility.

This work could not have been realised without the help of many people. I first want to thank the company for giving me the opportunity to write my thesis with them as well as for the experience of formulating, writing and implementing out my own thoughts. In addition, I want to thank all of the company's employees for their cooperation, valuable contributions and proactive participation in conjunction with this project. I would particularly like to thank my colleagues for the help and advice they provided me on regular basis; I was grateful that they always made time to assist me.

Above all, my sincere gratitude goes to Peter Schuur, my supervisor at the University of Twente, for his guidance and feedback during my research. I also want to extend special thanks to my supervisor for answering all of my questions, providing support and taking the time to learn about the practical implementation of the move I was proposing. I additionally want to thank my second supervisor for his feedback and valuable contributions.

Last but not least, I thank my mother, sister, girlfriend, and other family and friends for their support throughout my research. The period may not have been completely pleasant for them, but I am very appreciative that they always stood by me.

This report is dedicated to my father who I wish was alive to share it.

Overall, I tried to fulfil the goal of this research with great enthusiasm; I hope this enthusiasm will be felt by all those who read this thesis.

Ben van Dongen
Enschede
May 2016

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Glossary

AHP:	Analytic hierarchy process
AR:	Action research
ATO:	Assemble-to-order
BOM:	Bill of materials
BTO:	Build-to-order
CODP:	Customer order decoupling point
CRAFT:	Computerized Relative Allocation of Facilities Technique
CSP:	Customer service processes
CTO:	Configure-to-order
DFMC:	Design for mass customization
DTO:	Design-to-order
ETO:	Engineer-to-order
FLING:	Facility layout using interactive graphics
FMS:	Flexible manufacturing system
IFLAPS:	Intelligent facilities layout planning and analysis system
KPIs:	Key performance indicators
LM:	Lean management
MCDM:	Multi-criteria decision-making
MOCRAFT:	Micro Computerized Relative Allocation of Facilities Technique
MTO:	Make-to-order
MTS:	Make-to-stock
MvB:	Make vs. buy
OEM:	Original equipment manufacturer
OFP:	Order fulfilment processes
PDP:	Product development processes
QRM:	Quick response manufacturing
REL:	Relationship diagram
SCC:	Supply chain council
SCM:	Supply chain management
SCOR:	Supply chain operations reference
SLP:	Systematic layout procedure
TMQIO:	Time, money, quality, information and organisation
WIP:	Work in progress
WPM:	Weighted product model
WSM:	Weighted sum model

1 Introduction

In the framework of completing my Master's in Business Administration at the University of Twente, I performed research on designing an effective workflow by optimising the production process for a new production facility at the company, which is located in the Netherlands. The company, which was founded in mid' 90s as a family concern, has developed into a specialised global manufacturer of machinery that focuses its activities on different industries. Its customers are transforming materials into more suitable forms (e.g., pellets) in order to create benefits such as size reduction (Al-Salem, Lettieri, & Baeyens, 2009; Mani, Tabil, & Sokhansanj, 2006; Obernberger & Thek, 2004; M. Thomas & van der Poel, 1996).

As part of the group (see appendix 1), the company currently specialises in creating maximum synergy among the different companies held by that group with the goal of strengthening turnkey group projects. The main activities of the company focus on the production machinery as well as on developing, engineering and servicing the equipment that the company supplies. For example, the company produces a press line (see figure 1.1 and figure 1.2). This is a combination of machinery, in which raw materials are the input and pellets (figure 1.3) are the output.

Developing and producing high-quality and reliable machinery enables the company to create customer benefits in multiple ways, such as by lowering energy consumption and maintenance requirements and increasing company yields. In addition, the company transforms state-of-the-art technology into added value for its customer. With customers all over the world and a large established customer based, the company has become a respected original equipment manufacturer (OEM).

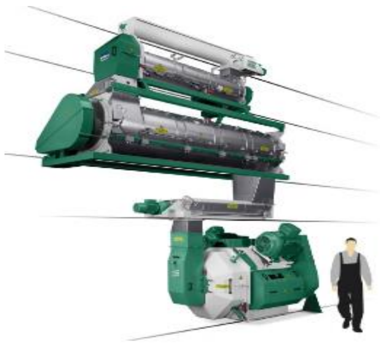


Figure 1.1: Designed production line with related machinery

Figure 1.2: Installed production line in Germany

Figure 1.3: Different types of pellets

1.1 Problem definition

In order to fulfil the ambition to become a reliable OEM, the company has upgraded and optimised its production in recent years as much as possible given several boundaries. Furthermore, the demand for machinery is still increasing. Currently the company has two production sites, which leads to inefficiency due to the constant transport of unfinished goods between both production sites and the assembly department. In addition, the main production building houses dated and dusty machinery that must be used on a manual and individual basis. All of the examples of inefficient production noted above are reflected in lead times, product quality and the quantity of finished products that the company assembles.

In order to tackle such inefficiency problems and achieve its ambitions, the company is planning to move to a new facility at [location] The management department also wishes to increase the company's output by achieving an effective process in the new facility. It is thus mandatory that the company re-invent its production and logistic process. To remain competitive, organisations need to be constantly increasing their customer service while reducing their operating costs (D. J. Thomas & Griffin, 1996). As custom working methods are a major factor and influence operating costs, it is important to define which working method creates an effective workflow and results in reduced operating costs.

1.2 Problem statement

This section describes the research objective, the main research question, the research sub-questions and both the scope and the deliverables of this thesis.

1.2.1 Research objective

The goal of this thesis is to design an effective workflow by optimising the production process for a new production facility while reflecting the requirements of all stakeholders (which are financial as well as physical and technical). Results can be measured through several factors, such as reduced operating costs, reduced lead times, higher quality products and increased annual machine production quantities. The research question and the purpose of this thesis contain multiple terms that leave room for speculation, including “effective workflow” and “layout”. It is essential to define each of these terms in order to answer the research question correctly and understand the purpose of this thesis. The definitions of these terms will be given in chapter 2 (theoretical framework).

1.2.2 Main research question

As stated in the introduction, the company’s target can be transformed into the following central research question:

“How can the company’s production process be optimised by establishing an effective workflow for a new production facility?”

1.2.3 Research sub-questions

In order to answer this question, it must be divided into different sub-questions. A distinction is made between the current situation (or as-is state) and the ideal future situation (or to-be state) (Wiele, Kok, McKenna, & Brown, 2001). The as-is situation mainly focuses on analysing the current situation at the company, while the to-be situation is derived from a literature review that is combined with a set of restraints and requirements identified from stakeholders. Stakeholders are defined as key players who have great interest in this research and can influence its outcome significantly.

The sub-questions identified for this research are as follows:

1. What is the as-is situation at the company with respect to its production and logistic processes?
    a. Within that process, what are the company’s activity priorities and where does the added value within these activities lie?
    b. How does the current working method influence the actual operating costs?
    c. How does the company use supply chain management (SCM) in its production and logistic process?
    d. Which key performance indicators (KPIs) are used to measure the current production and logistic process and how are these KPIs currently performing?
2. What are the main current bottlenecks within the process and how can they be improved?
3. What is the ideal to-be situation at the company with respect to the new production and logistic processes at the new facility?

a. Which general types of layout (route of the flow of materials) are applicable to the company within the parameters set by key stakeholders?
b. What work methods may produce an effective workflow and how do they influence operating costs?
c. Which KPIs can be used to measure an effective workflow in the production and logistic process?

4. How can the structural approach be applied within the new facility at the company while taking the wishes and restrictions of key stakeholders into account?
    a. What are the main criteria for layout design In order to achieve efficiency in the production and logistic process?
    b. What practical requirements and restrictions do key the company stakeholders demand?
    c. Which techniques can be used to achieve an effective workflow by optimising efficiency in the production and logistic process?
    d. How can these techniques be applied to the general layout in order to solve the inefficiency problem?
    e. Which layout alternatives are suitable for the company and what are the pros and cons of each?
    f. Which scientific research method can be used to select the most appropriate layout design for the company?
5. Given the parameters set by key stakeholders, what is the most suitable layout design for the company with an effective work method to minimise operating costs and which KPIs are useful for monitoring this outcome?

1.2.4 Research scope

This thesis focuses on designing an effective workflow by optimising the production process used at a new production facility. The research is a limited greenfield optimisation project, concerning the reconstruction of a new facility. The alternative to a greenfield is a brownfield, which concerns restructuring an existing facility (K. Meyer & Estrin, 2001). This greenfield optimisation project has its limitations, given that it is limited to the facility that is located at [location]. the company became owner of the facility on July 3th 2015. The effective workflow must fit this new building and should be sustainable for the next 10 years. In addition, the scope of this research had to be narrowed even more due to resource and time limitations. External factors such as customer demands are thus considered as ceteris paribus. The management department of the company wishes to increase the company's output, which can be achieved by optimising the production process in the new production facility.

Consequences for the employees as a result of this research are not taken into account as considering these aspects may affect the process of designing an effective workflow. The condition of the company's current machinery is analysed, which may influence the mapping of the layout. Technical product analysis is excluded from this research, which results in the assumption that products created and machines used by the company will not dramatically change in the near future.

1.2.5 Deliverables

The deliverables that result from answering this project's main and sub-questions are summarised below.

1. A facility layout design for the production and logistic department, including the activities of distribution for the new design.

2. Practical implementation of the new production environment that is suggested by this research. This include several tasks to move smoothly to new the production facility:
    a. Explaining the new layout to the company's employees and stakeholders;
    b. Moving the actual production facilities to the new facility;
    c. Financial budgeting;
    d. Engaging, selecting and supervising different subcontractors;
    e. Starting to introduce change management for further research and implementation,
3. A useful and future-oriented working method that creates an effective workflow and results in near-minimum operating costs and that can be secured by monitoring essential KPIs.

This approach will be of great value to the organisation, as the report can be used as a guide for solving other facility layout problems.

1.3 Project design

The research framework model that is used to answer the main research questions is designed around visual steps (figure 1.4). For the sake of clarity, the model uses different coloured boxes. Furthermore, boxes with a red border contain the output of research. This project includes seven different phases:

Phase 1: Analysing the as-is situation in order to understand the company's production and logistic process. Also in this phase we analyse factors such as SCM and working methods.

Phase 2: Identifying bottlenecks derived from the as-is state of the company. Besides, practical limitations defined by key stakeholders are taken into account (given that they affect the possible outcomes).

Phase 3: Exploring the theoretical background, which reveals layout criteria, possible working methods and KPIs and creates an effective flow whereby operational costs can be minimised.

Phase 4: Combining the bottlenecks, stakeholder wishes and theoretical background to create a structural approach for designing an effective flow within a new facility.

Phase 5: Carrying out a case study for the company, which enables the structural approach to be tested and an effective flow with minimal operation costs to be designed for the company. Multiple optimisation techniques can be used to improve the layout and solve the bottlenecks.

Phase 6: After analysing the alternatives and evaluating their pros and cons, designing a facility layout that features a working method and KPIs that can be used to monitor the production and logistic process.

Phase 7: Drawing conclusions, answering the main research question, discussing the results and making recommendations for further research.

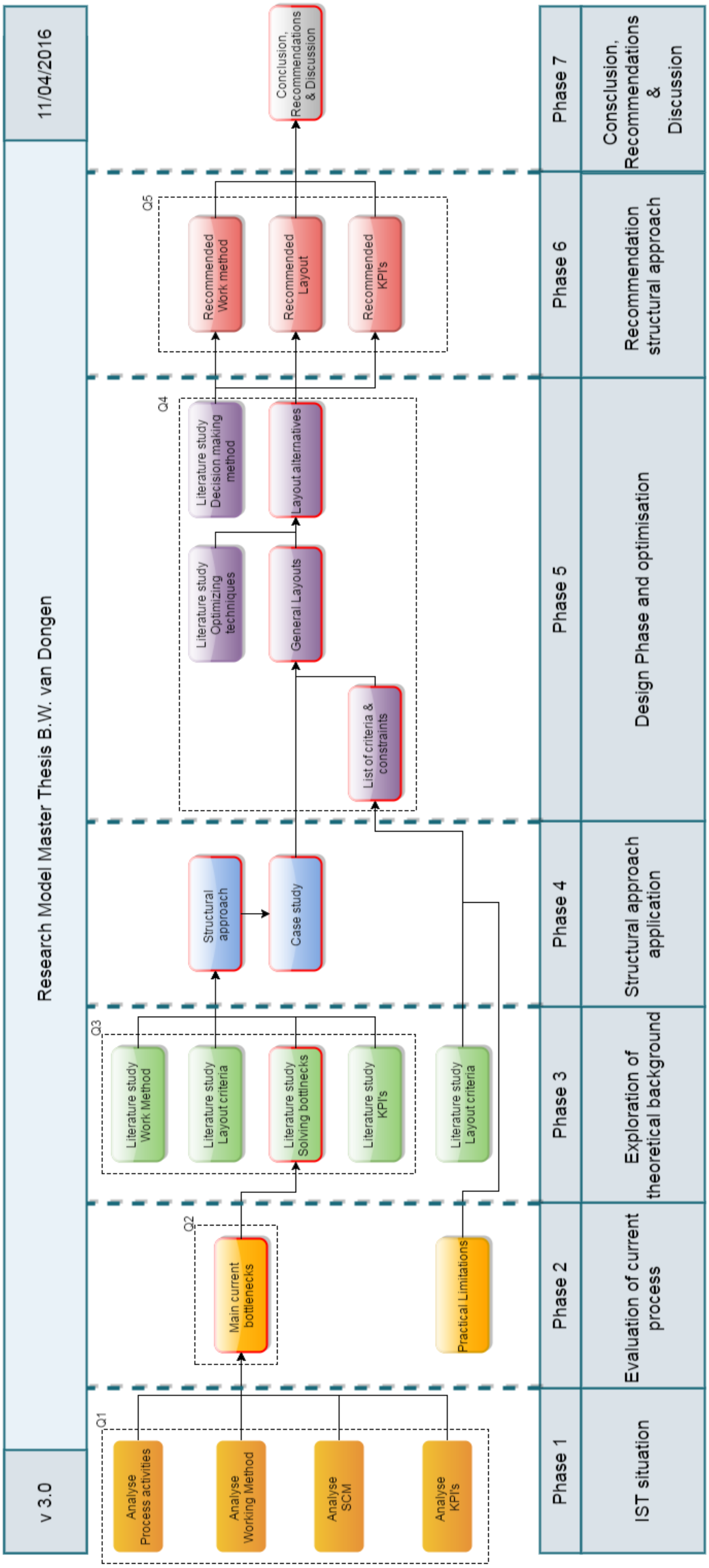


Figure 1.4: Research framework of Ben van Dongen

1.4 Research method

Different types of research methods and data sources can be used to obtain the essential information described in the research framework (figure 1.4). It is not recommendable to narrow the methodology down to one specific research approach, as doing so it may put the quality of the research at risk. Applying a specific research approach to each of the subjects covered in the study's sub-questions is a useful alternative. This study focuses on qualitative research rather than quantitative research. According to Strauss and Corbin (1990), qualitative research can be defined as "any type of research that produces findings not arrived at by statistical procedures or other means of quantification" (p. 10). Techniques associated with qualitative research include observations and interviews (Strauss & Corbin, 1990). In addition, Patton (2014) notes that qualitative findings can be derived from in-depth interviews, written communications and direct observations. Qualitative research can be divided into three components. First, data need to be collected (several possible techniques may be used). Second, procedures need to be followed to organise data. Third, a report must be written (Strauss & Corbin, 1990). Based on the qualitative research approach and a combination of possible techniques, the current situation is analysed through a combination of in-depth interviews, direct observations and written documentation. As stated previously in the research framework, information from stakeholders can be collected using one or more of the possible qualitative data techniques.

This research uses the action research (AR) method, which should lead to action (Lewin, 1946). Lewin, who defined this term in the mid-1940s, suggested that research should help the practitioner. As AR combines practice with theory, it brings researchers and practitioners together (Avison, Lau, Myers, & Nielsen, 1999). This approach consequently takes action, which results in creating knowledge and possibly theories about that specific action (Coghlan & Brannick, 2014).

Figure 1.5 shows the AR cycle, which is also called the cycle of activities. At the beginning, a problem is diagnosed or the context and purpose are defined. Six different steps are then divided into problem diagnosis, action intervention and evaluation (Avison et al., 1999; Coghlan & Brannick, 2014). As shown in the figure, the researcher's role is to monitor the entire cycle. Each AR cycle could eventually lead to a new cycle; it is even possible that a larger project consists of multiple smaller AR cycles (Avison et al., 1999; Coghlan & Brannick, 2014; Coughlan & Coghlan, 2002).

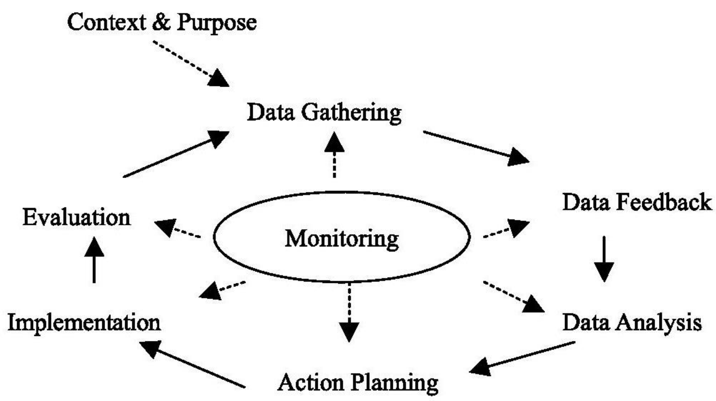


Figure 1.5: Action research cycle (Coughlan & Coghlan, 2002)

The role of the researcher consequently changes constantly within each AR cycle. The expertise of the researcher may be necessary in some instances, while the researcher can also be a participant. It is important to understand that the researcher should collaborate with stakeholders as well as with other participants (Berg, 2001). As Berg has suggested, constant interaction between the researcher and the different stakeholders is necessary throughout the project. It is important to maximise participation of these stakeholders by continuously sharing research results (Berg, 2001).

1.5 Report overview

In order to answer the central research question and related sub-questions, in chapter 2 we analyse different models derived from the literature. The purpose of this chapter is to select the models that are applied in subsequent chapters. Thereafter, chapter 3 analyses the company's current situation and performance to identify important bottlenecks. This chapter also provides background information on the company that helps to clarify their core competency, product marketing mix, production process and existing layout by using multiple theories. The purpose of chapter 4 is then to both define the company's production process in a to-be situation and choose the most suitable flow of materials, both of which are derived from the literature and adapted to the case of the company. This chapter also tackles several identified bottlenecks. Once the production process has been defined, it is necessary to develop a suitable layout for the new facility. The layout selection is thus described in chapter 5. As implementation was included within the timeframe of this research, a summary of the implementation process is presented in chapter 6. Finally, chapter 7 presents and discusses the study's conclusions.

2 Theoretical framework

This chapter presents the theoretical framework. The main purpose of this chapter is to select different models, which can be applied to this research. In order to design a structure for this chapter, different steps within the strategic layout planning (SLP) model are used as guidance. Therefore, section 2.1 will elaborate the layout procedure. Section 2.2 focuses on the input of data and activities, where information is gathered about the product, process and schedule design as all three affect the layout. The following section is the first step in the analysing phase of the SLP model and is named as the 'flow of materials'. The purpose of this section is to define and map an effective flow. Next, the activity relationship is described in section 2.4 to actually map the routing of the flow of materials. As the aim is to reduce the influence of individual's intuition on the layout procedure, section 2.5 discusses the analytical analysis. Finally, the last section will discuss the models which we choose to apply in this research.

2.1 Layout procedure

The placement of facilities within a plant area is referred to as the facility layout problem or layout design (Drira, Pierreval, & Hajri-Gabouj, 2007). It has been formally studied since the mid-1950s (Heragu, 2008) and has had a significant influence on productivity, lead times, work in process and operational costs (Drira et al., 2007). Heragu (2008) describes facility layout as an arrangement of departments that is intended to make products or provide services. Efficiency can be created by minimising movements of both people and resources between departments (Heragu, 2008). If layouts are not well-implemented, dramatic results such as inflexible operations, high lead-times, increased costs and over-long flow patterns can occur (Francis, McGinnis, & White, 1992; Slack, Chambers, & Johnston, 2010). Slack, Chambers and Johnston (2010) therefore define layout as "how [a company's] transformed resources are positioned relative to each other and how its various task are allocated to these transforming resources" (p. 179). As the proposed definitions differ in detail, only the definition of Slack et al. (2010) is used in this thesis. This definition reflects a combination of workflows, work methods and the physical mapping of the various tasks to transform recourses.

Different layout procedures have been developed over time by different authors, such as Apple, Muther, Tompkins and Reed (Francis et al., 1992; Tompkins, White, Bozer, & Tanchoco, 2010). Their methods can be summarised as collecting data, analysing (flow) relationships and space requirements, designing layout alternatives, evaluating the performance of these alternatives and finally moving to implementation. The models they have proposed serve as a foundation for the current scientific literature. As described by Muther (1973), today's SLP is a method that is recommended for facility layout design (Chase, Jacobs, & Aquilano, 2005; Heragu, 2008). This layout procedure, which was revised by Francis et al. (1992), is used as a framework for this thesis.

Unless stated otherwise, the model used in this research is based on the original approach of Muther (1973) and the modified SLP procedure proposed by Francis et al. (1992). The modified framework, which is shown in figure 2.1 (see page 11), can be divided into three phases: analysing the layout problem (steps 1 through 5), searching for design alternatives (steps 6 through 9) and selection of the layout (step 10).

In the first phase of figure 2.1 (see page 11), information needs to be gathered about product, process and schedule design. Interaction between these three function designs and the layout design is necessary, given that all three directly or indirectly affect the layout. These forms of designs are elaborated further in the next section. The flow of materials describes the routing from raw materials to a finished product. Quantitative measurement entails measuring movement between activities and department. In contrast, activity relationships are measurable with non-quantitative factors. Input from both of these steps can be used to construct a relationship (REL) diagram, which presents a picture of the collected data. Before a space relationship diagram can be constructed, the space requirements and availability must be identified. This diagram is also a crude layout or layout plan, as modifying considerations and practical limitations are not taken into account. Step 6b was developed by Francis et al. (1992) in order to reduce the influence of individuals' intuition on the traditional layout procedures. Layout alternatives can be developed once the space relationship diagram, analytical analysis, modifying considerations and practical limitations are all available. Finally, the layout alternatives must be evaluated in order to select the preferred design (which is mostly the best compromise between different objects). For example, objects are minimising costs, minimising production times and enhancing employee convenience. These objects still differ in each facility layout problem and hence need to be formulated as goals. As the new design is future orientated, expected future costs must be taken into account in the evaluation phase.

Nevertheless, identifying a new layout design is not the final phase in the research. The new layout must also be explained to appropriate employees in order to create the necessary support and acceptance of the new layout before it can be installed. The complete process of designing the layout is monitored and evaluated, and a redesign decision can sometimes occur. In summary, the design process is actually a cycle, whereby data input is necessary to create a layout design and implementation cannot be achieved without an organisation's support. To illustrate the process, the following section focuses on the input of data and activities (as shown in figure 2.1, see next pages).

Discussion layout procedure

As stated in the research objective (1.2.1), terms as "layout" need to be defined in order to clarify the research goal. Therefore, the meaning of layout for this research is equal to the definition described by Slack et al. (2010). The definition does not only cover the physical mapping but includes workflows and work methods as well. All three subjects are essential for answering the research questions. In the sequel, we modify the SLP procedure to our purpose as it provides us guidance to solve the layout problem as well as to structure the theoretical framework. The reason for choosing this framework is the wide interpretation and the possibility to link other theories within this framework. In this thesis we split the SLP procedure in a theoretical part (e.g., input data and activities, flow of materials, activity relationships and analytical analysis) and a practical part (all other steps). Within the practical part most of these steps are used in section 5.5 (detailed layout).

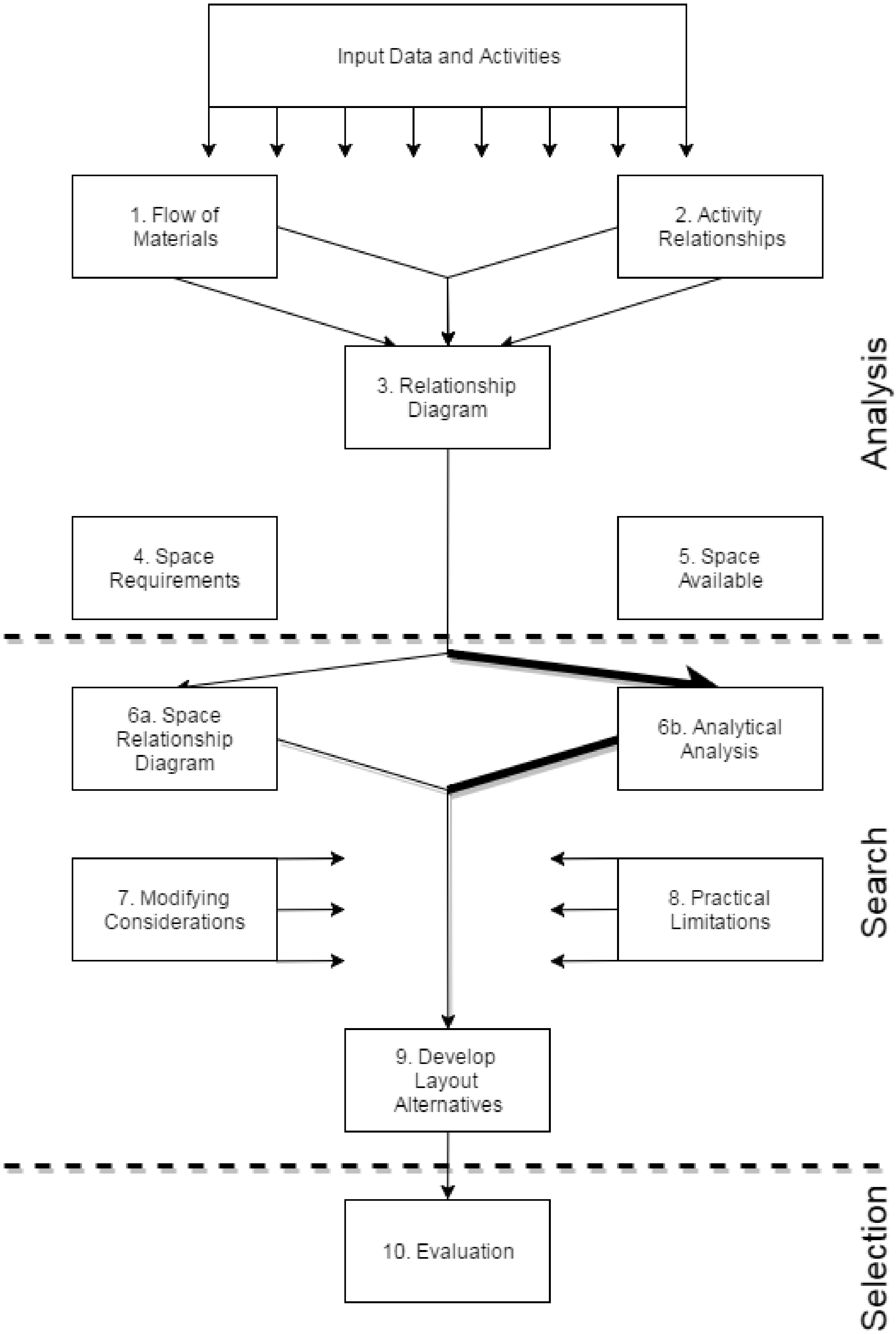


Figure 2.1: Modified SLP procedure (Francis et al., 1992)

2.2 Input data and activities

As stated in the previous section, it is necessary to identify input and data of activities as this influences the layout directly or indirectly. Therefore, it is essential to define definitions and derive models from literature for product, process and schedule design. The first section will elaborate on product design, as the form of the product influences the flow of operations. Section 2.2.2 identifies a set of operations established to produce the product, so called process design. Finally, section 2.2.3 provides us performance measurement tools in order to monitor the daily production process.

2.2.1 Product design

No commonly accepted definition for product design exists in the scientific literature (Luchs & Swan, 2011). Luchs and Swan suggest that form and function should be integrated into the term's definition; they state that product design is "the set of properties of an artefact, consisting of the discrete properties of the form (i.e.,, the aesthetics of the tangible good and/or service) and the function (i.e.,, its capabilities) together with the holistic properties of the integrated form of function" (Luchs & Swan, 2011, p.12). A definition from Creusen (2011) suggests that "product design refers both the process and result of determining the physical execution and arrangement of the characteristics of a product offering. These characteristics refer to functionalities and physical appearance/form" (p.1). The form of the product can influence its functionality (Luchs & Swan, 2011) and thus the flow of operations. The design of the product also significantly affects the layout, both directly and indirectly. In addition, the sequence of operations directly influences the layout, while process design has an indirect effect on the layout (Francis et al., 1992).

2.2.2 Process design

According to Francis et al. (1992), process design is a set of operations that is established to produce a defined product. Central subjects within process design discussions include determining outsourcing and the operation time for components (Francis et al., 1992). Another definition for process is a "structured, measured set of activities designed to produce a specified output for a particular customer or market" (Davenport, 2013, p.5). In order to achieve a process's goal, interaction between entities both within and outside of the company is necessary (Lin & Shaw, 1998). Several other classifications exist in relation to topic of the business process (Aguilar-Savén, 2004). The terms "core process" and "supportive process" are commonly used in the literature; the former describes an organisation's primary process, while the latter has a supportive task in creating the circumstances required in order to undertake the core process. A possible third term is "management process", which could be described as a supporting process (Davenport & Ould, as cited in Aguilar-Savén, 2004; Lin & Shaw, 1998). The core competency of firm is further elaborated in section 2.2.2.5 (core competency of the firm).

As noted before, the set of operations followed is actually a firm's primary process. It is the chain of activities that is used to transform raw materials into a product, which is then delivered to a customer (Aguilar-Savén, 2004; Kochhar & Heragu, 1999). According to Lin and Shaw (1998), three types of primary processes exist: product development processes (PDP), order fulfilment processes (OFP) and customer service processes (CSP) (Champy, 1995; Davenport, 2013; C. Meyer, 1993). The focus of PDP is on transforming customer knowledge into a product design that can be manufactured (Champy, 1995; C. Meyer, 1993; Smart, Maull, & Childe, 2010); an example of a PDP user is a pharmaceutical business (Champy, 1995). In contrast, the OFP focus is on manufacturing a customer order and then delivering that product (Lin & Shaw, 1998; C. Meyer, 1993; Smart et al., 2010). Finally, CSP transfers customer knowledge and markets it into a customer order (Smart et al., 2010); this is the primary process used by banks (Champy, 1995).

The set of operations to produce a defined product depends not only on in-house activities, but includes the activities out-side the company as well. Therefore, in subsection 2.2.2.1 the supply chain is defined. In order to manage these multiple relations, supply chain management is introduced in section 2.2.2.2. This section provides us the possibility to choose a model in order to measure the supply chain performances. The Supply Chain Operations Reference recommended by several authors is briefly discussed in section 2.2.2.3. The model is a strategic planning tool, simplifying the complexity of supply chain management. As other methodologies, in particular the customer order decoupling point (CODP) are integrated, it is necessary to define the term CODP. Because the process is depending on the strategy a company chooses, the possible core competency of the firms are defined in paragraph 2.2.2.5.

2.2.2.1 Supply chain

To produce a specified output as Davenport (2013) has suggested in his definition of process, business and primary processes are integrated into supply chain networks (Cooper, Lambert, & Pagh, 1997; Lin & Shaw, 1998). Many other definitions for supply chain are also proposed in the literature. Stevens (1989) defines a supply chain as a “connected series of activities which is concerned with planning, coordinating and controlling material, parts and finished goods from suppliers to the customer” (p.3). This definition is almost the same as that of Towill (1996). A similar supply chain definition is also suggested by Beamon (1998): “an integrated process wherein a number of various business entities work together in an effort to: (1) acquire raw materials, (2) convert these raw material into specified final products, and (3) deliver these final product to retailers” (p.281). Stevens (1989) suggests that two types of flows exist within a supply chain, namely material and information flows. While the material flow goes forward, the information flow goes backward through the supply chain (Beamon, 1998; Stevens, 1989; Towill, 1996). It is important to manage both the forward-moving material flow and the backward-moving information flow (Shin, Collier, & Wilson, 2000).

From the above definitions it is clear that the supply chain focuses on the supply and distribution side of an entity. The customer who consumes the product is always at the end of the supply chain (Wisner, Tan, & Leong, 2015). In order to fulfil the needs of the customer, companies are part of a large and complex supply chain system. The value chain focuses on flows as primary (internal) activities, while the supply chain focuses more on an enterprise’s demand side (Enarsson, 2006).

2.2.2.2 Supply chain management

Supply chain management refers to managing multiple relations between various business entities (Cooper et al., 1997). According to Cooper et al. (1997), SCM is “the integration of key business processes from end user through original suppliers that provides products, services and information that add value for customers and other stakeholders” (p.1). Similar definitions for SCM are suggested by Enarsson (2006) and Lambert (2008). Efficiency and effectiveness management of the supply chain improves value for the customer (Lee & Billington, 1992) and results in the company achieving a sustainable competitive advantage (Ellinger, 2000).

Adding value for customers and other stakeholders are not the only possible objectives of SCM. According to Simchi-Levi, Kaminsky and Simchi-Levi (2003), SCM is “a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations and at the right time in order to minimise system-wide costs while satisfying service-level requirements” (p.2). The ability of SCM to reduce system-wide costs is also recognised by Fergueson (2000), as is its value for creating a strong relationship with the customer. Results are possible increases in both market share and sales (Fergueson, as cited in Shepherd & Günter, 2011).

All of these advantages of the supply chain can be measured by supply chain performance, which provides an understanding of how the supply chain works, how the chain can be influenced the and how to improve its performance (Chen & Paulraj, 2004; Shepherd & Günter, 2011; Wisner et al., 2015). While performance measurement is widely discussed in the literature, it is rarely defined. Neely, Gregory and Platts (2005) therefore propose defining it as “the process of quantifying the efficiency and effectiveness of action” (p.1229). The research of Shepherd and Günter (2011) highlights well-known performance measurement models, such as the performance measurement matrix (Keegan, Eiler, & Jones, 1989) and the balanced scorecard (Kaplan & Norton, 2010). The authors criticise these different models and share their own analyses. Examples of the limitations they identify are failing to answer a fundamental question about what competitors are actually doing, the lack of strategic focus and encouraging short-termism (Alsyouf, 2006; Neely et al., 2005; Shepherd & Günter, 2011). Furthermore, the balanced scorecard has not integrated the extended value chain (Alsyouf, 2006). Different authors and studies have confirmed these notable limitations and therefore suggest the need for new methods to measure supply chain performance (Shepherd & Günter, 2011).

The limitations revealed by Neely et al. (2005), Alsyouf (2006) and discussed by Shepherd and Günter (2011), Chen and Paulraj (2004) add up to supply chain performance have a limited focus. Different authors have tried to develop balanced performance measurement systems over time. The Supply Chain Operations Reference (SCOR) developed by the Supply Chain Council (SCC) in 1996 has emerged as the most popular (Huan, Sheoran, & Wang, 2004; Shepherd & Günter, 2011; Wisner et al., 2015).

2.2.2.3 SCOR model

Unless stated otherwise, this section is based on Huan et al. (2004); the SCC, as cited in Lambert, García-Dastugue and Croxton (2005); the SCC (2010); Shepherd and Günter (2011); Agami (2012); and Wisner et al. (2015).

The SCOR model, which is schematically illustrated in figure 2.2, is a cross-functional framework that spans all customer interactions, physical material transactions and market interactions. Several authors recognise that while the model does not describe every activity or business process specifically, it does focus on three process levels. Furthermore, if an organisation wants to apply the model, it must undertake improvement extension (level 4).

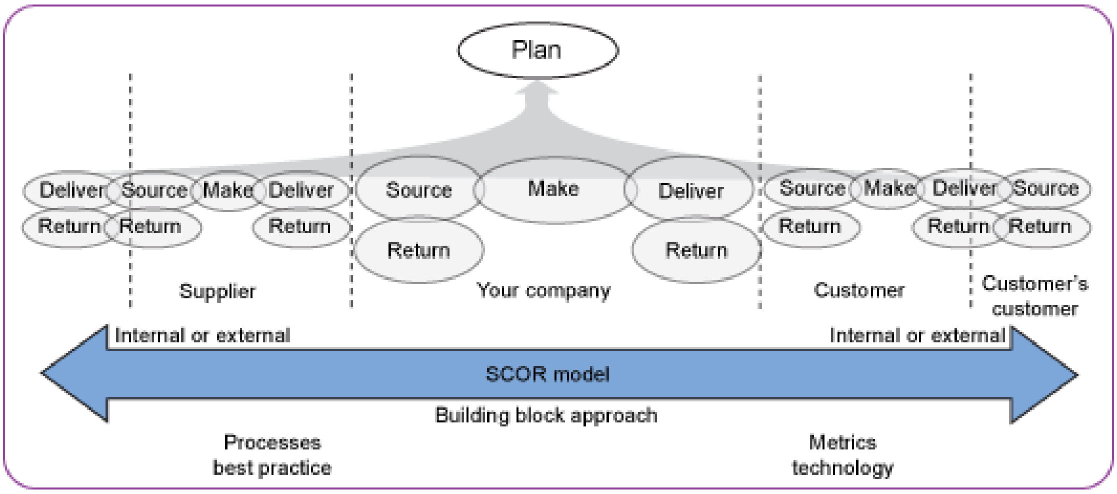


Figure 2.2: SCOR organised around five management processes (Ren, Shao, He, & Dong, 2012)

Three techniques integrated into one approach

The SCOR model is a cross-functional framework that is orientated around three core components of a business process (table 2.1), each of which captures in detail the as-is state of a process and analyses the desired to-be state. The three components are as follows:

- **Process reengineering:** Process reengineering techniques are used to analyse the current state of a process and compare it with the to-be state. Business process templates for plan, source make, deliver and return are useful for determining the to-be state.
- **Benchmarking:** Target values for operation performance metrics are used to determine the to-be state of the process.
- **Best practices analysis:** This entails identifying successful management practices and software solutions that are similar to those that top-performing companies have implemented. A best practices analysis is a roadmap for implementation to achieve the to-be state.

Table 2.1: Cross-functional business process reference model (SCC, 2010)

Business Process Reengineering	Benchmarking	Best Practices Analysis	Process Reference Model
Capture the "as-is" state of a process and derive the desired "to-be" future state			Capture the "as-is" state of a process and derive the desired "to-be" future state
	Quantify the operational performance of similar companies and establish internal targets based on "best-in-class" results		Quantify the operational performance of similar companies and establish internal targets based on "best-in-class" results
		Characterize the management practices and software solutions that result in "best-in-class" performance	Characterize the management practices and software solutions that result in "best-in-class" performance

The SCOR performances

The performance section of SCOR is an important part of the model. The standard metrics that are used to describe process performance are defined, as are the strategic goals. As noted before, the as-is state of a company must be captured first. Depending on the depth of the analysis, process elements, categories and types are then compared with the best-in-class competitors (which is also called benchmarking). The SCOR model uses two types of elements to assess performance: performance attributes and metrics (see appendix 2).

Performance attributes themselves cannot be measured; they only express a strategy direction and are actually a group of metrics. The model is based on five attributes that are divided into two groups (see table 2.2): customer focused and internal driven. While reliability, responsiveness and agility are part of the first group, cost and assets (which is also called asset management efficiency) are part of the second. The SCC defines these attributes as a way for users to systematically approach the model. It also provides definitions given for each performance attribute. Three diagnostic levels are possible within the strategic metrics.

Level I strategic metrics are associated with the performance attributes and measure the ability of a supply chain to achieve the chosen performance attributes (table 2.2), while level II performance metrics can explain improvements or gaps in level I on a more detailed manner. Level III explains the level II metrics by in depth defining the performance metrics. The metrics are coded according to the performance attributes, where **RL** indicates reliability, **RS** is responsiveness, **AG** is agility, **CO** is costs and **AM** is asset management. A number is added to indicate the level, which is followed by a unique identifier. For instance, **RL.1.1** represents "perfect order fulfilment" and is a level I metric within the reliability performance attribute, while **RS.3.17** is a level III metric for responsiveness that explains the level II metrics (delivery retail cycle time, coded as **RS.2.4**).

Table 2.2: Performance attributes with definitions and metrics (SCC, 2010)

Performance Attribute	Performance Attribute Definition	Level 1 Strategic Metric
Supply Chain Reliability	The performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer.	Perfect Order Fulfillment (RL.1.1)
Supply Chain Responsiveness	The speed at which a supply chain provides products to the customer.	Order Fulfillment Cycle Time (RS.1.1)
Supply Chain Agility	The agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage.	Upside Supply Chain Flexibility (AG.1.1)
		Upside Supply Chain Adaptability (AG.1.2)
		Downside Supply Chain Adaptability (AG.1.3)
		Overall Value At Risk (AG.1.4)
Supply Chain Costs	The costs associated with operating the supply chain.	Supply Chain Management Cost (CO.1.1)
		Cost of Goods Sold (CO.1.2)
Supply Chain Asset Management	The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Cash-to-Cash Cycle Time (AM.1.1)
		Return on Supply Chain Fixed Assets (AM.1.2)
		Return on Working Capital (AM.1.3)

A company can precisely measure how it is performing in relation to these performance attributes. Comparing its performance with the best-in-class firm and looking at different metrics also enables it to analyse gaps and identify possible improvements.

The five management processes

Now that the performance section of the SCOR has been clarified, its process section can be explained. The process section contains pre-defined descriptions for business activities that most companies undertake. This model is actually a strategic planning tool that companies commonly use to simplify the complexity of SCM. By integrating the process of supplier delivery with the buyer's source, links in the supply chain are arises (figure 2.2). The overall process can be separated into five standard building blocks:

- **Plan:** This entails balancing demand and supply planning as well as creating plans for the supply chain. Planning manages the execution process (namely, source-make-deliver and return) and sits on top of the supply chain. Within the planning process, resources are aligned in order to fulfil delivery.

- **Source:** This is the processing of acquiring materials, goods and services in order to fulfil planned and actual demand.
- **Make:** This involves transforming sourced materials, goods and services into a finished state in order to fulfil planned and actual demand. The process can be categorized as MTS, make-to-order (MTO) or ETO.
- **Deliver:** This entails providing the finished materials, goods or services to fulfil planned and actual demand. It includes order, transportation and distribution management for the product processed in the "make" step.
- **Return:** This final stage involves receiving products that customers return or returning materials to a supplier for a variety of reasons (such as defects or replacement goods). Return is linked to customer satisfaction.

The three product types

As noted above, the SCC incorporated different classifications into the SCOR model to facilitate a systematic approach to its use. The model defines three categories, which are then used within the five process categories.

- **Stocked product:** In this inventory-driven process, products are made before a customer order arrives and are thus already available before they are requested.
- **MTO:** In this process, which is customer order driven, products are made for a specific customer order. Alternatives to MTO are build-to-order (BTO), assemble-to-order (ATO) and configure-to-order (CTO).
- **ETO:** In this customer requirement-driven process, products are specially designed and manufactured based on the requirements of a specific customer. An alternative ETO is design-to-order (DTO).

The three levels of analysis and one implementation level

The SCOR model contains four standardised levels of process details that become successively more detailed (figure 2.3, see next page). Each of these standard building blocks is implemented in four levels of details. Levels II and III are more supporting metrics for level I.

- **Level I:** This top level deals with the appropriate process categories. The scope and content for the supply chain are selected based on competition performance attributes.
- **Level II:** The second level is also known as the configuration level and describes process types with process categories. The execution and planning processes are defined as material flows. In this level companies implement their operation strategy.
- **Level III:** This lowest level of the analysis within the scope of the SCOR model is the process element level. The inputs, outputs and process flows are defined with specific tasks for the process categories that are formulated in level II. Simply put, the ability of firm to successful compete in the defined markets is measured. Process elements are defined with the information inputs and outputs. Specific performance measures and best practices can also be identified within this level.
- **Level IV:** The last level is actually a detailed implementation of SCM in order to achieve competitive advantages. The implementation phase is unique for each firm.

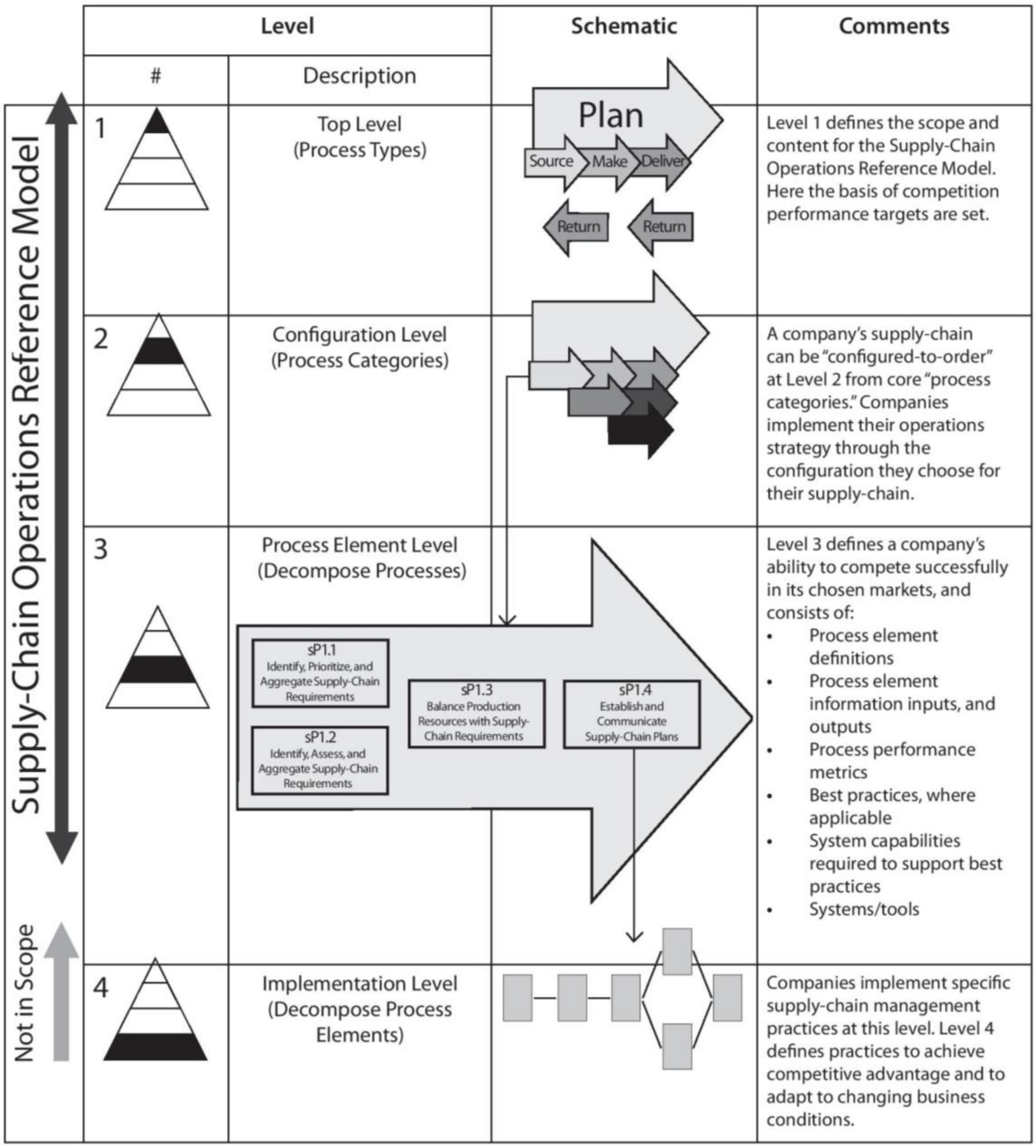


Figure 2.3: Overview of the four different levels of the SCOR model (SCC, 2010)

It is clear that the SCOR model uses characteristics that other authors have used in their models. According to Olhager (2010), this model is relevant to the CODP. Efficient upstream operations are applicable for the CODP, while market-responsive studies can be used for downstream operations. Furthermore, different process types are possible in level II depending on the influence of CODP. Other authors suggest to combine the SCOR model and the CODP. The CODP influences the execution process, regardless of if it is MTO or MTS (Immawan, ., Arkeman, & Maulana, 2015; Persson & Araldi, 2009). The CODP is further elaborated below.

The activities performed by most companies are codified within the process section of the SCOR and are quite varied (as shown in appendix 2). The codification differs by each score level. In the first level, a capital letter is added after "s" to represent the process. The codification is as follows: **sP** for plan, **sS** for source, **sM** for make, **sD** for deliver and **sR** for return. Within the return element, a distinction can be drawn between source return (**sSR**) and deliver return (**sDR**). The former when the customer returns finished products to a company, while the latter is when that company returns something to a supplier.

Furthermore, **E** stands for enable elements, which are associated with a process element. For example, **sEP** stands for enable plan and **sEM** for enable make. These codifications fall within the first levels of SCOR (see appendix 2). The element process manages the information and relations within the planning and execution process.

Within the second level of the SCOR, a number is added to the codification used in the first level. This level indicates if the product is a stocked product (**1**), MTO (**2**) or ETO (**3**) in terms of source, make and deliver. For example, **sS1** stands for source stocked product and **sD3** for deliver ETO product. With the development of SCOR, the SCC codes the configurations of the execution and plan process in order to ensure a structural approach. Within these configurations, related process can be analysed. For example, when companies produce to stock (**sM1**), it is most likely that they also deliver stocked product (**sD1**). In addition, when a supplier delivers stocked product, customers mostly use the source stocked product (**sS1**) configuration. Different processes are therefore related to each other within these configurations, although combining multiple configurations remains possible within the supply chain.

During the third-level analyses, a new number can be add to the second-level number in order to add more information. For example, **sS1.4** means transfer products within the source stocked product, while **sM1.4** means package in MTS. As noted before, the inputs, outputs and process flows are defined with specific tasks for the process categories that are formulated in level II. For example MTS (**sM1**) can thus describe several elements in this part of the execution process.

As noted previously, SCOR serves as a standardized structural approach for evaluating supply chains in an efficient and effective way. Methodologies such as six sigma and lean management (**LM**) are related to SCOR, this model introduces different concepts that both of these methodologies use to eliminate waste and reduce variability. The focus of SCOR lies on transactional areas (such as customer service and sales) as well as on traditional processes. Furthermore, only SCOR can be used to measure an organisation's business impact. Because of the relationship between the three methodologies, improvement teams will probably use all of them. As a result it is possible to conclude that similar tools can be used to serve different methodologies. A selection of these tools is presented in figure 2.4.

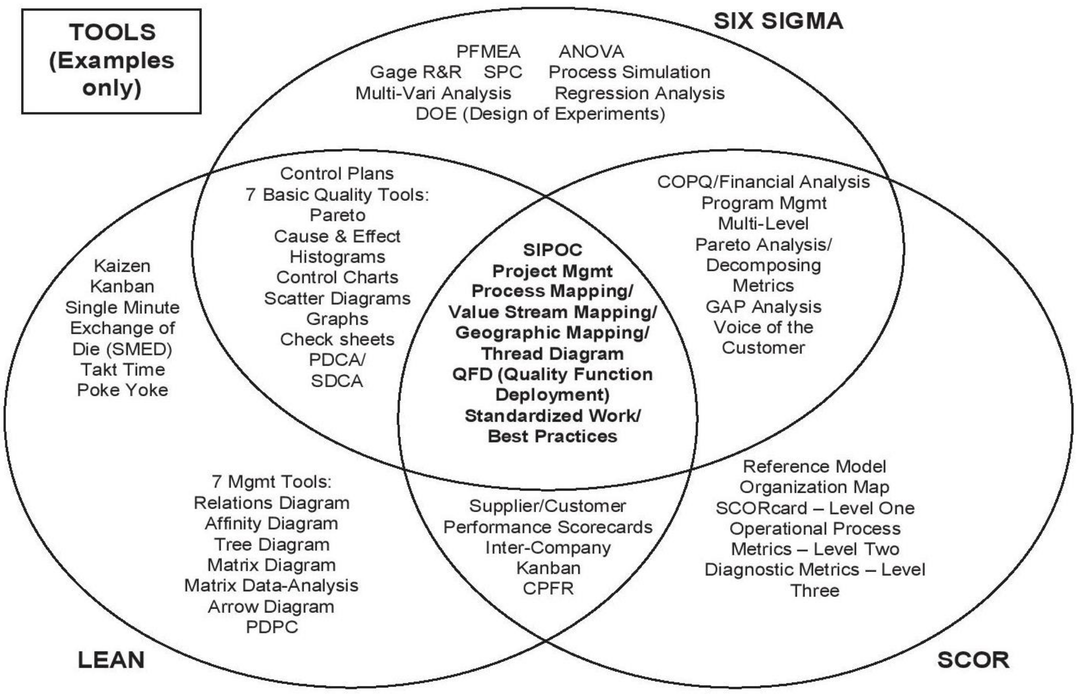


Figure 2.4: Venn diagram with examples of tools for SCOR, six sigma and LM (SCC, 2010)

In addition to these tools, several authors suggest that SCOR recognise four different models in particular, namely:

- **Business scope diagram:** A tool to set up the scope for a project or organisation.
- **Geographic map:** A tool that highlights complexity or redundancy by describing material flows in a geographic context.
- **Thread diagram:** A tool that can be used to describe high-level process complexity or redundancy. Its focus is specifically on process connectivity in level II and it can be classified as a material flow diagram.
- **Workflow or process models:** These tools are especially used to analyse information, material and workflows in level III. These models highlight interaction between systems, people and information within an organisation or between entities.

Within this research, the workflow or process models and the thread diagram are used in particular to gain a better understanding of the process within the company. Other tools are less important in this study, but it is helpful to keep in mind that they are useful for analysing the SCOR model. Optimisation techniques can be used to create an effective and efficient workflow. As mentioned above, LM, six sigma and SCOR may share similar tools. Which of these optimisation methodologies is used will be discussed in section 2.5.2 (optimisation techniques).

2.2.2.4 Customer order decoupling point (CODP)

It is becoming clear that SCOR can be related to other methodologies, such as LM, six sigma and the CODP. Level II of the SCOR model can be influenced by the CODP, as it is applicable for efficient upstream operations within the supply chain (Immawan et al., 2015; Persson & Araldi, 2009). Within the supply chain, success depends on the end customer. Definitions for concepts such as customer satisfaction and market requirements are crucial for a new supply chain strategy. Finding a balance between customer satisfaction and driving costs is largely difficult for an organisation. Supply chain performance tries to match supply with demand (Christopher & Towill, 2001; Olhager, 2010).

According to Martin and Towill (2000), a problem in the supply chain is that entities within it are mostly forecast driven. The real demand of the customers is only partially visible, due to the multiple levels of inventory in a chain. The CODP is a point in the supply chain that customers can reach. It is also where the market “pull” meets the upstream “push” (Martin & Towill, 2000). Hoekstra and Romme (1992) define the decoupling point as the separation between the planning part of the supply chain and the customer-order activities. At the CODP, the product is specifically tied to a customer order (Olhager, 2010).

In this respect, a distinction is drawn between the supply chain and company perspectives. Within the supply chain perspective, typically only one CODP is positioned for the whole supply chain. Within the company perspective, the CODP is positioned within the firm’s production process. However, in the latter it remains possible that the CODP is positioned more upstream (i.e., toward the supplier side) or downstream (i.e., toward the demand side) within the supply chain (Olhager, 2010, 2012).

As Hoekstra and Romme (1992) point out, the decoupling point is accompanied by a stock point. This means that stocks are used for the planning part of the company, while the CODP is used downstream. Almost no stocks are found upstream. By balancing elements such as lead times and the production process with the market requirements, the CODP will more likely move upstream (which will result in stocks being avoided downstream from the CODP). This is only possible if a firm has short lead times and is flexibly organised. Hoekstra and Romme (1992) describe five different positions for the CODP: make and ship to stock, MTS, ATO, MTO, and purchase and MTO. As shown in figure 2.5, the CODP determines if the stocks are forecast driven or customer order driven.

In the literature there is consensus that operations within forecast-driven activities are different from those within customer order-driven activities (Olhager, 2012). Nonetheless, different authors have analysed multiple areas within the CODP. Hoekstra and Romme (1992) treat the logistic area, while Olhager (2010) focuses more on supply chain planning and Sackett, Maxwell and Lowenthal (1997) discuss the subject in combination with manufacturing strategies. These analyses may lead to a derivation of the CODP. For example, Hoekstra and Romme (1992) use five different situations, while Olhager (2012) reduce the CODP to three positions. According to Wikner and Rudberg (2007), however, the traditional CODP still contains four typical situations. Different authors have characterised the traditional CODP over time, including Wortmann, Muntslag and Timmermans (1997); Sackett et al. (1997); Porter, Little, Peck and Rollins (1999); Wikner and Rudberg (2007); and Stadtler and Kilger (2015). As shown in figure 2.6, the typology of the traditional CODP defines the following situations:

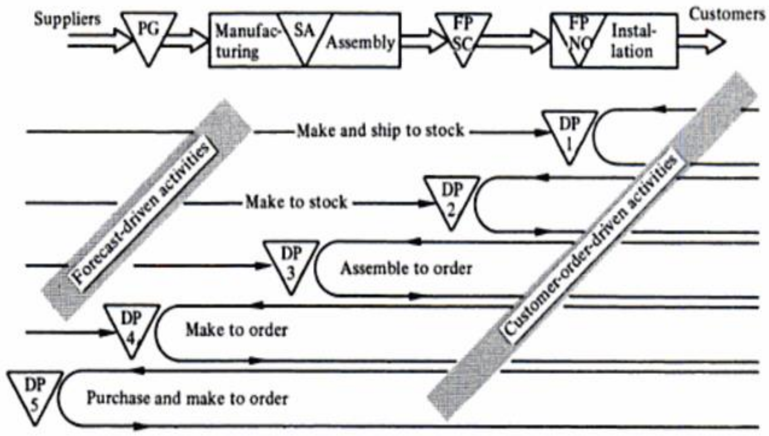


Figure 2.5: Five different positions for the CODP (Hoekstra & Romme, 1992)

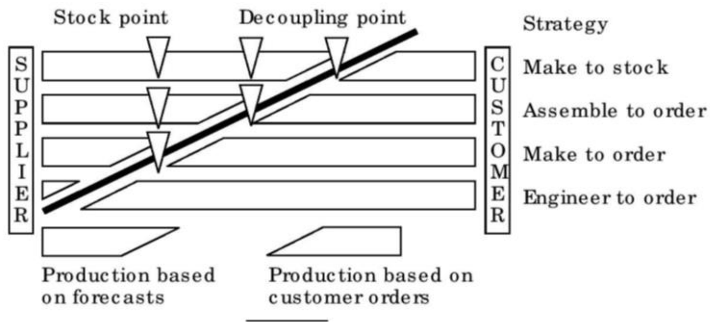


Figure 2.6: Four traditional situations for CODP (Sackett et al., 1997)

- **MTS:** The demand and production in this manufacturing process is based on forecasts; it is also called PLAN (see the SCOR model). As customers have a limited influence, the product is available before it is requested.
- **ATO:** Components of the product are manufactured based on a forecast and are mostly temporarily stored in a warehouse as a buffer to decrease lead times. Customers have more influence on the product as it is configured to a range of available specifications. Lead times depend on the availability of the components.
- **MTO:** Manufacturing begins after a customer order is receive, although only raw materials must be purchased given that customers order standard products.
- **ETO:** This manufacturing process includes standard products; modifications and customisation are only possible upon request. This process is thus customer order driven and customers have a high degree of influence on the manufactured product (Porter et al., 1999; SCC, 2010).

There is a difference between inventory-driven and order-driven production. The turning point is influenced by the CODP. A balance needs to be found between stock holding and customer responsiveness. The relationship between the four possible positions, production volume and the amount of stocks held can be found in figure 2.7. According to Berry and Hill as cited in Olhager (2012), an MTS approach should be followed for standard products with high volume per period, while an MTO approach should be used for special products with low volumes. Srivastava, Shervani and Fahey (1999) also note that products should follow a modular design when a company uses an MTO strategy.

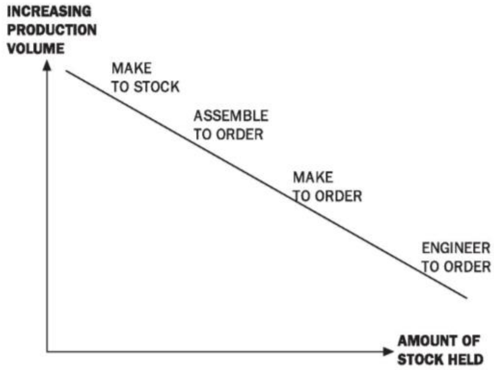


Figure 2.7: Relationship between stock and manufacturing volume (Porter et al., 1999)

According to Porter et al. (1999), in practice production processes in manufacturing firms do not fit just into one specific class. Processes could cross the boundaries of the theoretical descriptions and thus reflect a combination of multiple positions (Porter et al., 1999; Wikner & Rudberg, 2007).

2.2.2.5 Core competency of the firm

As global competition grows, manufacturing industries in Europe are fighting to leave their competitors behind (Jovane, Westkämper, & Williams, 2008). Defining a company's core competency could help it to create long-term competitive advantages (Chase et al., 2005). Nevertheless, the structure of manufacturing has changed in recent years, and operations are more concentrated on niches and customisation in order to create higher profitability. Products have become customer-specific and variants are increasing as a result. The complexity of the products is also increasing, as are product development costs (Jiao, Ma, & Tseng, 2003; Jovane et al., 2008). Highly skilled workers employed by European manufacturing firms have a great influence in these structural changes. Nonetheless, transforming to customised production remains a challenge for most manufacturing firms (Jovane et al., 2008).

The key to success within the global competitive market is to design and make high quality products that are manufactured at minimum costs and in a short time frame (Jiao et al., 2003). Jiao et al. suggest that OEM-based industries can generate premium revenues by customising high value-added products and services. However, a balance needs to be found between customer satisfaction and cost savings. This could be accomplished through design for mass customization (DFMC), which entails basing product design on product families and not on individual products. The result would be that products are not developed from scratch for each individual but that several product variants are created (Jiao et al., 2003). Firms also need to break through traditional boundaries, and support from different departments (e.g., marketing, sales, distribution and services) is necessary to apply mass customisation (Jiao et al., 2003). The product, the process and the supply chain network should be designed in a module manner in order to create effective mass customisation (Chase et al., 2005).

As the structure of manufacturing has changed over time, a trend to outsource activities that were previously done in-house has developed. Today the main focus of companies is their core activities (McIvor & Humphreys, 2004). As such a fundamental question for a company's strategy arises: the company needs to decide what it will make and what it will buy, which is the so-called the make vs. buy (MvB) decision. This question is traditionally answered by financial criteria (e.g., if a supplier can produce a component with the same quality against lower costs) (Platts, Probert, & Cáñez, 2002). Non-financial factors influence the MvB as well. According to Tallman and Fladmoe-Lindquist (2002), these non-financial factors are called the capability perspective. Unique internal resources and capabilities and the ability to apply them can also result in competitive advantage (Tallman & Fladmoe-Lindquist, 2002).

As previously mentioned, it is important that a firm defines its competency in order to differentiate itself from its competitors. In this connection, Treacy and Wiersema (1997) discuss three value disciplines that a company could choose as a strategy (Chase et al., 2005; Treacy & Wiersema, 1997):

- **Operational excellence:** When this strategy is chosen, a company focuses on a combination of quality, price and ease of purchase for its customers that none of its competitors can match. Examples of companies that focus on operational excellence are Dell Computers and McDonald's.
- **Product leadership:** When a company focuses on product leadership, it pushes its products into the unknown. These designs are usually untried before and become highly desirable for the customers. Intel and Sony are examples of companies that use these strategies.
- **Customer intimacy:** A company that focuses on customer intimacy tries to create a relationship with individual customers. It knows what the customers want and who they are.

Nowadays researchers have added another strategy to the traditional three strategies, customer experience management. This approach is a process-oriented satisfaction idea and measures the entire experience concerning a product or a company (Schmitt, 2010).

In summary, a company chooses its own core competency in order to achieve competitive advantage. As each value discipline demands different operating processes, the company needs to answer the MvB question in order to stay on track.

2.2.3 Schedule design

Within schedule design, a firm needs to have a strategy in relation to the market forecast, production demand and production rate. This strategy depends on the product marketing mix and the required production rate. Schedule design still influences the layout, as it affects both machinery occupancy and the production schedule (Francis et al., 1992). The aforementioned strategy needs to be monitored by the firm. This includes monitoring daily activities and aligning them with strategic objectives, both of which can be done using performance measurement tools.

Parmenter (2010), Cox, Issa and Ahrens (2003) define similar definitions for KPIs are a performance measurement tool created for an organisation (Chae, 2009). According to Parmenter (2010), there are four types of performance measurement:

- Key result indicators, which tell how a firm has done something and are a result of many actions. As such they give information about the direction in which things are moving, but not on how to improve the results. Examples of KRIs include net profit before tax, return on capital employed and customer satisfaction.
- Result indicators measure what a firm has actually done. All financial performance measurements fall into this category, including net profit on key product lines and sales made yesterday.

- Performance indicators tell a firm what to do. They align teams within an organisation and ally them with the organisation's strategy. It is important to understand that PIs are nonfinancial and complement KPIs. Examples include late deliveries to key customers, sales calls organised for the coming weeks and the number of employees suggestions implemented in a quarter.
- KPIs tell a firm what to do in order to dramatically increase performance.

In a practical side note, Parmenter (2010) observes that many of the performance measures that are applied in enterprises reflect a mix of the four types (which he believes is inappropriate).

As noted before, an organisation can measure both itself and the complete supply chain. Using these performance measurements reveals how the supply chain works, how the organisation can influence the chain and how it can improve the chains performances (Chen & Paulraj, 2004; Shepherd & Günter, 2011; Wisner et al., 2015). Chen and Paulraj (2004) divide supply chain performance into financial, operational and time-based performance, which is reiterated by Wisner, Tan and Leong (2015). Economic performance indicators are useful for measuring the fulfilment of a firm's financial goals, and factors that influence financial measurement are more likely orientated outside of the company. In contrast, operational performance reflects the effectiveness and efficiency of a company's process. It includes quality, flexibility, delivery speed and cost. Examples of time-based performance are lead-time, delivery speed, product development and customer responsiveness.

Performance measurement can vary between departments within an entity. Table 2.3 shows typical function-based measurements and related goals for the relevant departments. A disadvantage of pure function-based measurement could be that individuals tend to improve their own department performance, which results in conflicts with organisational goals (Lapide, 2000). Co-operation is thus necessary between departments as well as between organisations in the supply chain. As such the focus of supply chain performance lies on the integrated supply chain instead of individual supply chain entities (Chen & Paulraj, 2004).

Table 2.3: Typical function-based measurements and related goals (Lapide, 2000)

	PURCHASING	MANUFACTURING	LOGISTICS	CUSTOMER SERVICE/SALES
Measures	• Supplier Performance • Cost Per Unit Purchased	• Set-ups and changeover Times • Plant Utilization • Waste and Scrap	• Inventory Turns • Transportation Costs • Warehouse Productivity	• Customer Satisfaction • Customer Order Cycle Time
Goals	• Multiple Supplies (potential varying quality) • Large Purchase Orders • Increased Materials Inventories	• Long runs • Increased Finished Goods • Decreased Materials Inventories • Bulk Customer Orders • Product Quality	• Decrease Finished Goods Inventories • Centralized Stocking Locations • Bulk Customer Orders	• Increased Inventories • Multiple Stocking Locations Close to Customers • JIT Customer Orders

While the SCOR model also includes a performance section, it does not offer a way in which to measure performance attributes. It instead sets a strategy direction for the company using five represented attributes (see table 2.2) (Huan et al., 2004; Lambert et al., 2005; SCC, 2010; Shepherd & Günter, 2011; Wisner et al., 2015). Chae (2009) also discusses potential KPIs for the four processes within the SCOR model. A distinction is only drawn between primary and secondary KPIs (see figure 2.8).

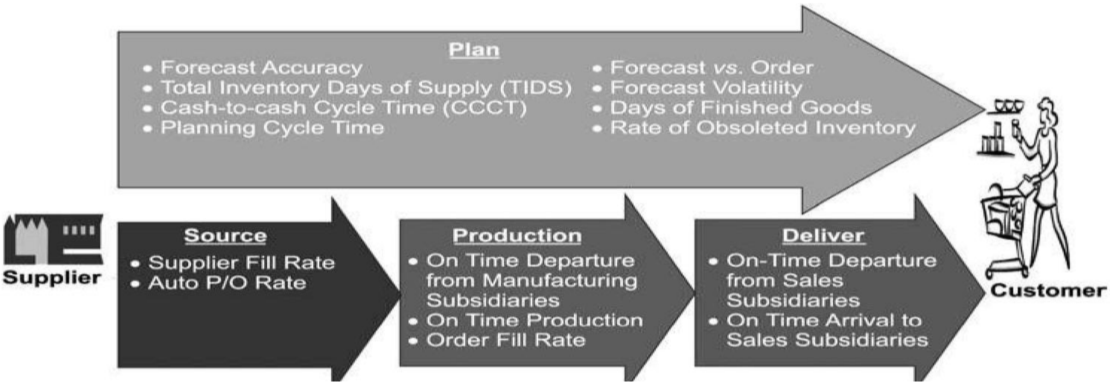


Figure 2.8: Proposed KPIs within the four processes of SCOR (Chae, 2009)

Limiting the number of KPIs is a great challenge for many companies. To secure and monitor the measurement process, it is necessary that they limit the number of measures in specific areas (for instance, a strategy-consulting firm recommends a maximum of three to five). The tendency is that companies want to measure more than is actually recommended (Lapide, 2000). The proposal of Parmenter (2010) is to use 10 KRIs, 80 RIs and PIs, and 10 KPIs. Unlike the general perception of performance measurement, less should be better. A company should only monitor the KPIs that are absolutely necessary in the first place and thus start with a small number of KPIs (Chae, 2009).

Discussion input and data activities

In this section, different models are derived from literature for process and schedule design. First of all, the assumption is made that we excluded technical product analysis for product design within the research scope. However, in section 3.2(products) the products built by the company are analysed, as this section provides essential input for the subsequent sections.

As the strategy determines the different kinds of products, it influences the production process. To determine the core competency of the firm, we apply the model of Treacy & Wiersema (1997) within section 3.1 (the company's core competency). The model is well known in literature and applicable in practical situations. Working methods and MvB decisions are closely related to the strategy of the company and therefore analysed in section 3.1 (the company's core competency) and in section 3.4 (production process in the existing situation). Still, improvement is possible within both subjects and will be further carried out in section 4.3 (production process in the to-be situation). As the process of producing product not only depends on in-house activities, the supply chain influences the production process as well. the company chooses to focus on in-house activities (further elaborated in section 3.1 (the company's core competency), the company's core competency). Therefore, we do not apply the recommended SCOR model in this thesis. When the strategy and the MvB decision change in the future, this model could be applied to the company's supply chain to monitor it.

The last part of the discussion is schedule design or also related to KPIs. These KPIs measure the performances and aligning them with strategic objectives. Firstly, it is necessary to identify possible KPIs used by the company, which is carried out in section 3.6 (performance in the existing situation). As a result, we identify bottlenecks in section 3.7 (bottlenecks in the existing situation). As literature suggests several KPIs, recommendations are given in section 4.4 (KPIs).

2.3 Flow of materials

Within the SLP model of Muther (1973), which was later revised by Francis et al. (1992), the first step is to analyse and investigate the flow of materials. The flow describes the movement between departments or activities. The layout facilitates the flows of materials from raw materials into finished products (Francis et al., 1992; Muther, 1961). All of these authors describe possible ways to measure the flow of materials (e.g., through assemblage sheets) but do not define an effective and efficient flow.

According to Georgakopoulos, Hornick and Sheth (1995), little agreement on the definition of the word “workflow” can be found in the literature. It is used in a casual way with related to many different subjects, such as specification of a process and business process. Georgakopoulos et al. (1995) describe workflow as “a collection of tasks organised to accomplish some business process” (p. 123). Humans, software systems or both can perform these tasks. Van der Aalst, Hofstede, Kiepuszewski and Barros (2003) suggest that a workflow process or workflow schemas can be defined as “specifying which activities need to be executed and in what order” (p.9), adding that devices and humans each have roles in the activities. Directed flows can be considered as effective when they move uninterruptedly from their origin to their destination. Tompkins, White, Bozer and Tanchoco (2010) define effective flows as progressive movements of people, information and materials through/between workstations and departments. The details of these three definitions differ. In every description of flow, workflow or workflow process, however, people, (information) systems and materials are transmitted through an organisation in order to accomplish a business process. In this thesis, the definition of workflow offered by Tompkins et al. (2010) is used seeing as the workflow and effectiveness elements are both reflected. Achieving an effective workflow includes lowering both workflow cost and total workflow by maximising the direct workflow through an organisation. Tompkins et al. argue that the impact of facility planning decreases operation costs by up to 30% in operation costs by reducing and eliminating unnecessary activities that cause waste (Tompkins et al., 2010).

Process mapping (or process blueprinting or process analysing) can be used to identify different flows of activities that have taken place during a process within an organisation. Many process mapping techniques are available, including flow process charts (Slack et al., 2010). The study of Królczyk, Legutko, Królczyk and Tama (2014) suggests three different stages for analysing the material flows. The first stage entails analysing the material flow’s current situation, the second stage involves detailing the internal transport program and the final stage revolves around identifying opportunities for possible actions. Optimisation is especially important for suggesting possible actions in the final stage (Królczyk et al., 2014).

Francis et al. (1992) identify different types of flow patterns, which can be reduced to five basic horizontal flow patterns (see figure 2.9):

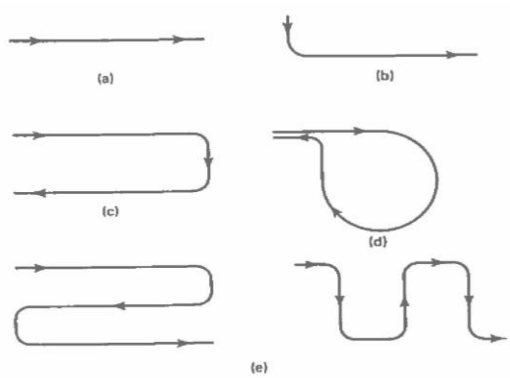


Figure 2.9: Five basic horizontal flow patterns
(Francis et al., 1992)

a) **I flow or straight line:** This is the simplest form of all basic horizontal flows. In practice, the straight line of this flow requires a distinction between the receiving and the delivery departments.
b) **L flow:** This flow pattern is normally adopted when it is not possible to use an I flow in an existing facility.
c) **U flow:** If the receiving and shipping departments are combined in practice, the pattern is usually a U flow. It is a very popular pattern.

d) **O or circular flow:** This flow type is adopted when the flow needs to finish near to where it originates.
e) **S or serpentine flow:** Zigzagging is necessary if a production line is too long for the production facility. In such cases, an S or serpentine flow is desirable.

In addition to horizontal flows, it is also possible that organisations have vertical flows. These patterns are commonly only applicable in multi-store structures (Francis et al., 1992). They are not elaborated here further, seeing as the company only has one level production.

As previously mentioned, the layout depends partially on the flow of materials; this step has a major influence on the outcome of the final layout. The definition for layout accepted in this thesis is “how [a company’s] transformed resources are positioned relative to each other and how its various task are allocated to these transforming resources" (Slack et al., 2010, p.179). The above-mentioned definition for an effective workflow explains how the flow of materials should be positioned in the future. Flows should be direct and can be considered as effective when they move uninterruptedly from their origin to their destination.

Discussion flow of materials

Within the main research question (1.2.2), a term such as “effective workflow” needs to be defined in order to answer the research question correctly. An effective flow moves uninterruptedly from their origin to their destinations. The definition described by Tompkins et al. (2010) is used for this research because it defines different movements. The method used to analyse flows is named process mapping and will be used in section 3.7 (bottlenecks in the existing situation).

2.4 Activity relationship

Just as the flow of materials describes the routing, the activity relationship records the relationship between movements/activities (Francis et al., 1992; Muther, 1961). These movements/activities can be captured within different layout types that also affect the flow pattern (Francis et al., 1992). The chosen design depends on the variety of products and the production volume (Drira et al., 2007). The literature distinguishes between four general layout types (Chase et al., 2005; Drira et al., 2007; Francis et al., 1992; Slack et al., 2010):

- **Fixed product layout:** The transformed resources do not move this type of layout; components, machines and personnel are instead moved to perform the operations. It is not wise to move the product for several reasons. This type of layout is commonly found in industries that manufacture large products, such as aircraft building and shipbuilding.
- **Process or functional layout:** This layout entails all similar processes being located together; an example it having all stamping machines in one area. The needs of the product define the route of the materials flow. Various products could have other needs and result in different routes. Given that there is often a wide variety of products, a product layout is frequently not justified. Hospitals and manufacturers may use this layout.
- **Product (or product line) layout:** In this layout, the progressive steps that are followed to make a product define the work processes. Each product follows a prearranged route according to the sequences associated with it. This general layout is commonly used for products with low variety but high volumes. Continuous production is justified. The product layout is common in automobile assembly, lean application processing and car washes.
- **Cellular layout:** This general layout involves creating cells with similar process families. It has similarities with the product and process layouts. A limited range of products go through a cell that are designed for a specific set of processes. When

they are finished, the materials are transferred to another cell. It is necessary to find the best layout for the machinery within each cell. The cellular layout can be found in hospital maternity units and on laptop assembly lines.

Once information on the type of material flows and different layouts is combined, a detailed layout needs to be designed. According to Allegri as cited in Yang, Peters and Tu, (2005), it is important to design both a material flow path and an efficient layout. It is particularly important to achieve high productivity in a flexible manufacturing system (FMS). In addition, FMS is designed to optimise effective flows, which results in reduced production time and an approximate 20 to 50% decrease in costs (Ficko, Brezocnik, & Balic, 2004). As previous mentioned, cellular layout is one of the four general layouts. A combination of FMS and cellular layout leads to an FMS cell, which consists of several machines. According to Das as cited in Yang et al. (2005), differences exist between these cells and the general layouts (e.g., FMS cells have fixed shapes and defined pick-up/drop-off points). Four different FMS configurations consider material handling devices (Drira et al., 2007; Niroomand, Hadi-Vencheh, Şahin, & Vizvári, 2015; Yang et al., 2005) (see figure 2.10):

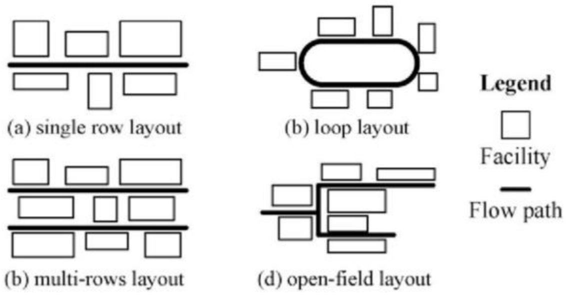


Figure 2.10: Four different FMS configurations (Drira et al., 2007)

a) **Single-row layout:** The single-row layout can be considered as the basis for different material handling situations (e.g., straight line or U flow) (Hassan, as cited in Drira et al., 200s7)
b) **Loop layout:** The loop layout has a unique pick-up/drop-off point. The materials are transported in one direction within a closed ring.
c) **Multi-row layout:** According to Hassan as cited in Drira et al. (2007), a multi-row layout involves several rows within a department. It is possible to move between facilities within a row as well as from row to row (Ficko et al., 2004).
d) **Open-field layout:** Unlike the other three FMS layouts, open-field layouts do not have restrictions (e.g., transportation must move in one direction).

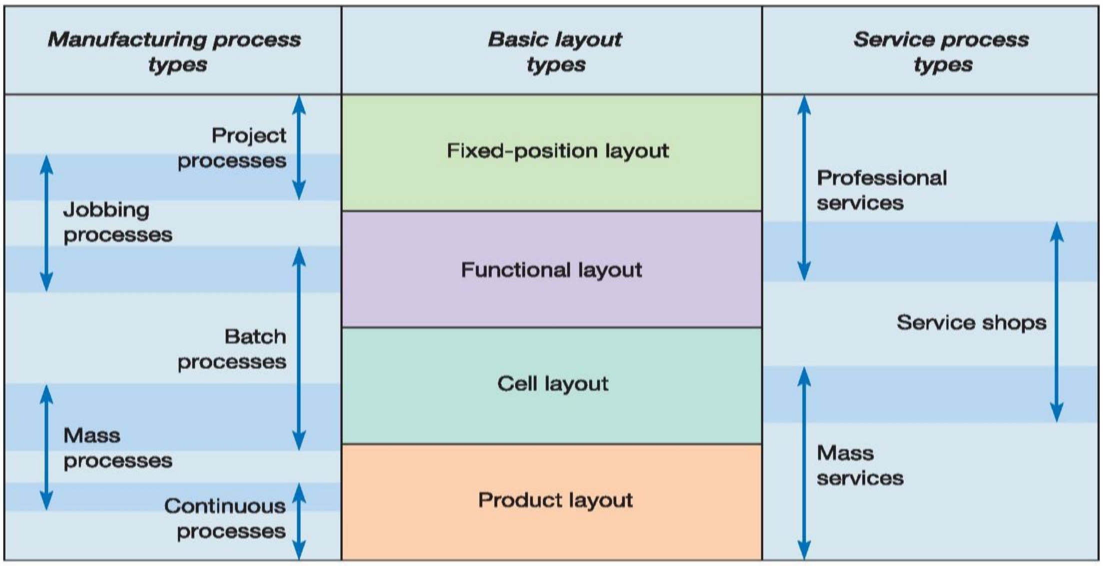
Some authors assert that a fifth layout configuration is possible, namely the ladder layout (Niroomand et al., 2015; Yang et al., 2005).

The literature does not offer a clear-cut rule for deciding between a product and a process layout. Many layouts are a combination of different layouts. It is also possible to consider different layouts for different products (Francis et al., 1992). It should be kept in mind that possible production volumes can change in the future. Slack et al. (2010) describe the relationship between the general layout types and possible process types (see table 2.4, next page). These authors note that a process type could imply different kinds of layouts as well. Chase et al. (2005) define an example for a combination of different kinds of layouts within in a company as follows; process layout could be used in the fabrication department, cellular layout is the central layout for the subassembly department, while in the final assembly could be a product layout applied.

Discussion activity relationship

The activity relationship provides us information concerning a general layout depending on information required from chapter 3 (description of the existing situation). In section 4.2 (routing of the flow of materials in the to-be situation) we elaborated the best suitable general layout type for the company's case, which influence the manufacturing process (section 4.3, production process in the to-be situation)

Table 2.4: Relationship between basic layouts and process types (Slack et al., 2010)



2.5 Analytical analysis

As mentioned before, the SLP approach was revised by Francis et al. (1992). A significant difference between his revised model and the original SLP model of Muther (1973) is step 6b (see figure 2.1), which Francis et al. developed in order to reduce the influence of individual's intuition on the traditional layout procedures (Francis et al., 1992). In the original approach, individual intuition could be decisive. In this section, a scientific research method is used to select the most appropriate layout design for the company and possible optimisation techniques are discussed.

2.5.1 Decision-making method

After designing multiple layout alternatives based on the revised SLP approach, it is necessary to select the most appropriate layout design. Multi-criteria decision-making (MCDM), which is well known in the decision-making branch, entails combining alternatives and a set of decision criteria in order to select the best alternative (Triantaphyllou, 2000). Examples of popular MCDM models include the analytic hierarchy process (AHP), the weighted product model (WPM) and the weighted sum model (WSM) (Triantaphyllou, 2000; Zolfani & Saparauskas, 2014).

Selecting the most appropriate layout design is defined by Francis et al. (1992) as "the selection of the design that results in the most favourable compromise among competing objectives" (p.75). These authors also recommend comparing the performance of the new design with that of the existing design (Francis et al., 1992), especially in a redesign case. Several studies have used an effective decision-making tool to evaluate layout alternatives, including the AHP (Cambron & Evans, 1991; Yang & Kuo, 2003). The AHP, which was developed by Saaty (1990), is a multiple performance measurement tool that is based on trade-offs between several criteria and a verbal scale (Cambron & Evans, 1991; Saaty, 1990; Yang & Kuo, 2003). Nevertheless, several studies suggest other approaches to solve the objective layout problem. For example, the intelligent facilities layout planning and analysis system (IFLAPS) was described by Kumara, Kashyap and Moodie (1987 and 1988). Another approach is the facility layout using interactive graphics (FLING), which was developed by Blair and Miller (1985). The Micro Computerized Relative Allocation of Facilities Technique (MOCRAFT), which is a modified version of the original Computerized Relative Allocation of Facilities Technique (CRAFT) model discussed by Svestka (1988), is another possible approach. Nonetheless, Cambron and Evans (1991) assert that there are two main reasons for applying the AHP instead of these other approaches. First, designers and decision-makers are perfect consistent between trading-offs of different criteria to evaluate an design. This is suggested by several approaches, but in practice designers and decision-makers are inconsistent. The AHP thus allows room for inconsistencies on behalf of the designer or decision-makers. Second, the AHP model applies a hierarchy to structure a decision problem (Cambron & Evans, 1991).

The simplest form of the AHP hierarchy structure entails distinguishing three levels (see figure 2.11). The first level places the decision-making goal at the top of the hierarchy. The criteria to measure the alternatives are located in the second level. The actual alternatives are then located and evaluated in the third level (Saaty, 1990). Further, usage of the AHP model requires fours steps (Cambron & Evans, 1991; Saaty, 1990):

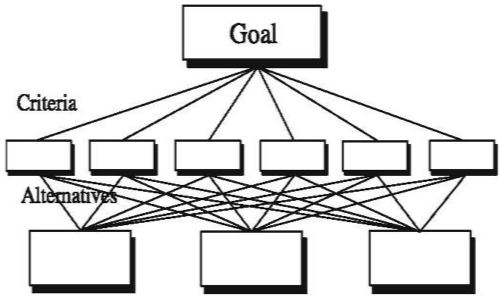


Figure 2.11: Three-level hierarchy (Saaty, 1990)

Table 2.5: Scale of importance (Yang & Kuo, 2003)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	For compromise between the above values

1. Structuring the above-mentioned hierarchy for a decision problem. The hierarchy becomes more specific at each lower level.
2. Defining the potency of the different factors' influence. Pairs of criteria are considered in order to compare the importance of factors (e.g., costs vs. environment). These pairwise comparison weights are the sum of several 'local weights'. The scale of importance is shown in table 2.5. This step results in an influence matrix.
3. Applying the "eigenvalue method" to set up comparison ratios within the matrix. The weights defined in step 2 (influence matrix) are determined by the decision-maker. To control the weights, an inconsistency ratio that measures the decision-maker's inconsistency could be added.
4. Synthesising the priorities of the alternatives.

2.5.2 Optimisation techniques

Manufacturing industries in Europe are fighting to leave competitors behind in today's globally completing market (Jovane et al., 2008). Hicks and Matthews (2010) describe an overview of paradigms (figure 2.12) to optimise manufacturing systems and the cause of failed implementation. The core of this framework is manufacturing capability, which can be achieved by the dimensions of flexibility, efficiency and quality (Hicks & Matthews, 2010). These dimensions define the prices of finished goods. These factors are heavily interrelated with each other and optimising one could have an undesirable effect on another (Hicks & Matthews, 2010). As stated by Hicks and Matthews, "to improve particular aspects of, for example, the product design or the manufacturing process can lead to improvements in the areas of either quality, efficiency or flexibility, it is ultimately the sum of all systems, actors and inputs associated with the realisation of the product that determine levels of quality, efficiency and flexibility" (p.3). Optimising these factors to the highest possible level is also referred as "world class manufacturing" (Maskell, 1991). The organisation not only influences the capability to improve quality, efficiency and flexibility; it also depends on people, processes, products and practices (Hicks & Matthews, 2010; Maskell, 1991). This phenomenon, which is represented as the third layer in figure 2.12, has led the literature to describe a wide variety of tools, methods and approaches that could improve the three dimensions. These tools can be applied constantly due to the changing environment and constitute the last layer of the framework that consists of business environment, suppliers and the customers (Hicks & Matthews, 2010).

Figure 2.12: Overview of manufacturing system improvements (Hicks & Matthews, 2010)

Hicks and Matthews also present a more detailed overview, as shown in figure 2.13. The layers are split into eight paradigms, based on principles of different methods and tools. Choosing a dimension, for example efficiency, makes it possible to use product modification and new product introduction as well as other possible manufacturing philosophies (e.g., lean management (LM)). The framework described by Hicks and Matthews (2010) is the starting point for optimisation. As it is still not clear which bottlenecks are possible to optimise, further research is done in the recommendation phase (see chapter 6, layout implementation).

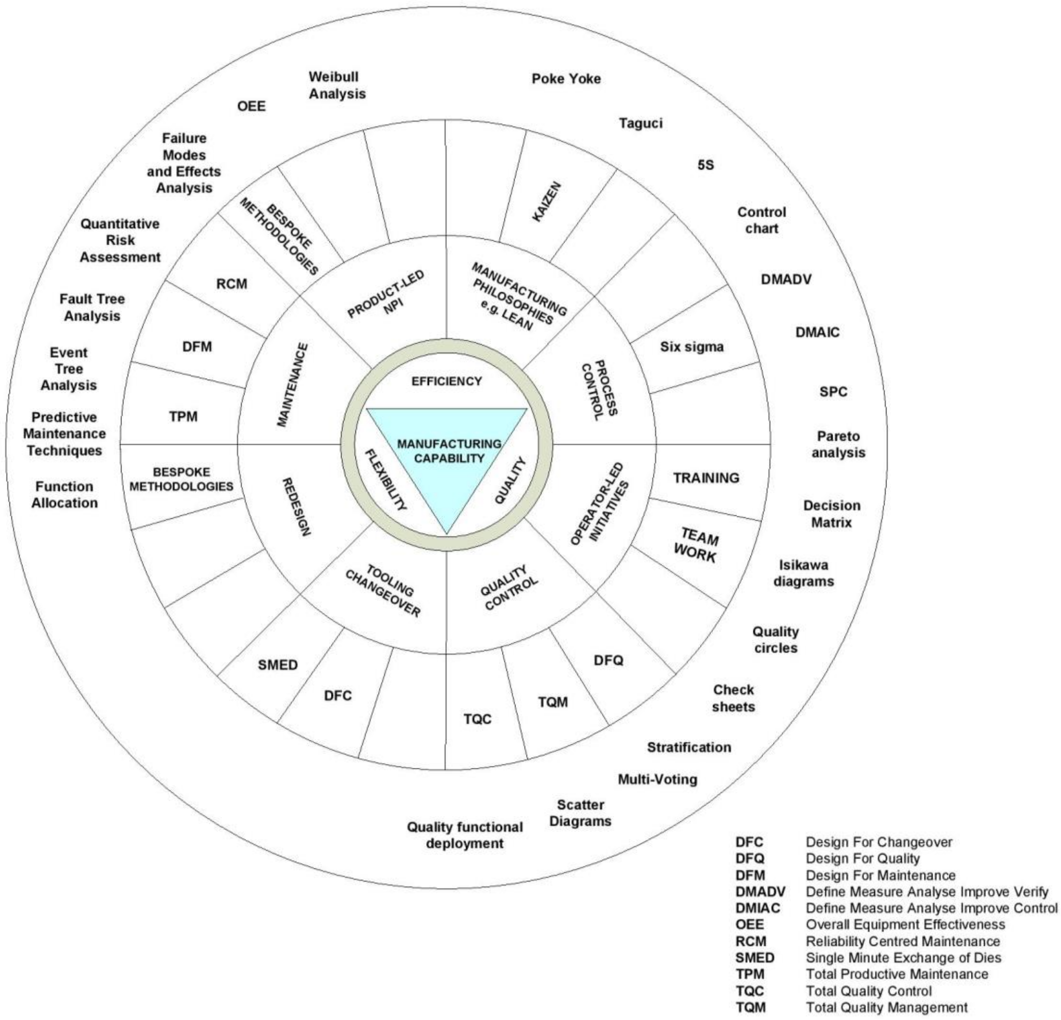


Figure 2.13: Improvement paradigms and their corresponding tools and methods (Hicks & Matthews, 2010)

Discussion analytical analyses

After designing different layout alternatives, it is important to select the most suitable layout for a company. Therefore, we modify the AHP model suiting our purpose for the company's case in section 5.3 (list of criteria). According to literature, different alternatives are designed before selecting the layout. We decide to use the AHP model in the designing process in this research, as the other matter is more time consuming.

Within the timeframe of this thesis it was not possible to imply different optimising techniques to the chosen layout due to the fact that the move itself was a major change for the personnel at the company. Therefore we discuss several options for the company to optimise their production process and the layout for the future in chapter 6 (layout implementation).

2.6 Discussion of the theoretical framework

The goal of this discussion is to choose the models used in the following chapters. The best model is identified from a set of competing models using several criteria (Pitt, Kim, & Myung, 2003). Several authors (Cordeau, Gendreau, Laporte, Potvin, & Semet, 2002; Hipel & McLeod, 1994; Schwartz, 2006) suggest the following criteria:

1. Simplicity;
2. Accuracy;
3. Speed; and
4. Flexibility.

We used these four selection criteria to compare the models listed in the previous chapters according to their function (see table 2.6). As all of the models shown in table 2.6 satisfy most of the criteria, they are all suitable for the company's case. A more detailed discussion of the models mentioned in table 2.6 is already included in previous sections; the outcome of each decision can be briefly described as follows:

Table 2.6: Comparison of the models using four criteria

Different models	1	2	3	4
Layout procedures				
Strategic Layout Planning	√	√	-	√
Performance measurment system				
Supply Chain Operations References	-	√	√	√
Core competency				
Value disciplines	√	√	√	-
Decision-making method				
Analytic Hierarchy Process	-	√	√	√
Optimising techniques				
Overview of paradigms	√	√	-	√

- The SLP procedure is modified to our purpose in order to help solve the layout problem, as well as to structure the theoretical framework. Part of the model is used in section 5.5 (detailed layout).
- To determine the firm's core competency, in section 3.1 (the company's core competency) we apply the model of Treacy and Wiersema (1997). This model, which is well known in the literature, is applicable in practical situations. Closely related subjects such as working methods and MvB decisions are analysed in both sections 3.1 (the company's core competency) and 3.4 (production process in the existing situation). Improvements in these areas are described in section 4.3 (production process in the to-be situation).
- The SCOR model (which is used to analyse the supply chain) is not used in this thesis, as the company's chosen strategy focuses on in-house activities. If this strategy and the MvB decision change in the future, it is recommended that the company use this model to monitor their supply chain.
- As the literature suggests that different KPIs may be applicable for the company, the current KPIs must be identified first. This is done in section 3.6 (performance in the existing situation). Possible bottlenecks are then discussed in section 3.7 (bottlenecks in the existing layout). In section 4.4 (performance in the to-be situation), we suggest several new KPIs that are applicable for the company.
- The process mapping method is used in section 3.7 (bottlenecks in the existing layout) to analyse current movements with the company. The outcomes serve as input for subsequent chapters.
- The activity relationship provides us with the information required to select the general layout type that is most suitable for the company, which is done in section 4.2 (routing of the flow of materials in the to-be situation). Information from chapter 3 (description of the existing situation) about products, variety and volume is essential in order to decide which type of general layout is applicable for the company.
- We then modify the AHP to our purposes within section 5.3 (list of criteria). We use the AHP model to judge the layouts and try to improve on them by designing a new

alternative. This is foreseen as being less time consuming than designing all alternatives and selecting the most suitable layout therefrom.

- Due to the fact that the move itself was a major change for the company's personnel, it was not wise to implement different optimising techniques. In chapter 6 (layout implementation) we therefore discuss which techniques the company could use to optimise their production facility. Further research is nonetheless still required.

As we select different models in this chapter, we apply several of them (e.g., the model of Treacy ns Wiersema (1997), the CODP and KPIs) within the next chapter to analyse the as-is situation at the company. Our goal is to identify several bottlenecks in the existing situation.

3 Description of the existing situation

In this chapter the existing situation and its performance are analysed. The main purposes of this chapter are: to describe the as-is state of the company, to identify several bottlenecks and to provide answers on several sub-questions. Different models that are derived from the theoretical framework are used to analyse the as-is state. In the first section of this chapter, the core competency and working method of the company is identified. Because the strategy determines the products and the production process, this strategy also influences the as-is state of the company. Therefore, in section 3.2 the products that the company sells are analysed and in section 3.3 the markets in which the company sells their products are identified. Next, the production process is analysed in section 3.4, because this provides to a better understanding of the layout. Subsequently, the existing layout is described in section 3.5. After the as-is state of the company is analysed, we need to measure its performance. These performance measurements are described in section 3.6 and result in the identification of several bottlenecks (section 3.7), which need to be tackled in the to-be situation (chapter 4, to-be situation at the company).

3.1 The company's core competency

Global competition is growing and manufacturing firms are trying to achieve competitive advantage within their industries. It is important for them to differentiate themselves from their competitors by choosing a strategy that influences their operations as well as their working methods. According to the model of Treacy and Wiersema (1997), the company's current strategy is customer intimacy: the company specialises in making customised high-value added products and delivering services that are adapted to its customers' needs. The company seems to be producing what the customers ask. Moreover, it seems to be case that the company is rolled into this strategy. So, the company probably did not choose between the defined strategies by Treacy and Wiersema (1997). An example that clarifies customer intimacy as a strategy is the following; the product build by the company, further elaborated in the next section - was based on a competitor's product. After a the company customer desired an equal machine designed by a competitor, the company developed and build this type of product. Nevertheless, the company has expanded through this thought. Therefore, delivering service to the customer is important for the company. Their focus is on solving customer problems as quickly as possible by trying to be operational on a 24/7 basis.

The current working method of the company is ETO, which results in complete customisation of the machines to customer requirements. This may include that a machine is designed completely from scratch, but most of the time older drawings are modified for new designs resulting in parts proliferation. Parts proliferations is the production of many variations of the same product, resulting in numerous of different part types (with unique part numbers) (Anderson, 2006; Hammond, Amezquita, & Bras, 1998). The products and the variety will be further elaborated in section 3.2 (products).

Moreover, the company's operations have mainly focused on in-house production. At the moment, the fundamental question for the company – namely what it will make and what it will buy – has been answered. This decision is part of the value discipline the company has chosen, which is to deliver as quickly as possible and be independent of supplier deliveries. The company wants to create an brand image as an OEM, to be capable to have its own machining and sheet metal departments. Having these departments enables the company to distinguish itself from its competitors. Another reason for the in-house production is more focused on the capability perspective, as mentioned in the theoretical framework. The company possesses internal resources and capabilities and is willing to apply them. While the machines in the machining department are quite old (generally from the mid-80s), almost all are in good shape; this was verified when an external company was contracted to inspect and test several of them (e.g., Cazeneuve HB575, Tos SU100, Boehringer DM-480, Boehringer VDF D-480 and ZMM CU-800-TRD). Only the Cazeneuve requires some minor repairs. In financial terms, the machines are fully depreciated and only marginal costs are applied for product calculations.

The chosen strategy for the company results in an added value for the customer. Specifically the company delivers products that are adapted to the customer's needs. While the company has logically decided to produce mainly in-house, it has not fully integrated the supply chain into the production processes. For this this reason, the SCOR model will not be applied to the company case (as mentioned in section 2.2.2.3, SCOR model). Of course, raw materials are bought from different suppliers and the machines are delivered to the company's customers. Only select components are actually outsourced; within the bill of materials (BOM) they are referred to as "phantom parts" (e.g., special eye-bolts). The raw materials for phantom parts are ordered by and delivered to the company, before the phantom parts are transported to an outsourcing firm. In conclusion, the company's choice of strategy has led to the supply chain having only a minor influence in the company's production process.

The MvB question must be answered again for the future. It is possible that machines in the machining department will malfunction in the future. Furthermore, these machines are non-computer controlled; as new generations of machining employees are trained to work with computer numerical control milling machines, it will be harder for the company to find qualified employees. The current value-adding processes could also change in long undesired downtime as the role of the supply chain becomes more important. If either the strategy or the MvB decision change in the future, it is recommended that the company monitors their supply chain by use of the SCOR model.

3.2 Products

As mentioned in the introduction (chapter 1, introduction), the company was founded in the mid'90s as a family concern and developed into a specialised global manufacturer of machinery. According to the overview presented in table 3.1, the company has sold several different types of machines over the last five years.

Table 3.1: Machinery sold by the company (2010-2014)

Machine	2010		2011		2012		2013		2014	
	New	Revised	New	Revised	New	Revised	New	Revised	New	Revised
A	25	1	10	2	4	3	6	2	14	3
B	5		8		7		9		8	
C	24	1	31		29		26		28	2
D	11		10		3		5		4	
E	22	2	23	1	20	1	33		27	
F	9	1	10		15		16		18	
G	21	1	23		14		32		29	
H	4		0		4		1		1	
I	0		0		0		0		0	1
J	0		0		0		0		0	
K	2		3		4		1		2	
TOTAAL	123	6	118	3	100	4	129	2	131	6

Being a flexible OEM has enabled the company to expand substantially, as customers can modify the machinery to their requirements. This strategy has resulted in the company manufacturing a wide variety of machines. While the company has built several different machines over the last five years (as noted above), there is also variety within each group of machines (e.g., different series of product E). Over the last six years, the company has built a total of 147 product E (see appendix 4). This group includes a range of eight types of variances. It is also possible for a customer to modify the machine's width or the number of roles within the machine or to add special features. The overall result is greater variety within this group. For example, in the past six years the company has built 10 different types of variance A, based on the main BOM. There is also variety within certain types of product E including several variances models). These differences arise within the lower levels of the BOM. To show the variety, a comparison is made between variance A and several other variances (table 3.2), all of which vary slightly. Over the past six years, the company has sold 31 different main types of product E, based on the main BOM (see figure 3.1). As can be seen in the figure, the variety of product E are increasing of the last years, which results in parts proliferations as each type consists of more than 400 components. Appendix 4 shows an overview of the variety with the product E.

Table 3.2: Product E model comparison

Machine type E	Different components
Variance A	
Variance B	4,8%
Variance C	7,1%
Variance D	11,9%
Variance E	4,8%
Variance F	2,4%
Variance G	2,4%
Variance H	9,5%
Variance I	14,3%
Viriance J	2,4%
Variance K	2,4%

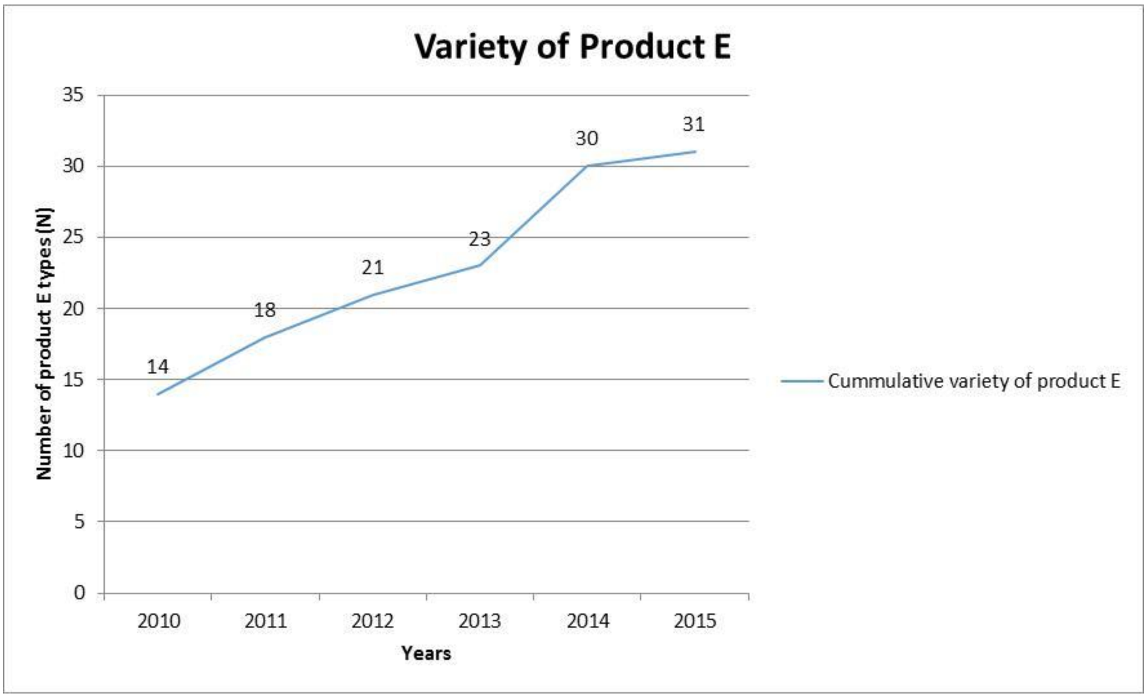


Figure 3.1: Variety of product E sold by the company (2010-2015)

Erens and Verhulst (1997) suggest developing product families in order to offer a large variety of products while keeping development and manufacturing costs as low as possible. At the company, efforts are still being made to manage these product families. It is currently possible to distinguish five different families. One of the variances was actually based on a competitor's product E. As a result, it is completely different from the company's other E products. The engineering department is trying to redesign this variance to reduce the number of product families to four.

The company generates revenues by selling both new machinery and spare parts for existing machines. Having delivered installations all over the world, the company's service department has a solid foundation. Customers need to replace consumables for their machines once a year on average; intensive machine usage raises this to twice a year. Wear parts are replaced once every 10 years, or once every 5 years following intensive usage. The machinery's lifetime is approximately 25 years. Thereafter the machines are sold to a second-hand market, where they will operate for approximately 15 years more. During this time the company can generate revenues by selling consumables and wear parts. Over the last seven years, the company had an average intake over 1000 service orders. In conclusion, selling a machine enables the company to generate future revenues in relation to consumables and wear parts.

3.3 Markets

In recent years, the company has expanded substantially through both acquisition and organic growth; it has yielded € xxxx in revenues and grown to xxx employees. The revenues are generated by selling machinery and service parts to customers spread throughout tens of countries. The countries yielding the most revenue in 2014 were the country X, country Y and country Z (figure 3.2). However, most existing customers (figure 3.3) are located in the country x, country V and in country w. Currently, xx% of the company's revenues are generated through industry 1, while xx% stems from industry 2 and xx% arises from the industry 3. Although industry 3 is growing in countries such as country Y in particular, due to a lack of subsidiaries industry 2 is declining worldwide. The main focus of the company is thus industry 1, which generates significant revenues for the company. While this industry is a replacement market in Europe, it is booming in developing countries. The company could therefore expand more through acquisition and organic growth in the future. Besides, as the company is part of the Group (see appendix 1), the company could benefit from maximum synergy among the different companies held by the group. The goal of the group is to strengthen turnkey projects and to distribute the received orders to their subsidiaries. This example is result of inter-company business.

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Figure 3.2: Revenue generated by the company in different countries, 2014

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Figure 3.3: Number of the company customers within different countries

As noted before, external factors such as customer demands are considered as cetris paribus within this research. Nevertheless, it is important to keep in mind that the company has expansion possibilities for the future, which is one reason why management wishes to increase the company's output (especially in the new production facility).

3.4 Production process in the existing situation

In order to better understand the existing layout, this section presents an analysis of the production process. As noted in the previous section, the company's product range is quite varied. In addition, a product E consists of over 400 components. As it would be too time-consuming to analyse the production process in detail, a decision has been taken to describe the production process in a more general manner.

Several processes must take place before an order is taken into production (e.g., the sales department has sold the order and the engineering department has created the new machine for the customer). The production starts with controlling the stocks for the BOM. If necessary, components are ordered from suppliers and on arrival transformed into "incoming goods" (see figure 3.4, next page). Before they are accepted as stock, these goods are handed over to a controller who generally checks quantity and labels; depending on the goods, however, measurement could also be necessary. After the materials are approved, they are transported to their location; possibilities include the warehouse, the sawing department or the sheet metal department. The location depends on the type of good. In addition, the company also separates specific components for specific orders. These goods have PO numbers and are stored in a specific part of the warehouse.

The sawing department delivers 70 to 80% of all products directly to the machining department with the other 20 to 30% going to the sheet metal department. The machining department receive its materials from the sawing department as well from the warehouse. After these materials are fabricated into semi-finished products, the products are always checked by quality control. Measuring is an especially important issue here. Most of the semi-finished products are MTS (60%), while 20% go directly to the assembly department and 20% go to the sheet metal department.

The sheet metal department is currently located at another production facility (company 2), which means that getting semi-finished goods to it requires transport. This is elaborated further below. Among other things, the sheet metal department makes frames for both product E and product F. Of these semi-finished products, 10% stay in the warehouse at company 2. The other products are transported to the paint shop, which is located at the other facility. Thereafter, 45% go to the pre-assembly department and the other 45% go directly to the final assembly (which is sometimes located at company 2).

The assembly departments mostly receive their materials from the warehouse. The other materials are semi-finished goods from the machining or sheet metal departments. A distinction can be drawn between pre-assembly and final assembly. The difference is the process: whereas a machine is painted and transported back after pre-assembly, it undergoes final inspection following final assembly. This inspection involves checking the machine and inspecting for damage and functionality.

As shown in figure 3.4, the warehouse plays a major role within the company's production process. The process described in this flowchart is more general than in practice. Within the four different departments (namely the machining and sawing department, the sheet metal department, the assembly department and the warehouse), different actions are undertaken to transform a material into a semi-finished product. Some of these processes are described in greater detail in the following section.

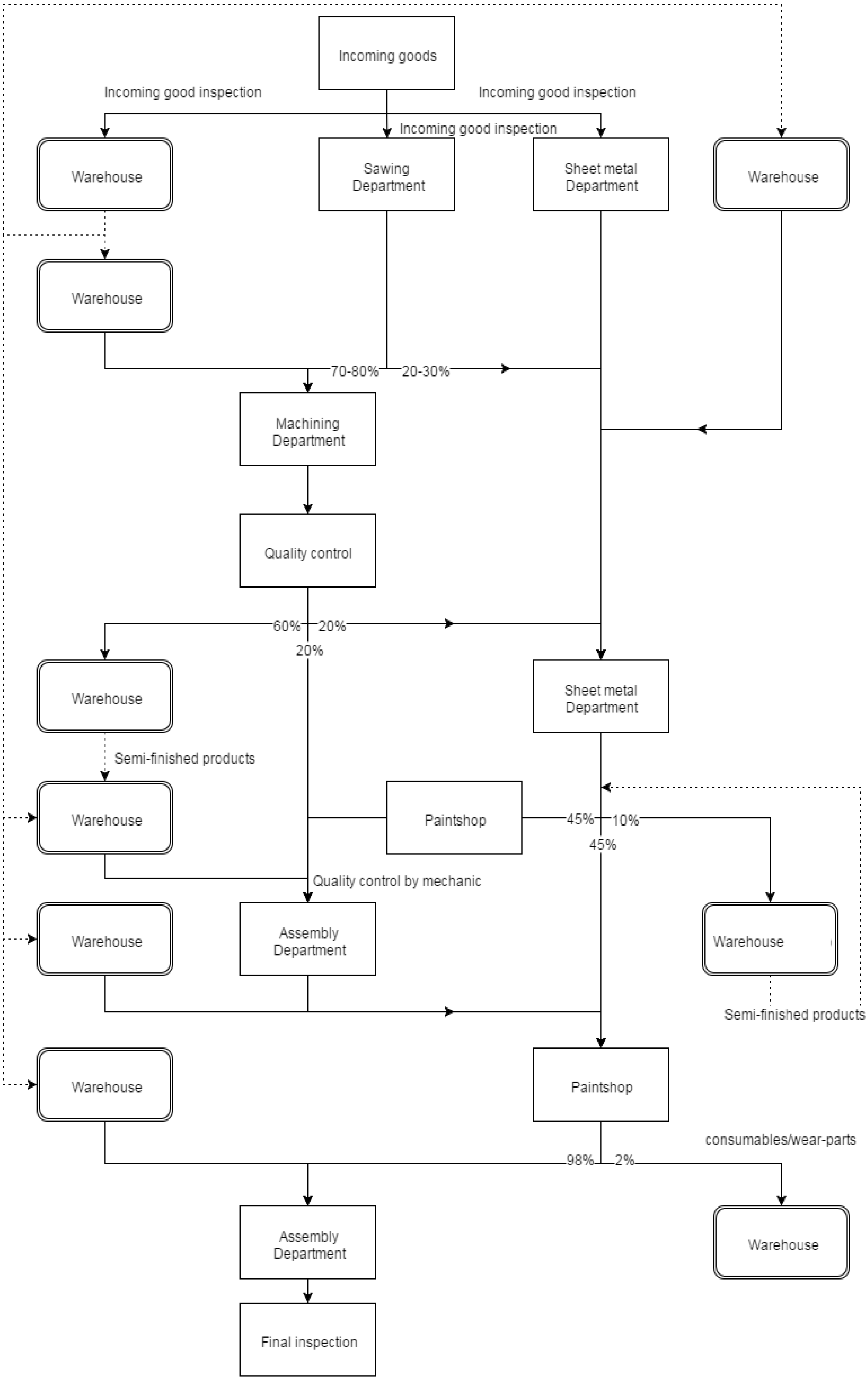

Figure 3.4: Flowchart of the production process at the company

3.5 Layout of the existing layout

As noted before, a facility layout is an arrangement of everything needed to produce finished goods. A facility contains all items related to the full range of manufacturing cells, from a warehouse to machine tools. Good facility placement contributes to an efficient workflow and reduces operating costs. In short, an overall process is significantly affected by the design of the layout facility and vice versa. These impacts can be measured in terms of productivity, manufacturing costs, lead times and work in progress (WIP) (Drira et al., 2007). A new design should be more effective than the existing one. Francis et al. (1992) suggest comparing the two designs, especially in a redesign case. Understanding the existing layout is thus critical.

In recent years, the company has upgraded its production expeditiously. It now has two production sites, which are referred to as company 1 and company 2. Company 1 production facility is in the main building, while company 2 (which is a production facility for the sheet metal department) is at another location. The constant need to transport unfinished goods to and from both production sites leads to inefficiency.

An overview of the layout of company 1, which is the main production facility, is presented in figure 3.5. The production plant can be divided into five departments: the machining department, the assembly department, the paint shop, the warehouse and the sawing department. Several operations take place within the machining department, including turning, milling, broaching and boring. Each department has defined routes for transforming materials into components for a machine. For example, a solid round bar is sawed in the sawing department. Thereafter, it is transported to the machining department as a WIP. The bar is then transformed into an axle in three steps: a series of turning operations that utilize lathes, broaching or milling, and a fine finishing operation that involves boring holes into the axle. The semi-finished product is now ready and can be transported to the next location (namely quality control). It will later be transported to the warehouse, although it sometimes flows directly to the assembly department.

The assembly department is currently divided into three separate assembly workplaces and one roll assembly workplace. Welding is also done in the roll assembly workplace, which is not desirable. It is performed by the sheet metal department at company 2 (see figure 3.6). As transportation of materials (e.g., products, machines and raw materials) is always required, the solution was to integrate welding into company 1. The other assembly workplaces focus mainly on both assembling new machines and revising older ones. Some of the mechanics are also field service engineers.

The drying room, which is located above the assembly department, is an open space where components that are painted in the paint shop are allowed to dry for a period of time. In contrast, the paint shop (which is located top centre) is completely closed with its own ventilation system. Below the paint shop is a part of the warehouse that is used for storing small components and materials that are all picked by hand. Quality control, which checks the quality and quantity of both incoming goods and produced components, is located here as well. The pallets are stored in the centre of figure 3.5. Finished machines that are ready for transportation to the customer are commonly stored in the corridor between the racks, while outgoing goods (e.g., consumables and wear parts) are stored in the sawing department, whose space is used to expedite both incoming and outgoing goods.

Figure 3.6 represents the second production facility, or company 2. The sheet metal department features five different workplaces for building particular frames. Some frame components are delivered by suppliers, while others are made by the company itself. Several machines are therefore used for forming processes of sheet metal (e.g., laser cutting, press brake forming, rolling and welding). Over time, a part of the office within company 2 became a small warehouse for floor stocks. Company 2 has a warehouse where tools to build frames and raw materials and revisions or trade-in machinery that will be sold on the secondary market are stored. Most of the trade-in machinery is refurbished by the assembly department before being delivered to the customer. Again transportation is necessary for the trade-in machines.

Note: the colour of the arrows does not have any meaning for both figures below. It shows the flow of material from one department to another.

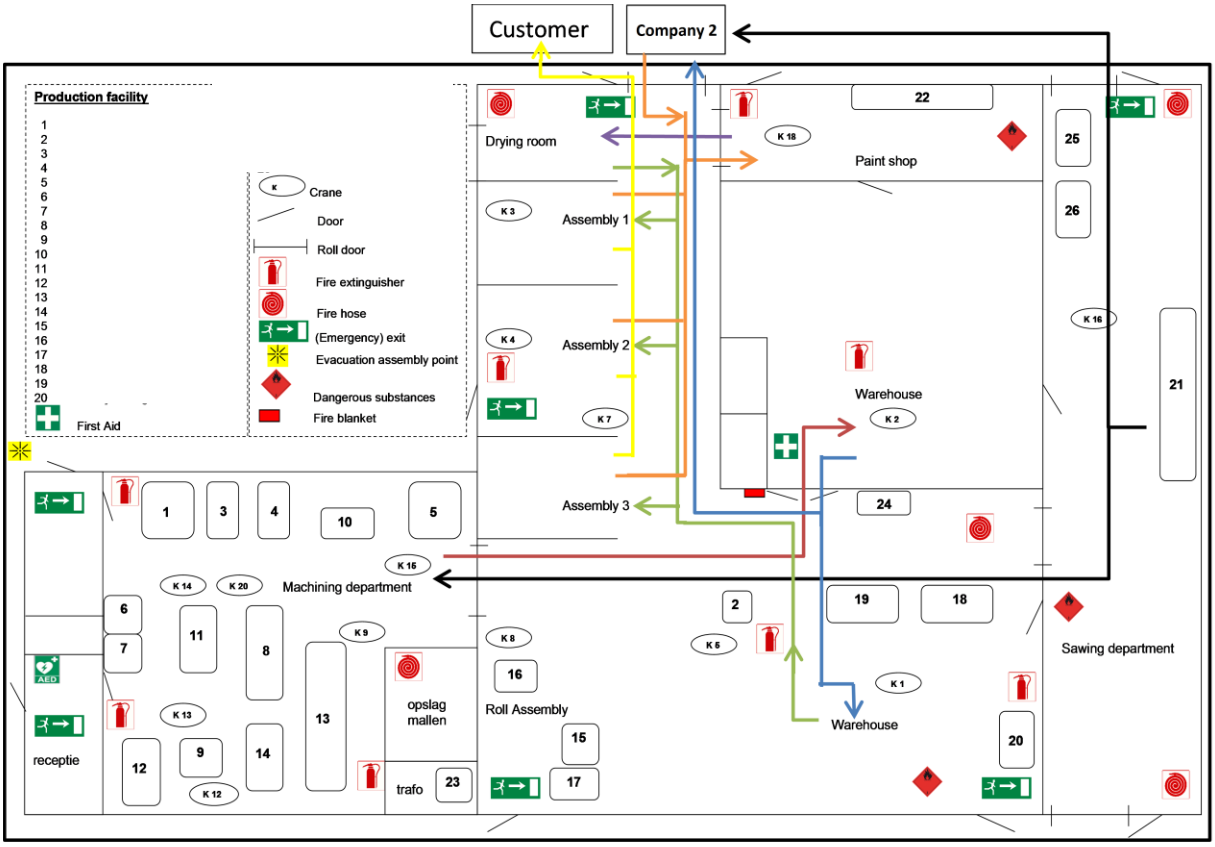

Figure 3.5: Overview of the company's main production facility (company 1)

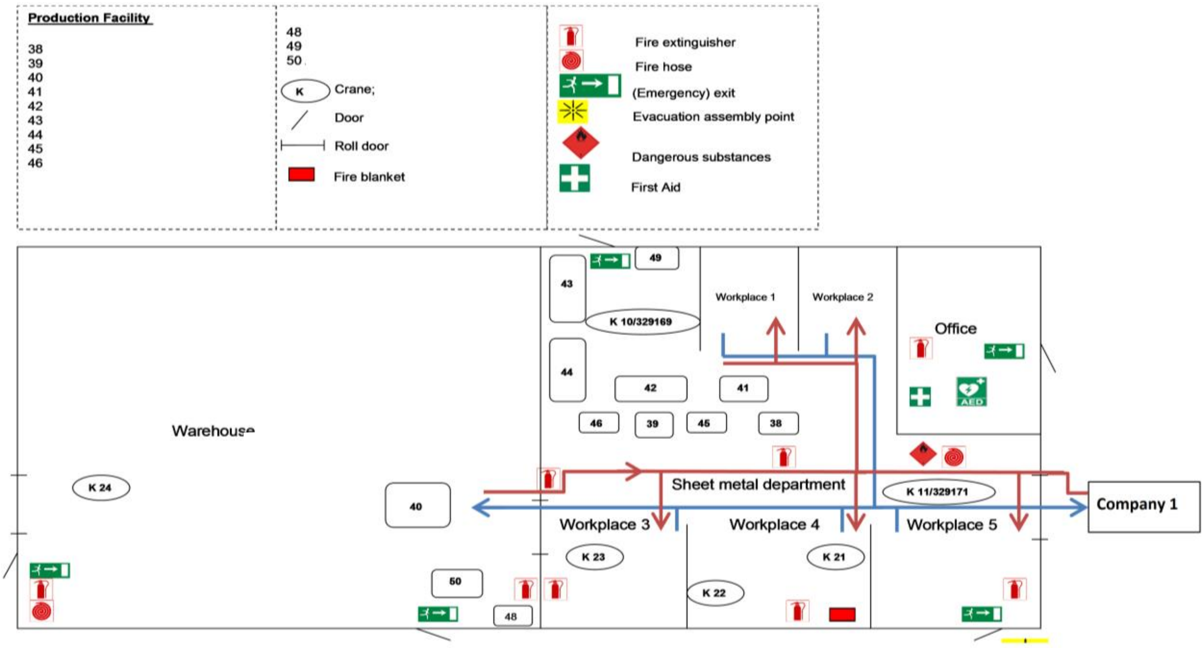

Figure 3.6: Overview of the company second production facility (company 2)

3.6 Performance in the existing situation

Performance measurement helps companies to monitor their daily activities and align them with the strategic objectives. According to Chen and Paulraj (2004), there are three types of performances: financial, operational and time-based. Performance measurement tools include KPIs (Chae, 2009). Organisations commonly apply KPIs within their processes. Performance measurement tools are usually already integrated within a firm's activities.

Several measurement tools are used to monitor different processes within the company. The results generated are not related to functional goals in order to align daily activities with chosen strategic objectives. Moreover, a functional goal has been defined for the sales department: in 2015, the company wanted to increase turnover to €xxx. This goal, which is monitored monthly during sales meetings, is actually a KPI (i.e., financial performance).

As noted, measurement can be useful if the company defines goals and KPIs. Within the production flowchart (see figure 3.4), materials are subjected to multiple quality and quantity control checks. According to Chen and Paulraj (2004), quality belongs to the operational performance category and influences the effectiveness and efficiency of a process. When goods are rejected, the materials are transported back to their previous destination (e.g., a supplier or a department intern) and their registration numbers noted. However, as no cost or goals have been defined for this measurement, the company does not seem to use these measurements to monitor improvement.

Another example of this phenomenon is lead times, which can be calculated given that production employees must register both the start- and end-times of each production order (see table 3.3). The BOM distinguishes four types of components: making, buying, phantom and composing. The lead time for each component is known, as is the total time to

Table 3.3: Lead times for product E components (Knies, 2014)

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build a product E (Knies, 2014). Other specifications are also recorded, such as the employee's name and the department where the production took place. The production order is currently recorded at the department level; before it was done at the machine level. As a result, capacity utilisation is hard to measure. Furthermore, as the company opted for in-house production, measuring capacity utilisation at the machine level is essentially useless. All material handling operations are undertaken by the company itself, although machines are sometimes used for one particular operation. For this reason, capacity utilisation gives a distorted representation of the production process's effectiveness and efficiency

In conclusion, measurement is available but improvements cannot be monitored due to the lack of goals.

3.7 Bottlenecks in the existing situation

In 2013, the company contracted an extern company to investigate possibilities to integrate its two production facilities. More specifically, the goal of the research was to identify a way to integrate the sheet metal department into the main production facility (company 1). According to Kiens (2013) a consultant contracted by the company, integrating these facilities should have some advantages:

- Creating synergy among all employees;
- Breaking the "kingdom" in company 2 down; and
- Increasing efficiency.

Future volumes are estimated by Kiens in combination with lead times. In 2013, the company needed to build approximately several products each week. Painting and drying are assumed to require one to three days together. Table 3.4 is used as input for calculating the work times required by the assembly and sheet metal departments.

Table 3.4: Estimated volumes and lead times for the company in 2013 (Kiens, 2013)

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When the company opted for in-house production, it was assumed that it would assemble all of the machines completely in-house as well. The figures in table 3.4 indicate that xxx hours were necessary to assemble all machines in 2013. The assembly department focuses on assembly of product A, product C and product E. With total xxx hours available between two workplaces, the assembly department's capacity utilisation is 75%. The same calculations are also done to determine the necessary workplaces for the sheet metal department. In total, an estimated xxx hours are being used while xxx hours are available. The result is a capacity utilisation of 89% for five workplaces. The layout that was proposed by an extern company is contained in appendix 5 (Kiens, 2013).

It is theoretically possible to integrate company 2 into company 1. The move should lead to an increase in the efficiency and would save rent. However, these advantages disappear if the production process is disrupted several times. As currently the process is regularly disrupted, losses exceed revenues (Kiens, 2013). It is therefore not advisable to integrate the metal sheet department into company 1. As other options were also not viable, the situation remains as it was in 2013. Therefore, the desire to integrate company 1 and the company2 with a new production facility became greater than before.

The situation of the company is undesirable in terms of efficiency. Bottlenecks are limitations within the current process and should not occur within the new facility. Therefore, the current bottlenecks needs be analysed.

Bottleneck 1: Transportation costs

A goal of this research is to increase the efficiency of the company's production process. A simple way to do this would be to decrease costs. Transportation costs between the two production facilities do influence efficiency and could be eliminated by integrating the facilities. These costs can be predicted using the measurement method of Kiens (2013) and then calculated per hour:

- Material transports are estimated to occur approximately 10 times per week (see figure 3.7). These transports are time-consuming, as each one requires 45 to 60 minutes.
- Assembly department employees also travel to company 2 every two weeks. The travel time is estimated to be approximately 30 to 45 minutes.
- The employees working at company 2 have one break per day while at company 1 and one at their current location. In 2013, four employees worked in the sheet metal department. Traveling between the locations took approximately 15 to 20 minutes per employee. More employees are now working at the company 2 than in 2013.
- One employee from the engineering department also travels to company 2. In the past this occurred twice a day, and each trip took 15.

Overall, traveling between these departments is time-consuming and influences the efficiency of the production process. In total approximately 20 to 24 hours are wasted each week as a result of both goods and employees moving between locations.

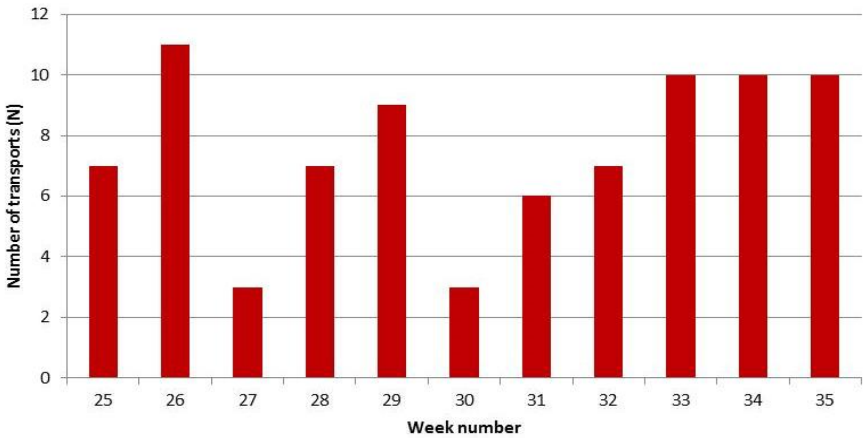

Figure 3.7: Overview of transport between company 1 and company 2 (per week) (Kiens, 2013)

Bottleneck 2: Inventory costs, actual cost price and phantom parts costs

Inventory costs

As the company currently has the core competence of customer intimacy and an ETO working method, variance in the product range has expanded – which has in turn resulted in a rapid expansion of inventory in recent years. As mentioned before in section 3.1 (the company's core competency), this is called parts proliferation. According to Anderson (2006) parts proliferation lowers assembly productivity, adds cost (e.g., inventory costs, lower machinery utilization) and results in flexibility issues. As the inventory rises, the warehouse plays an important role within the production process. Moreover, 60% of the components made by the machining department are destined for the warehouse. Therefore, another working method so called MTS is relevant for the company. In addition, the changes in the machine designs could lead to obsolete components. This could be problematic for the company in the future. The actual value of dead stock is €xxxx. In total, xxxx components have not been used or sold since 2014. Some of these components are meant to be spare parts.

Actual cost price
Due to the variance in the machines, most of them are unique; for instance, almost no two product E have the same features or configurations. There is therefore too much uncertainty to calculate exactly the actual cost, which depends on the different features and configurations. It seems that a part of the price is based on estimating. The differences in cost prices may stem from the following reasons:

- Prices are not related to features;
- It is impossible to estimate the actual cost price for a unique product E or therefore to calculate an additional charge;
- Some features are size dependent; and
- Specific features are not included in the actual cost price. In the past components with features could be cheaper than those without.

Prices lists are in essence useful, especially for comparing the actual sales prices with the estimated cost price. The ratio between sale and cost is 1.78, including an average discount of 10% (Knies, 2014). The actual ratio does not match the agreed ratio. In addition, the cost prices may be incorrect given that it is impossible to calculate an actual cost price for features.

Phantom part costs
Some components (the so-called phantom parts) are outsourced to suppliers. The procedure used is as follows: the company orders and receives the necessary raw materials; the company transports these materials to the suppliers, which fabricate them into the phantom parts; and the suppliers ship the components back to the company. Much of the transportation is unnecessary, as the supplier could also order and receive the raw materials. Unnecessary transport is reflected in costs and influences the efficiency of the production process. In addition, employee time is needed to both order and handle these products.

Bottleneck 3: Workflows within the existing layout
From the description of the production process and current layout in section 3.4 and 3.5, it is clear that there is currently scope for different bottlenecks to arise. The first relates to transportation between company 1 and company 2, which is mentioned in the above discussion of bottleneck 1. Much transportation also occurs within company 1. Due to the expansion of the company, the existing layout is not designed as effectively as it could be. Figure 3.8 shows a schematic overview of the transportation of a component (e.g., an axle) that is fabricated by the machining department in the existing layout. As department locations are not tuned toward the production flow, there is much length- and crosswise transportation. This results in a less effective production process. As mentioned in section 2.3 (flow of materials), the literature suggests that flows should be direct and can be considered as effective when they move uninterruptedly from their origin to their destination. Figure 3.9 shows a more effective flow for the same situation that could be considered in the future.

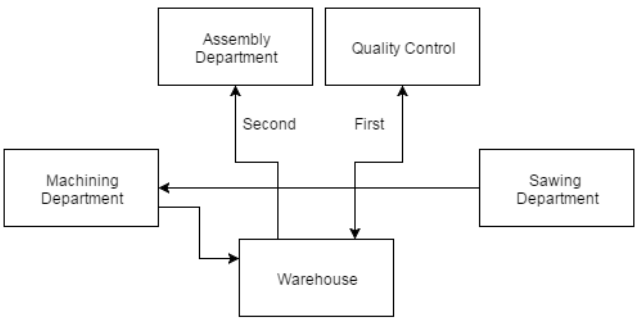

Figure 3.8: Schematic overview of products fabricated in the machining department based on the existing layout

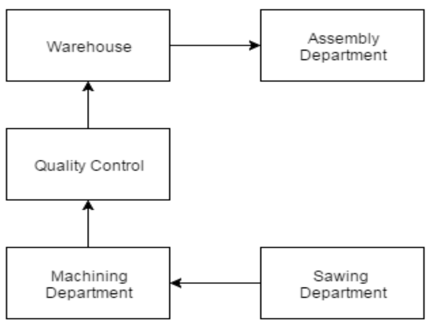

Figure 3.9: A more effective schematic overview

Within the above workflow, the company also has other possibilities for increasing effectiveness. The sheet metal department constructs product E frames, and welding is a part of the process it follows. When they are finished, these frames are transported to the paint shop for priming. The pre-assembly department then builds each machine's inner housing as well as the motor support. Welding is again needed to adjust the motor support to the frame in the right place, which is a time-consuming process. The motor is assembled on the frame and later disassembled before the frame is sent to the paint shop. After the frame is painted in the colour required by the customer, the motors are re-assembled on the frame. If possible, welding should be done within the sheet metal department – where it originally belonged. The mechanics from the assembly department also need to select the larger components from the warehouse themselves, which is a task that should be relegated to warehouse employees. Overall, the workflow does present different opportunities for improvement.

Bottleneck 4: Order decoupling point

The chosen strategy of the company has a major influence on the lead times as well, as recently investigated by another student (although his research does not focus specifically on the production process, but rather on surrounding processes such as meetings, warehousing and planning). Kiens (2013) conducted a more detailed analysis of the lead times (as shown in figure 3.10), which are crucial understanding the order decoupling point bottleneck. As the CODP define the possible working methods, these methods have influence on the lead times.

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Figure 3.10: General overview of the company lead times (Kiens, 2013)

It is always hard for an organisation to balance customer satisfaction and operational costs. The order decoupling point might help to find the balance. As mentioned in section 2.2.2.4 (CODP), there are four possible situations for a company to choose its working method, ranging from MTS to ETO. The situation influences both the amount of stock held and the production volume. For the most part, the company is operating as an ETO manufacturer, which aligns with its chosen strategy. The literature suggests that ETO has low volumes but high stock levels. However, many components also serve an MTS purpose as 60% of the components made by the machining department are destined for the warehouse. The production of these components is not forecast related. The focus lies on short-term revenue (only one unit) and on cost-per-unit (making the single unit cheaper, but at the same time producing more units on stock). It might be possible that the total costs of machines are not minimised.

As spare parts are also included in the production process, the company chose to maintain a vast amount of stock in combination with an increase in production volume. In sum, the literature suggests that choosing the CODP creates possibilities for reducing both costs and lead times.

3.8 Summary of the existing situation

This chapter focussed on the identification of several bottlenecks within the as-is situation at the company and discussed aspects related to its production and logistic processes. It therefore provides answers to the following sub-questions as formulated in section 1.2.3 (sub-questions):

1. *What is the as-is situation at the company with respect to its production and logistic process?*
    a. *Within that process, what are the company's activity priorities and where does the added value within these activities lie?*
    b. *How does the current working method influence the actual operating costs?*
    c. *How does the company use SCM in its production and logistic process?*
    d. *Which KPIs are used to measure the current production and logistic process and how are these KPIs currently performing?*
2. *In terms of efficiency, what are the main current bottlenecks within the process and how can they be improved?*

At the moment, the company seems to be producing what the customer is requesting, which aligns with the customer intimacy strategy of Treacy and Wiersema (1997). This strategy results in the company adding value for their customers by delivering products and services that are specially adapted to these customers' needs. Therefore, the company is operating as an ETO manufacturer and seems to be rolled into this strategy. However, ETO is not the only working method used by the company; many components are also served as a MTS purpose (e.g., 60% of the components made by the machining department). Both working methods influence the actual operating costs. A result of ETO is parts proliferation, as also evidenced by the variety of product E. Parts proliferation is expensive (e.g., it adds inventory costs, lowers machinery utilization and makes parts obsolete), lowers assembly productivity and creates flexibility hurdles. A result of MTS is the focus on one piece and cost-per-piece instead of the total cost of machines.

Moreover, as the company's operations have mainly focused on in-house production, the supply chain is not fully integrated into the production process. As the supply chain has only a minor influence on the company's production process, the SCOR model is not applied to the company case. If either the strategy or the MvB decision change in the future, it is recommended that the company monitor their supply chain using the SCOR model.

In order to monitor their production process, the company integrated different measurement tools. As no cost or goals have been defined for this measurement, improvements cannot be monitored. However, for this research we have identified the following four main bottlenecks in terms of efficiency that relate to using these measurement tools as part of the current working method:

1. Transportation costs;
2. Other costs due (such as inventory cost, possibly incorrect cost prices and the actual cost of phantom parts);
3. Inefficiencies due to workflows within the existing layout; and
4. The customer order decoupling point.

The next chapter describes the to-be state, as well as further exploring these bottlenecks.

4 To-be situation at the company

This chapter describes the to-be state with respect to the new production and logistic process at the company's new facility. Its purpose is to both define the production process for the company in a to-be situation and choose the most suitable flow of materials for their new production facility. The bottlenecks identified in the previous chapter are also tackled within the to-be situation. The first section identifies the different process factors applied to the company case, which affect the routing of the flow of materials. Section 4.2 selects the actual route of the flow of materials, based on suggestions from the literature (section 2.4, activity relationship). The chosen flow offers both advantages and disadvantages. The latter can be minimised by using an appropriate work method, as elaborated in section 4.3. Finally, as it is important to measure the production process, section 4.4 recommends several KPIs that should be applied to the company case.

4.1 Process factors at the company

The route of the flow of materials is influenced by different factors, including product variety and volume; the material handling systems in use; the facility's shape, dimensions and number of floors; and the pick-up and drop-off locations (Drira et al., 2007).

Variety and volume

As variety and volume are discussed in sections 3.2 (products) and 3.7 (bottlenecks), these factors are not described again here. Variety concerns differences between the machines made by the company, while volume relates to the number of machines produced. It is therefore clear that the company has much variety and relatively low volumes.

Material handling systems

In the company's existing situation, employees in different departments do not use automated material handling systems. Transportation is done using overhead cranes, forklifts and pallet trucks or undertaken by hand. There are no restrictions on the direction of the workflow, given the number of transportation options that are available.

The facility's shape, dimensions and number of floors

Multi-floor layouts and vertical flows are not applicable, given that the company's new facility only has one production floor. As the model defined by Francis et al. (1992) and Muther (1961) considers space availability, however, shape and dimensions are constraints; this issue is further elaborated in section 5.5.1 (required elements).

Pick-up and drop-off locations

Pick-up and drop-off points represent where parts leave and enter a production facility (Drira et al., 2007). These locations (which are illustrated in the following section) are considered to be fixed at the company given the related restrictions that management has defined.

Integration of company 1 and company 2

The first bottleneck identified in section 3.7 (bottlenecks in the existing situation) is already tackled by integrating company 1 and company 2 in the new production facility. The efficiency of the company's production process has been increased, as traveling between these facilities is no longer necessary. This results in savings of approximately 20 to 24 hours of transportation time for both goods and employees.

4.2 Routing of the flow of materials in the to-be situation

As described in the theoretical framework (see section 2.4, activity relationship), the literature defines four types of general layouts: fixed product, process, product and cellular. As these layouts actually reflect the routing of the flow of materials, the term "layout" could be confusing. These forms also relate to the four FMS configurations, namely single row, loop, multi-row and open-field. The general layouts and FMS configurations are all dependent on the allowed material handling systems as well as on the defined flow of materials. An efficient flow, which is important for the general layout design, is a direct flow without interruption.

Before the general layouts' advantages and disadvantages are analysed in greater detail, it may be concluded that the fixed product layout is not applicable in this case. The machinery that the company produces is very heavy. These machines are transported internally within the existing facility. In the new production facility, 40T overhead cranes are available to transport them. Other components can also be transported using different material handling systems. It is therefore not necessary to move components, machines and personnel to the product; instead, the products flow through the process.

Other general layouts are applied when different characteristics are present. The cellular layout is suitable in medium-variety and medium-volume environments, while the product layout is suggested for low-variety and high-volume environments and the process layout is used for high-variety and low-volume environments (Visuwan & Phruksaphanrat, 2014). Table 4.1 shows the advantages and disadvantages of these product and process layouts (Francis et al., 1992).

Table 4.1: Advantages and disadvantages of the product and process layouts (Francis et al., 1992)

	Product layout	Process layout
Temporary storage	Low	High
Work in process	Low	High
Material handeling	Short	Long
Lead times (P/U)	Short	High
Flow of materials	Short	Long
Operator skill	Simple	Skilled
Production planning	Simple	High
Flexibility	Low	High
Machine utilisation	Low	High
Operator satisfaction	Low	High
Supervision	General	Specialised

Indented to the literature, the company should as an OEM integrate the process layout within its new layout design – and these process factors do match the practical situation at the company. A case study for another OEM also makes this recommendation (Jeong & Phillips, 2011). Components are fabricated in different departments before being transported to the assembly department. Within the company production process, there is a high degree of interdepartmental traffic as products are moved to new locations for subsequent operations. This situation is in line with layout theory, as process layout does operate in such environments (Chase et al., 2005; Visuwan & Phruksaphanrat, 2014).

As the pick-up and drop-off points are fixed within the new facility by the practical limitations (see section 5.2, practical limitations), the flows of incoming and outgoing goods must be at the back of the building while complete machines built by the company must leave from the front (see figure 4.1). The open-field layout (or FMS configuration) is therefore most suitable for the company. As there are no restrictions (e.g., route of transportation), this configuration offers the greatest flexibility for positioning the necessary resources.

Figure 4.1: Formulated drop-off and pick-up points

As bottleneck 3 describes, the inefficiencies due to the workflows within the existing layout are due to much length- and crosswise transportation. By using the open-field layout to create a direct flow of materials, the new layout could be designed in a more effective way that avoids crosswise transportation – which would contribute to increasing the overall effectiveness of the production process.

4.3 Production process in the to-be situation

As shown in table 4.1, the chosen general layout has several advantages and disadvantages with respect to product layout. For example, it is necessary to keep the WIP as low as possible. The WIP could be tracked within the production process, as the sequence of operations determines the route for each product. It is therefore necessary to position the machines in such an order that a direct flow can be created, which would address bottleneck 3. Kiens (2013) also suggests batching several projects or components together in order to decrease the WIP, inventory and costs. Slack et al. (2010) suggest that batch processes are related to process layout.

The disadvantages related to the process layout could be addressed by postponing the CODP to a later strategy. As a balance must always be found between customer responsiveness and stockholding as well as between customer satisfaction and operational costs, the company could shift to an MTO approach. Within this approach, product volumes are still low and machines remain customised; however, this is more balanced. Inventory is therefore kept to a minimum and lead times are reduced; reducing inventory also helps to tackle a part of bottleneck 2 (namely inventory costs). In addition, the strategy could also positively influence the WIP. Several authors support the suggestion for an OEM to use this strategy (Carr & Duenyas, 2000; Iravani, Liu, & Simchi-Levi, 2012; Mehrsai, Karimi, & Thoben, 2013).

As noted by Srivastava et al. (1999), products should have a modular design when the MTO approach is being used. A modular product can be made by combining different components into a machine that is built by the company. When the same parts are used in the same products, it is possible to decrease the proliferation of parts. According to Anderson (2006), this can be accomplished through standardisation steps. He hereby suggests eliminating approved but unused parts, parts that have not been recently used and duplicate parts as well as encouraging engineers to use existing parts when possible. This should lead to reduced inventory costs, the prevention of obsolete parts, increased machinery utilisation, improved flexibility and shorter lead times (Anderson, 2006). It is therefore possible to improve lead times by choosing MTO, which results in a more efficient production process. Introducing modular design and standardisation in the new production process could also make it possible to reduce uncertainty when calculating exact cost price.

Other bottlenecks require further research, such as the work method relating to how to assemble the motor support on the product E (as described in bottleneck 3). Other improvements (i.e., modular design and standardisation) are required to solve this part of the bottleneck.

As stated by Simchi-Levi et al. (2003), a company can decide to produce components in-house or to outsource them. As the company decided to focus on in-house production, this issue is not elaborated further in this study. Nonetheless, the company can improve phantom part costs as the supplier could order and receive the raw materials to make these parts. This would enable the company to avoid unnecessary transport costs and the company employees would not need to deal with the hassle of buying phantom parts. Quality control and agreements with the supplier could ensure that the quality of the products remains the same as today.

These changes carry some risk for the service department. As forecasts become more influential on the company's production process, it could happen that some components are not in stock. It is therefore recommended that the company define the actual core components within the machines they manufacture, as production could then focus more on these core components and possible risk could be reduced.

4.4 Performance in the to-be situation

Performance measurement helps a company to monitor their daily activities. As stated in section 3.6 (performance in the existing situation), the company monitor their production process. However, as no costs or goals have been defined for these measurements, it is not possible to measure improvements.

As noted in section 2.2.3 (schedule design), a company should limit their number of different KPIs as the tendency is for companies to want to measure more than is actually recommended. Strategy-consulting firms recommend a maximum of three to five KPIs (Lapide, 2000). For this reason the company should focus on the following KPIs, as formulated by Chae (2009):

1. The rate of obsolete inventory;
2. On-time production; and
3. The supplier fill rate.

The first recommended KPI should measure the capacity to reduce the parts proliferation that results from the changing work method. The second KPI is derived from the example described in section 3.4 (production process in the existing situation). As production always starts with controlling the stocks for the BOM, there are usually shortfalls in parts. Several parts therefore need to be produced before an order can be picked from the warehouse. This could lead to interruption within the production process, as most of these shortfalls are title as haste. Both the production and the planning for on-time production are interrupted. Finally, it is recommended that more measurement be undertaken in relation to suppliers. The supplier fill rate compares the number of items received against the number of items ordered. This KPI is easy to expand, for example to include the measurement of product quality. The suppliers' failures could thus be assessed.

4.5 Summary of the to-be situation

This chapter described the to-be state with respect to the production and logistic process at the company's new facility. It also provided recommendations for the company on subjects including the routing of the workflow, work methods and KPIs. It is therefore possible to answer the related sub-question as defined in section 1.2.3 (sub-questions):

1. What is the ideal to-be situation at the company with respect to the new production and logistic process at the new facility?
    a. Which general types of layout (route of the flow of materials) are applicable to the company within the parameters set by key stakeholders?
    b. What work methods may produce an effective workflow and how do they influence operating costs?
    c. Which KPIs can be used to measure an effective workflow in the production and logistic process?

The general types of layout or named as the routing of the flow of materials is determined by different factors, such as variety, volume and material handling systems. Seeing as the company is an OEM with a high-variety and low-volume environment, the process layout is most suitable. This layout should align with the open-field layout, as there are restrictions for drop-off and pick-up points. Applying process layout in combination with the open-field layout results in tackling bottleneck 3 (inefficiencies due to workflows within the existing layout). The new layout could be designed in a more effective way by avoiding crosswise transportation. The chosen general layout offers several advantages and disadvantages. The latter could be minimised by using an appropriate work method for the company.

A balance between customer satisfaction and operational costs is also always necessary. Instead of a combination of ETO and MTS, the company should apply the recommended MTO work method (which also addresses the disadvantages of the process layout). Modular products should be designed when the MTO approach is being applied, which will result in a decrease of parts proliferation. The modular design and standardisation of the production process also lead to reduced inventory costs, the prevention of obsolete parts, increased machinery utilisation, improved flexibility and shorter lead times. Nonetheless, further research remains necessary for bottlenecks such as the work method related to assembling the motor support on the product E. Other improvements that could be accomplished include fully outsourcing phantom parts, which would decrease unnecessary transport and require less attention from employees. In the future it may even be possible to outsource several other components to suppliers. To start the process, the company should define actual core components within the different machines.

For monitoring daily activities in combination with goals, we recommended using three KPIs, namely the rate of obsolete inventory, on-time production and the supplier fill rate. The first relates to reducing parts proliferation. The second KPI is formulated due to the shortcomings when an order goes into production. The final KPI is based on the supplier side of the chain and represents the first step in addressing supplier failures.

Now that this chapter has analysed the company's to-be status with the routing of the workflows, the next chapter describes the layout selection process.

5 Layout selection

After defining the production process, it is necessary to develop a suitable layout for the new facility. The purpose of this chapter is to proposes alternative layout solutions for the company's new production facility and finally choose the most suitable layout design for the company. To start the layout selection, first it is necessary to understand the main criteria for layout design. Therefore, section 5.1 describes the requirement and restrictions derived from literature. Next, practical requirements and restrictions demanding from key the company stakeholders are identified. Both sections are combined in the list of criteria (section 5.3). A part of this list is necessary to determine the possible general options, which are discussed in section 5.4. The next section then describes the detailed layout alternatives based on the chosen general layout. Finally, a decision-making method (namely the AHP) is used to select the most appropriate layout design.

5.1 Requirements and restrictions

Requirements and restrictions are both suggested by researchers. In the extensive literature available on layout design, several criteria are suggested for measuring the performance of the proposed layout. Authors such as Francis et al. (1992) and Muther (1961) suggest several factors, some of which may seem obvious:

1. Ease of future expansion
2. Flexibility of the layout
3. Material-handling effectiveness
4. Space utilisation
5. Safety and housekeeping
6. Working conditions
7. Ease of supervision and control
8. Appearance, promotional value and public or community relations
9. Fit with company organisation structure
10. Equipment utilisation
11. Ability to meet capacity and requirements
12. Investment or capital required
13. Saving, pay-out, return and profitability

Several requirements suggested by the literature do not appear in the list of criteria. For instance, the scope of this project (see section 1.2.4, research scope) ruled out all criteria related to the human aspect (e.g., working conditions, safety and housekeeping, and ease of supervision and control). Other criteria (such as investment and capital required) are not taken into account as they will not be determining factors in selecting an alternative, given that movement is already an expensive project. As space utilisation and equipment utilisation are elaborated within the SLP model (see section 5.5.1, required elements), they are irrelevant as criteria.

5.2 Practical limitations

According to Francis et al. (1992) and Muther (1961), management goals needs to be analysed in practice, as it could happen that a new layout design is less costly while management would like to see a design that best fits the company's organisational structure (Francis et al., 1992). This example shows how important it is to analyse the practical limitations as criteria. It is therefore important to analyse the practical limitations that are defined by stakeholders. In this case, stakeholders are defined as key players who have great interest in this research and can influence the outcome significantly; they include shareholders, managers and some other key players within the company. The following practical limitations are based on the AR method:

1. For promotional purposes, the assembly department must be visible from the office. A minimum of four workplaces are also required to increase the assembly department's output and change the production process.
2. The roll assembly should be located near the assembly department, as interaction between these workplaces is requested and it is desirable to keep the assembly department as clean as possible.
3. As requested, a trinity should be maintained among the assembly department, the paint shop and the sheet metal department as far as possible.
4. The sheet metal department needs a minimum of five workplaces and the machines it uses (e.g., for press brake forming and rolling) should be placed in its area.
5. The paint shop needs to be located on the building's periphery. It is not desirable to have a large workshop in the middle of the production facility. Besides for aspiration the department should be open on top (to facilitate overhead crane access).
6. A paint room and a special drying room are both desired. A paint storage room is also needed near the paint shop.
7. The machining department is essential for the company's production and has promotional value. The new design should only adapt the department's degree of importance.
8. The dirty machinery should be located as far back as possible within the new production facility.
9. As the warehouse can be analysed in more detail, no requirements are considered for the layout. The only concerns are that receiving and outgoing good flows are at the back of the building, while the finished machines that are built by the company leave from the front.
10. The full length of the production building's two main logistic paths (each of which is five meters wide) should be available for logistic transportation.
11. No trenches in the floor (e.g., for electrical wiring).
12. Using the existing facilities for compressed air.
13. The workplaces with the sheet metal department as well as several machinery (SU-100, ZZM 800 RD, D-480, DM-640, Cazeneuve and Carrousel) in the machining department needs fumes extraction.

These limitations, which stem from both the literature and the stakeholders, are transformed into a decision-making hierarchy model in the following section.

5.3 List of criteria

The AHP model suggests to structure the decision problem into layers (figure 5.1). The decision making goal is located on the top of the hierarchy, which is selecting the best appropriate layout for the company. Several main criteria (branches) (product capacity criteria branch, workflow criteria branch and practical limitations) are created to cover the defined requirements and practical limitations. These branches are necessary to compare the importance of factors between each other.

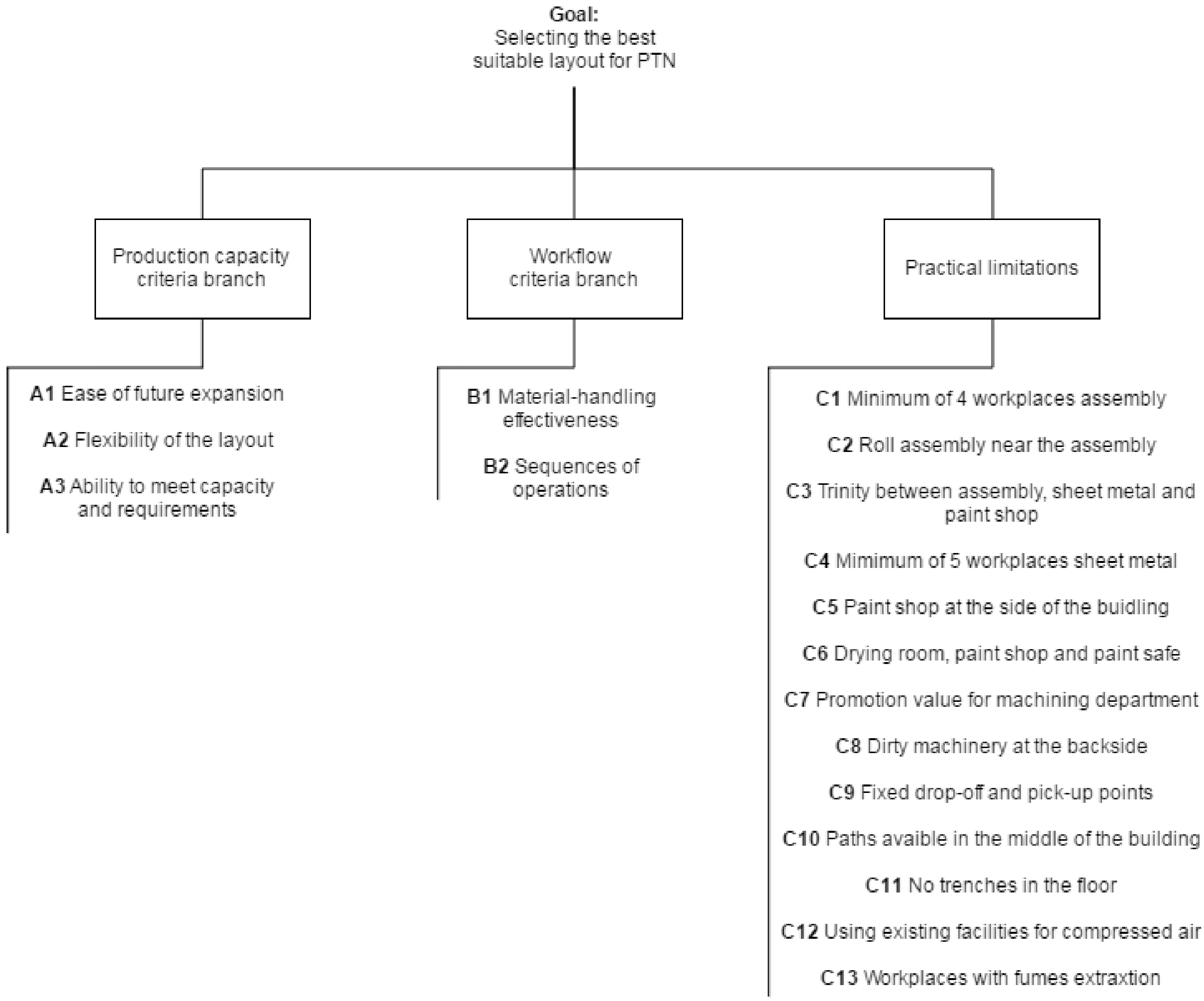

Figure 5.1: An overview of the decision problem according to the AHP framework

5.4 General layout options

As noted previously, this research is a limited greenfield project as the company has already bought the production facility. The affected layout must therefore fit within this building and should be the most suitable layout design for the company. As this research focuses on the production area, other areas are not taken into account when drawing a design. The total production area is approximately 65 m x 60 m, and one square within the layout has a surface of approximately 25 m^2. Several small rooms are spread throughout the layout (e.g., right-upper corner and bottom right). The middle of the building has rolling doors on either side (for loading and unloading goods). A 40T overhead crane is available in the upper and lower sections. The production area is connected to the office (bottom left), the canteen and the dressing area (upper left).

The purpose of this section is to choose a general layout option for the company, which can be designed in a more detail manner in section 5.5 (detailed layout alternatives). First, section 5.4.1 describes the number of departments which needs to be integrated in the general layout options. Some of these departments already have a fixed locations due to the practical limitations defined by key the company stakeholders. Therefore, section 5.4.2 describes briefly these practical limitations applicable on general layout options. The following section designed the actual general layout options for the company case. Finally, in section 5.4.4 the most suitable general layout is chosen for the company. This layout will be designed in detail in section 5.5 (detailed layout).

5.4.1 Number of departments

When analysing the company's production process and existing layout, it is possible to distinguish several departments, namely the warehouse, the sawing department, the sheet metal department, quality control, the paint shop and the assembly department. Some of the departments are already integrated, such as quality control and the warehouse (which have integrated mainly due to the constant exchange of materials, information and employees between them). It is also possible to combine the sawing department with the machining departments, as 70 to 80% of the materials coming from the former are transported to the latter. However, it has not been possible to implement this idea within the existing layout (first due to the lack of space and second because a sawing department employee also did several jobs for the warehouse department, including overseeing expedition). The new general layout alternatives should take these issues related to the company's department set-up into account.

5.4.2 Practical limitations taken into consideration in the general layout

As noted in section 5.2 (practical limitations), some key players have a great interest in the outcome of this design. They have defined practical limitations that must be fulfilled by the layout design. The following piratical limitations are applicable for the general layout options:

1. For promotional purposes, the assembly department must be visible from the office.
2. The assembly department, paint shop and sheet metal department must be kept in a trinity.
3. The dirty machinery should be located as far back as possible within the new production facility.
4. The receiving and outgoing good flows must be at the back of the building, while the complete machines that are built by the company must leave from the front.
5. The full lengths of the production building's two main logistic paths (each of which is five meters wide) should be available for logistic transportation.

5.4.3 General layout options

Given the requirements defined by the company's stakeholders, only two general options are available. As the assembly department should be visible from the office, this department has a fixed location (see figure 5.2 and 5.3). A trinity needs to be created between the assembly department, the paint shop and the sheet metal department; as the location of the assembly department is fixed, the other two department have fixed locations as well. Trinity still exist when the assembly department and the sheet metal depart have fixed location. Between both departments the paint shop should be located. The layout created in figure 5.2 aligns with principles three and five as well.

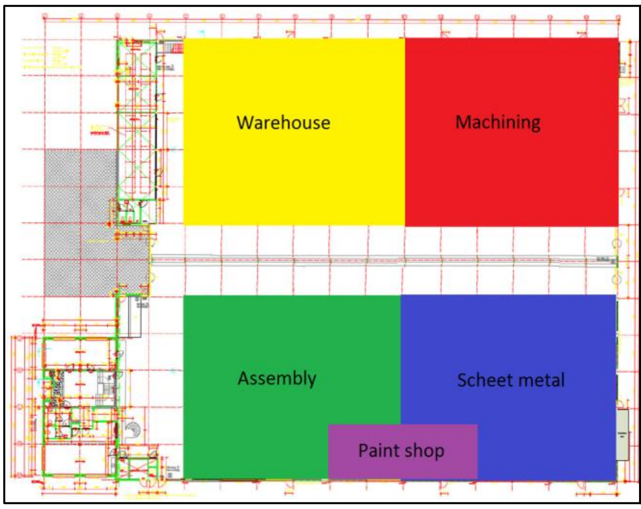

Figure 5.2: General layout, option 1

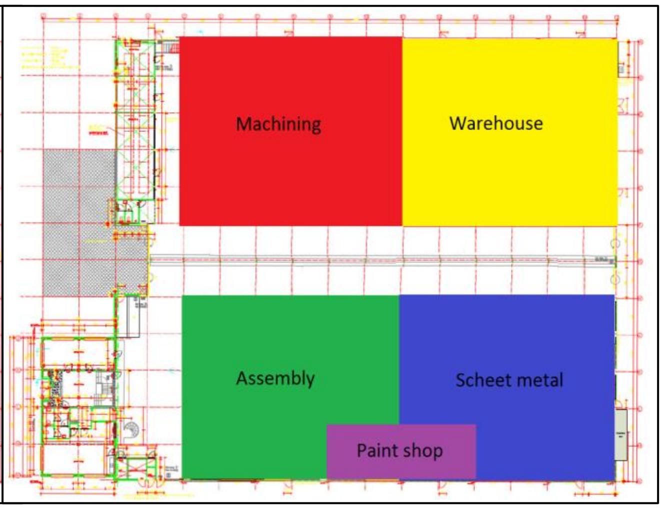

Figure 5.3: General layout, option 2

Table 5.1: Overview of incoming and outgoing orders in recent years

Year	Incoming	Outgoing	Machinery	Moments in/out	Total
2014	2402	1342	131	1211	3613
2013	2103	1339	129	1210	3313
2012	1803	1189	100	1089	2892
2011	2047	1298	118	1180	3227
2010	2211	1312	123	1189	3400
Average	**2113**	**1296**	**120**	**1176**	**3289**

There is another option for the general layout as well (see figure 5.3). In this scenario, the warehouse is positioned more towards the back while the machining department is placed at the front. Principle 4 suggests that the pick-up and drop-off points should are located at the back of the production area. As the warehouse is located in the front in option 1 site, material handling costs consequently arise. Applying option 2 is a possibility for reducing these costs. Furthermore, table 5.1 shows the incoming and outgoing orders in recent years. An order can range from a small package to multiple pallets. These numbers have been increasing and will probably continue to grow in the future as well. As the installed base of the company expands each year, more services are requested. There is also a wish to reduce the inventory level, which means products must be delivered just in time or in smaller quantities. Option 2 is thus interesting as well, even if it option does not fit all of the requirements.

5.4.4 Choosing the most suitable general layout

When choosing the most suitable general layout for the company, the evaluation process could face a danger: It is possible that one option is the least costly, while management prefers another for different reasons. It is therefore important to determine management's goals (Francis et al., 1992). During different feedback session organised to evaluate the possible general layouts, management preferred option 1. While the two options do not vary greatly, management disliked the idea of having dirty machinery at the front of the production area. They also preferred that the warehouse and the assembly department are located at a short distance. In option 2 this flow is longer than in option 1. Section 5.4.1 (number of departments) suggests including the sawing department within the machining department. In option 1, the sawing department employee can still fulfil his warehouse job, as truck unloading and loading happens at the building's rear. These factors excluded option 2 from being a feasible option for the company.

5.5 Detailed layout

After choosing the general layout, this layout needs to be developed in greater detail. In this section, the SLP procedure is used to develop possible alternative layouts. As the first steps in the analysing phase are elaborated in previous chapters, this section starts at step 4 (see figure 2.1). Therefore, section 5.5.1 describes the required elements which needs to be taken into account by designing the detailed layout alternatives. Once all of the required elements are known, the next step is to determine the possible layouts by using the roughed-out layout method. Section 5.5.2 describes this next step.

5.5.1 Required elements

Space availability/space requirements

The modified SLP procedure suggests that the space requirements for each department and machine should be analysed. In an ideal situation, the layout is developed before the building is constructed. In practise, the space available could be a constraint for any proposed solution. It is therefore necessary to consider space availability as well (Francis et al., 1992).

A decision must first be taken to identify which machinery should be moved to the new production area. This decision is required in particular for the larger machines, as smaller machines (e.g., sanding belts) can be positioned later. The existing layout (see figures 3.5 and 3.6) shows the machines in operation at the company. By analysing different machines with the same functionality, it is possible to choose the best machine for operations in the new building. These decisions are summarised below and taken in consultation with different key players:

- the company has two shear metal machines: the LVD (which is located in company 1) and the Darley (which is located in company 2). The Darley is used more by the employees of the sheet metal department. The operators think that the Darley is more accurate as well. Since only one shear metal machine is necessary in the new production facility, the Darley was selected.
- The sheet metal department houses two press brake forming machines. Of these, the Safan is used only infrequently due to its inaccuracy. In company 1, the Durma is fully operational and in good shape. The Durma was thus chosen to move to the new production facility.
- Within the machining department, the Schaublin 22 milling machine has not been used for a long time. The decision was thus to exclude it from the new layout.

All of the other machines need to be taken into account within the design of the production area; the detailed space requirements can be found in appendix 6. Both the current size and desired space have been measured. These spaces have all been discussed with the operators themselves and reviewed by key the company players. The amount of workspace is also analysed in the space requirements. The information required as input for the overview stems from the literature, previous research of other investigators (Kiens, 2013), key players within the company and by observations.

The space available within the new production facility is as large as the total area of both current locations. The new production facility has a surface area of 4,530 m^2, while company 1 has 2,620 m^2 and company 2 has 1,500 m^2. Extra space available is available for future expansion.

Modifying considerations and practical limitations
Before starting to develop alternative layouts, the practical limitations and modifications should be taken into account. The research within section 5.4.1 (number of departments) fixed most of the departments, which is a modified consideration. The practical limitations are already discussed in section 5.2 (practical limitations). During the process of layout design, the shareholders only desire was to not have any trenches in the production area's floor.

5.5.2 Detailed layout alternatives and evaluations thereof

Once all of the required elements are known, the next step is to determine the possible layouts by using the roughed-out layout method. Templates and models are placed on the layout to obtain an estimate general configuration and approximate space requirements (Francis et al., 1992). In reality, the overall layout was already designed within the general layout. This general layout is in theory a combination of the space consideration and the REL diagram, which is also called a block plan (Francis et al., 1992)

The literature suggests three methods for designing a layout: drawings or sketches, 2D iconic models and 3D models (Francis et al., 1992). These techniques are out-dated, as the literature refers to cross-section paper and templates made from wood, plastic or sheet metal (Francis et al., 1992). Today, computer programs are used to create these models. Designing layouts with a computer is easy, and the layouts can be modified when changes appear.

A total of 28 layout alternatives were designed manually by using two different computer programs. First, the program Paint was used to roughly sketch 2D models of each layout alternative. Second, after choosing the best suitable layout for the company, we used Google SketchUp. With this program we were able to create an accurate 3D model. This model will be further elaborated in chapter 6 (layout implementation).

The actual number of designed alternatives was higher, as layouts with small modifications were not counted as separate alternatives. Each layout was evaluated during feedback sessions with key the company players that focussed on improving the proposed alternatives. This research does not treat all 28 layout alternatives; instead, only four select alternatives are described. These four alternatives are outstanding, as they brought the biggest change compared to the other alternatives.

The SLP model suggests designing multiple alternative layouts before actually evaluating anything (Francis et al., 1992). As Francis et al. also state, implementation failure could result from a poor job of explaining the layout or the analyst not being involved with the implementation phase. These problems could be prevented by maximising participation through collaboration with stakeholders and participants. Time pressure influenced the design project, and participants and stakeholders had limited time in their daily jobs. The design process thus deviates here from the original SLP procedure. The AR approach and AR cycle were instead used as guidelines for designing layout alternatives. This research intended to use the AHP model as well, but as mentioned there is only a comparison between the four selected layouts.

Layout alternative 1: Starting point
The first alternative (figure 5.4) that we discuss was constructed by Kiens (2015) a consultant contracted by the company and our starting point. He combines six previous of his designs, which were discussed in a session with the company management. The layout still reflects a broad perspective; to make it more detailed, it must be enhanced with other alternatives. Kiens (2015) used information from earlier research (2013) to determine the space requirements for this alternative.

The list of criteria presented earlier can be used to assess if an alternative meets the requirements associated with improving the company's production process, which is the goal of this research. The main reasons why an alternative does not fit the desirable layout are summarised briefly by criteria branch. The branches are necessary for pairwise comparison if necessary. The assessment for layout alternative 1 is as follows:

- *Production capacity criteria branch:*
  - There is no ease of future expansion for either the assembly department or the sheet metal department. The layout is therefore too inflexible.
- *Workflow criteria branch:*
  - Transportation can be done by using overhead cranes, forklifts and pallet trucks or undertaken by hand. Within this layout there is space for transport by forklifts and pallet trucks. With exception of the two overhead cranes, this layout includes cranes for the sheet metal department. There are cranes necessary for the assembly and machining department as well. In conclusion, material-handling is not as effective as it could be.
  - Within each department the sequence of operations could be improved, as within this layout there was no actual focus on the detailed places of the machines.
- *Practical limitations branch:*
  - Within this design, no space is available for roll assembly.
  - The paint shop is located in the middle of the building, which is not desired by management. Besides, this layout excludes the paint safe.
  - Two locations are fixed for expedition, while the drop-off point for goods is located at the back of the facility. In addition, as machines are built in the assembly department, too much time is needed to transport them.
  - The lower main logistic path is used for production; to facilitate the transportation of goods, both logistic paths should be empty at all times.
  - As several machines are located in the middle of the facility, trenches are necessary in the floor (e.g., for electrical wiring). This is not desirable. Workplace with fumes extraction can be better placed near a wall, due to overhead cranes.

These points exemplify why this alternative does not fit within the given parameters. Other improvements could be noted as well; for example, the layout does not fit the sequence of operations or material-handling effectiveness (within the workflow criteria branch). As designing layout alternatives is a process, the layouts described below should better meet the noted requirements.

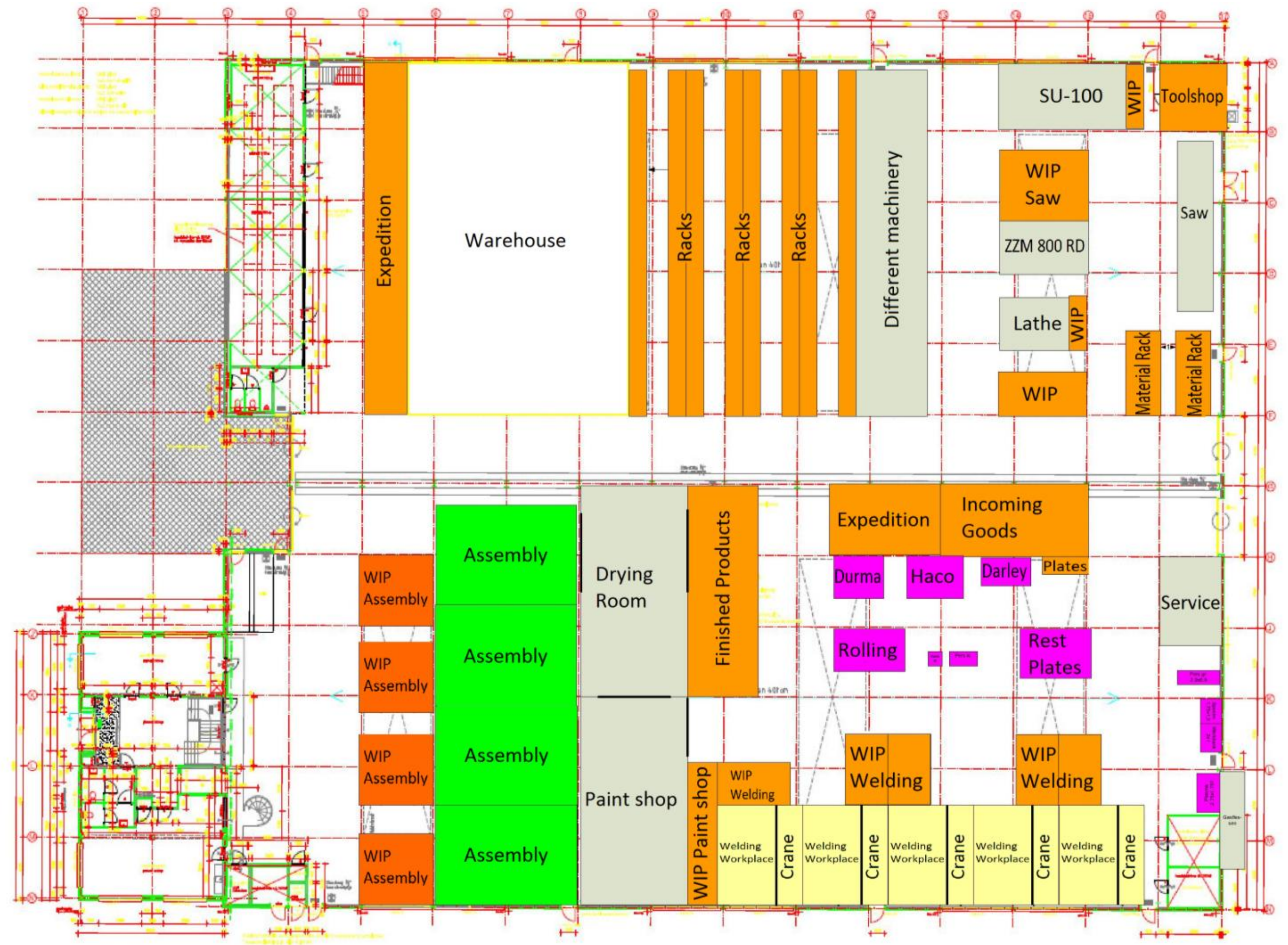

Figure 5.4: Layout alternative 1 (Kiens, 2015) (see appendix 7 for more detailed version)

Layout alternative 2: Improvement of the assembly department and paint shop
This alternative reflects several improvements that are intended to fulfil different requirements (figure 5.5). As the figure illustrates, the main centre path is cleared for material transport and space for roll assembly is created near the assembly department. Another improvement is the location of the paint shop, which is now at the side of the building. These improvements address issues within both the practical limitations and production capacity criteria branches. This alternative is more flexible than alternative 1. The assembly department may be expanded in the future. Still, this alternative has some limitations as well:

- *Production capacity criteria branch:*
    - It is necessary to ease of future expansion. As such an expansion would not be easy in this alternative for the sheet metal department, the layout does not meet the ease of future expansion criterion.
- *Workflow criteria branch:*
    - There are cranes necessary for the assembly and machining department as well. For the same reason as in alternative 1, material-handling is not as effective as it could be.
    - The company's production process involves a constant flow from the sheet metal department to the paint shop. In this alternative, flows will be convoluted.

- *Practical limitations branch:*
    - Two locations are fixed for expedition and incoming goods. In both cases, these locations are larger than necessary. Furthermore, machines are built in the assembly department and too much time is needed to transport them to the expedition area.
    - As several machines and workplaces are located in the middle of the facility, trenches are necessary in the floor (e.g., for electrical wiring). As noted previously, this is not desirable. The machines with fumes extraction can be better placed near a wall, due to overhead cranes.

In the next alternatives, both the warehouse and the machining department need to be developed in greater detail (alternative 2 does not include all machines within the machining department). Workflow routes also need to be drawn in order to check the different routes proposed within the layouts. The quality control unit and warehouse workplace are both missing from the previous designs.

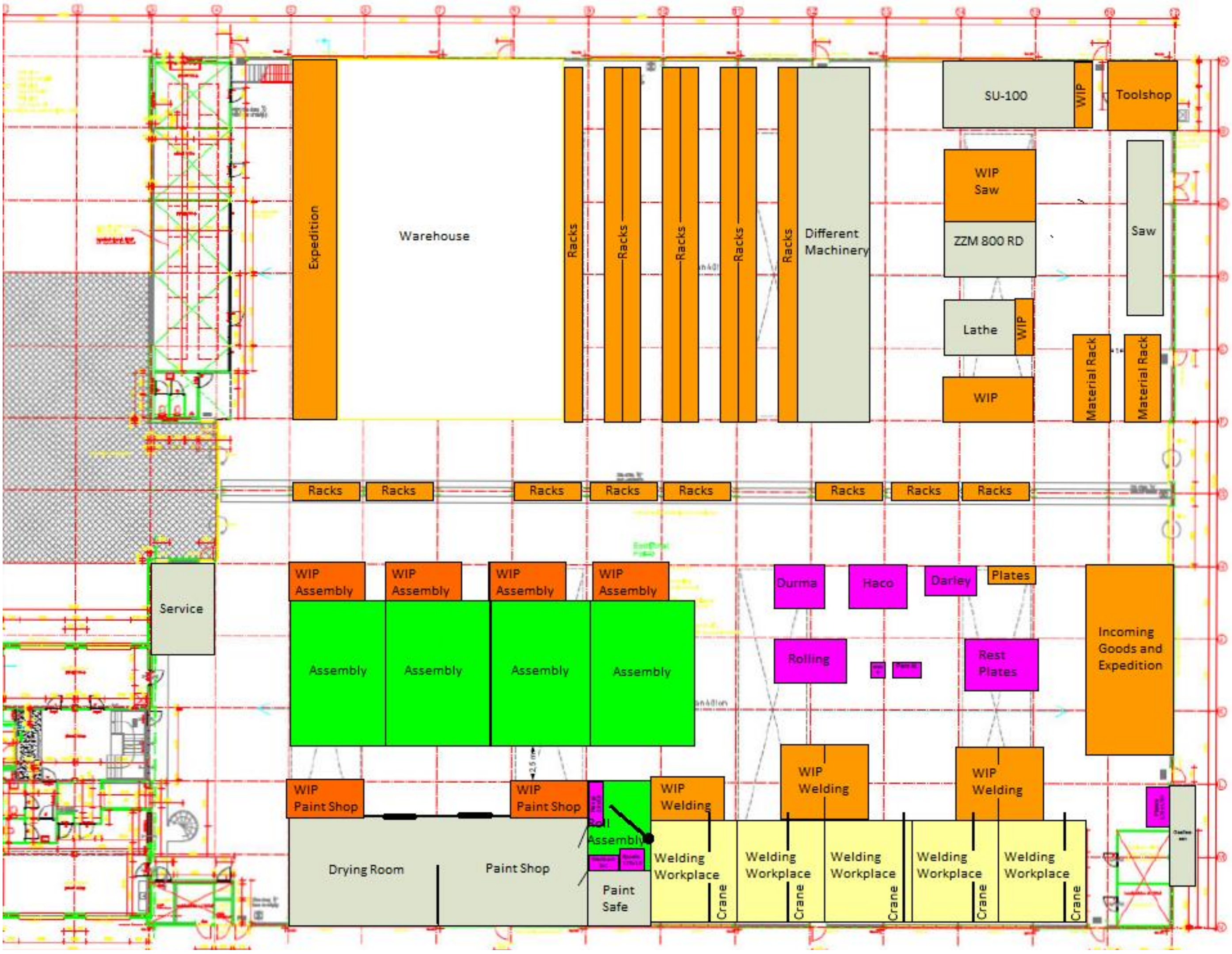

Figure 5.5: Layout alternative 2 (see appendix 7 for more detailed version)

Layout alternative 3: Detailed layout with workflow routes

This alternative (figure 5.6) was the first layout presented to the company employees and served as a milestone in the layout design process. Discussions with operators were held to determine what practical requirements needed to be met, such as cranes.

The warehouse

The warehouse plays a critical role within the production process. Furthermore, as inventory levels are rising, the warehouse needs a large space in the new layout. The orange bars in the figure represent racks. To reduce space between these racks, a reach truck must be purchased. Space is reserved for small components, but this area needs to be developed in detail in the following alternatives. Quality control and the computer workplace are both located in centre of the production area. There are racks between the two main paths that are intended to serve as buffers between workplaces. This alternative also includes a free space for trade-in machines. Improvement is only necessary vis-à-vis the pick-up and drop-off points, both of which are currently located at the front of the building.

The machining department

Exact machine location within the machining department has not been discussed yet; this is a simple overview of what it could be. The production flows for this department are also indicated (for more information, see figure 3.3). In the following alternatives, decisions must be taken as to the exact location of both these machines and the WIP. Besides, trenches are still required in this alternative to reach the machines in middle of the department.

The sheet metal department

For ease of future expansion, the workplaces are positioned on another location relative to the previous designs. It is possible to create another workplace if necessary. Still, we added an extra workplace in the contrary of the previous layouts. The machines are positioned in a U-shape to reflect the order in which employees use them (namely the Darley, the Haco or Durna and then possibly the roller). However, integration between these machines and the workplaces is still not optimal.

The paint shop

The paint shop, drying room and paint safe are moved to the right in order to create an entrance to the sheet metal department. The paint shop location is ideal for achieving the aforementioned trinity, as it can still easily interact with the assembly department.

Assembly department

Within the assembly department, there were almost no changes from alternative 2. A site for finished machines is identified and roll assembly is moved closer to the offices. There are small improvement for the assembly department necessary in the following layout, as trenches are still required in this alternative. There are cranes necessary within the assembly department as well. For possible expansion, it is still hard to easily expand the assembly department with a workplace.

Note: the colour of the arrows does not have any meaning for in the figure below. It shows the flow of material from one department to another.

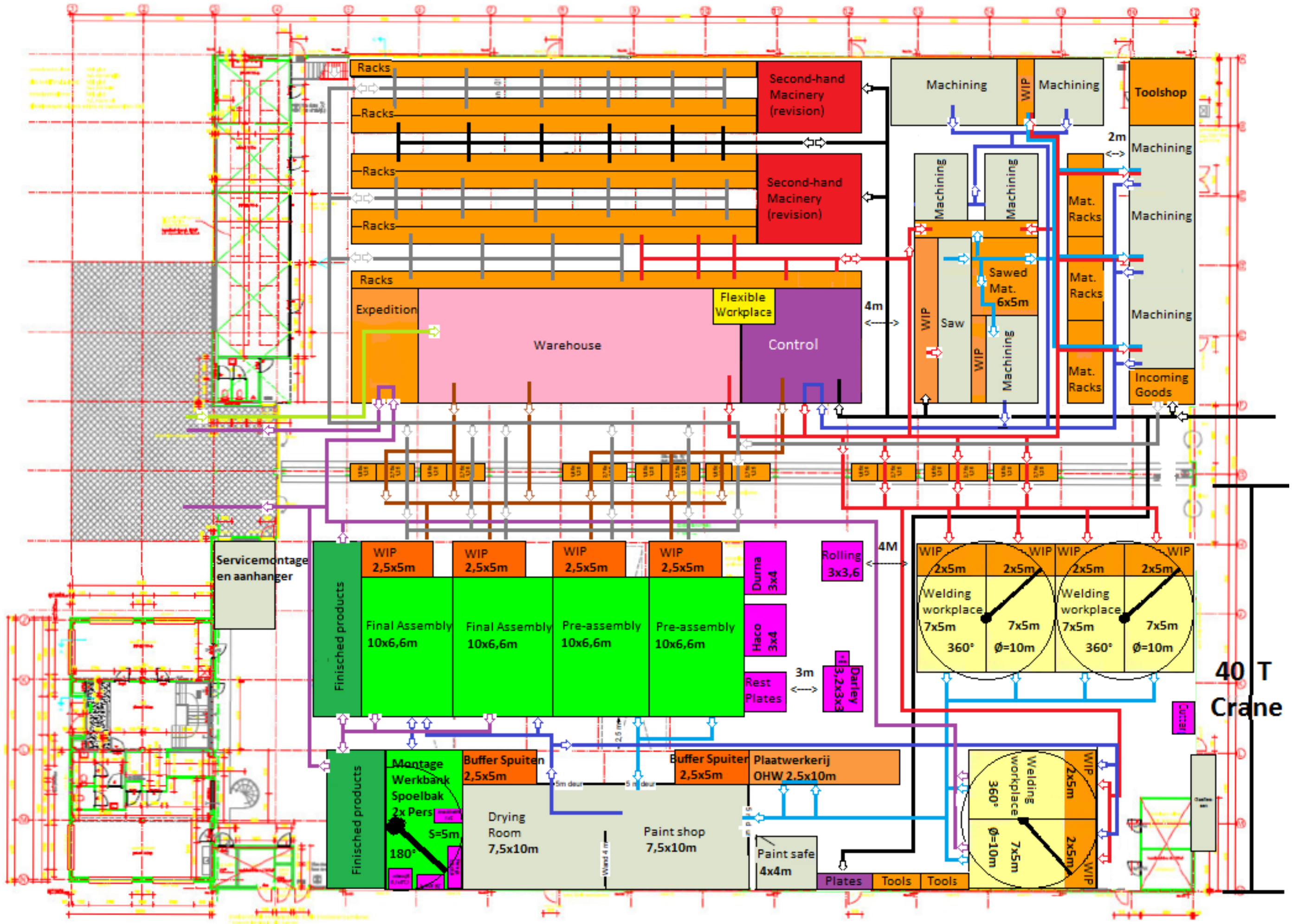

Figure 5.6: Layout alternative 3 (see appendix 7 for more detailed version)

Layout alternative 4: Final layout

The last alternative, which is used as input for the 3D model, is shown in figure 5.7. Several events led this model to completely changing. First, it was discovered that an electricity cabinet is located within the paint shop site proposed in alternative 3. Compromises therefore had to be taken. One option was to move the paint shop backwards, which would result in a worse sequence of operations between assembly and the paint shop. Another possibility was to place the paint shop in the middle of the production area, which was not a requirement. In this option, the paint shop would act as a natural barrier between the assembly and sheet metal departments and the sequence of operations would be more effective. Besides, the paint shop was adjusted from 7.5 meters towards 5 meters wide. Therefore the decision was drawn to let go the practical limitation of having a large workshop in the middle of the production facility. When the shareholders specified that there should not be any trenches in the floor (e.g., for electrical wiring), it became necessary to re-determine the positions of different workplaces and machines in the context of the latest alternatives. The number of the possible trenches is kept at as low as possible.

This layout meets the required capacity and fulfils both the theoretical criteria and practical limitations. There is also enough space for future expansion. (Note: If the machining department expands, it is likely that one new machine will be bought and two older machines will be traded-in.) The layout also has a more flexible design. If working methods change in the future, this alternative could easily be adapted.

Different kinds of flows appear within this alternative layout. For example, a U-flow is applied for the machines the sheet metal department machines while an L-flow is used for the machining department. Interaction between the sheet metal department's machines and workplaces is also improved.

Before it is possible to implement this layout, it needs to be elaborated further using a 3D model (which will make it more accurate). This would also create a clear picture of what the production area would look like, which would be helpful for selling the layout.

Figure 5.7: Layout alternative 4 (see appendix 7 for more detailed version)

5.6 Discussion and evaluation of the layout alternatives

The purpose of this chapter is to propose alternative layout solutions for the company's new production facility and then choose the layout design that is most suitable for the company. It therefore provides answers to the following sub-questions as formulated in section 1.2.3 (sub-questions):

1. How can the structural approach be applied within the new facility at the company while taking the wishes and restrictions of key stakeholders into account?
    a. What are the main criteria for layout design In order to achieve efficiency in the production and logistic process?
    b. What practical requirements and restrictions do key the company stakeholders demand?
    c. Which layout alternatives are suitable for the company and what are the pros and cons of each?
    d. Which scientific research method can be used to select the most appropriate layout design for the company?

The list of criteria reflects both the main layout design criteria identified from the literature and the practical requirements and restrictions demanded from key players. It is separated into three branches based on the AHP approach: product capacity criteria, workflow criteria and practical limitations. The first branch includes criteria related to flexibility and expansion; the second includes material-handling and operation sequences; and the last lists the practical limitations, ranging from the minimum workplaces to fixed locations for different departments.

As several departments already have fixed locations due to practical limitations, two general layout options were possibly applicable at the company's new production facility. During different feedback sessions organised to evaluate these options, management preferred option 1 (see figure 5.2).

After choosing the general layout, we used the AR approach to develop different layout alternatives. We then discussed the 4 of the 28 alternatives that brought about the greatest change. Table 5.2 summarises the comparison of these four layouts based on the criteria considered in section 5.3 (list of criteria). As layout alternative 4 (figure 5.7) satisfies more selection criteria than the other alternatives, we recommended it as the most suitable layout for the company to use. In the following chapter, we discuss the implementation of this layout.

Table 5.2: Comparison of the four layouts

	Criteria																	
	Production capacity			Workflow		Practical limitations												
	A1	A2	A3	B1	B2	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Layout alternative 1	--	-	++	--	-	++	--	++	++	--	-	++	++	-	-	--	+	-
Layout alternative 2	-	+	++	--	-	++	++	++	++	++	++	++	++	-	++	--	+	-
Layout alternative 3	+	+	++	+	+	++	++	++	++	++	++	++	++	++	++	--	+	+
Layout alternative 4	++	+	++	++	++	++	++	++	++	-	++	++	++	++	++	+	+	++

Note: The coded criteria (e.g., A1, B1 and C1) in table 5.2 are derived from figure 5.1.

6 Layout implementation

Once the most suitable layout for the company was chosen (see the previous chapter), we implemented the layout within the timeframe of this thesis. While most researchers only propose a layout, this chapter describes the implementation process. In this case we were actually involved in the implementation phase as project manager. The recommendations in this chapter thus concern how to implement the proposed solution. In the first section, the steps within the design cycle are identified to analyse the post-design process steps. Section 6.2 then describes the process of implementation using five control factors, as these factors help to solve problems related to implementation of the layout. Finally, section 6.3 outlines several accomplishments and presents a 3D model of the chosen layout.

6.1 The design cycle

Most researchers propose a layout but are not part of the actual implementation of that layout. Furthermore, the final phase of the design process is not the end of the layout problem, as shown in figure 6.1. Layouts with excellent designs could fail during implementation. As Francis et al. (1992) noted, implementation failure is caused by a layout not being properly explained or layout analysts not being part of the implementation project.

According to the design cycle, the previous chapters can be classified as the design process. The design process is not the final step; explaining and installing the layout are part of the implementation phase. The complete process should then be monitored and eventually evaluated within the follow-up phase. The results can lead to a request for the implemented layout to be redesigned within the reactivation phase (Francis et al., 1992).

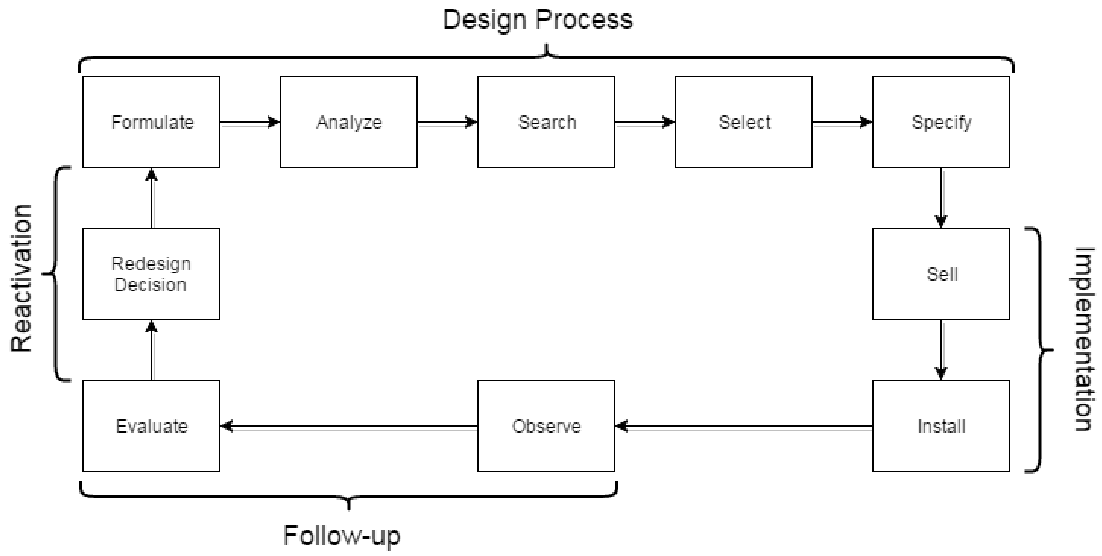

Figure 6.1: Design cycle (Francis et al., 1992)

6.2 Control factors for implementation

Research concerning layout implementation is very limited. Authors such as Francis et al. (1992), Heragu (2008) and Muther (1961) have mentioned the subject, but their suggestions are very general (e.g., communicate the changes with employees, plan the movement and assign responsibilities to employees). As these recommendations steps are not very relevant here, we selected the following five control factors: time management, money management, quality management, information management and organisation management (TMQIO)(Caluwe & Vermaak, 2002; Kor & Wijnen, 1999; Nijsten, Ridder, Jongejan, & Arts, n.d.). Table 6.1 presents the purposes of these control factors, which we use to help describe the layout implementation in the remainder of this research.

Table 6.1: Five control factors with their respective purposes (Kor & Wijnen, 1999)

Management perspective	Purpose
Time	Ensuring that the project deliverable/result is realised on time (within the set margins) and that the content project activities are carried out by the people and means delegated in the time allotted
Money	Ensuring that the project is profitable (within the set margins), that the costs do not exceed the budget and that the planned revenues of the project deliverable can be achieved
Quality	Ensuring that the project deliverable is good enough, i.e. that it conforms to the quality requirements (within the set margins), that interim deliverables are tested against the quality requirements and that the necessary resources for testing are available
Release	Ensuring that the project deliverable is unequivocally recorded and approved (within the set margins); which of the decision documents is valid, who is party to the information in these documents and in which way they may be changed
Organisation	Ensuring that the project deliverable can be handed over to the owner and that everyone knows the tasks, responsibilities and authority (within the set margins) of all those involved, as well as what cooperation, communication and jobs will need to be carried out to achieve the project deliverable

6.2.1 Time management

Implementing a layout design is an immense project that requires a considerable amount of planning. Some activities can be arranged simultaneously, while others need to occur successively. It is therefore necessary to organise, plan, manage and monitor all of the elements within a project. As a move always affects the existing production process, the project should be executed with the least amount of disruption possible and should minimise the moving time for both employees and the machinery. As such it is important to involve operators in the project, although not to the extent that they are distracted from their jobs. It is also advisable to prepare everything in the new production facility location before the actual move takes place. Furthermore, it is recommended that the move itself should occur as late as possible. Both of the company’s buildings were sold before a plan for the move could be made. As the company owned two production facilities, there were two different deadlines: the production facility at company 2 needed to be freed by 1 October 2015, while the deadline for company 1 was 1 January 2016. Furthermore, many things needed to be ready before the sheet metal department could move to the new production facility. Figure 6.2 shows a detailed daily plan that was used for monitoring the entire move. This plan enabled the master builder to see at a glance what would happen each day, monitor the progress being achieved and arrange for any necessary subcontractors.

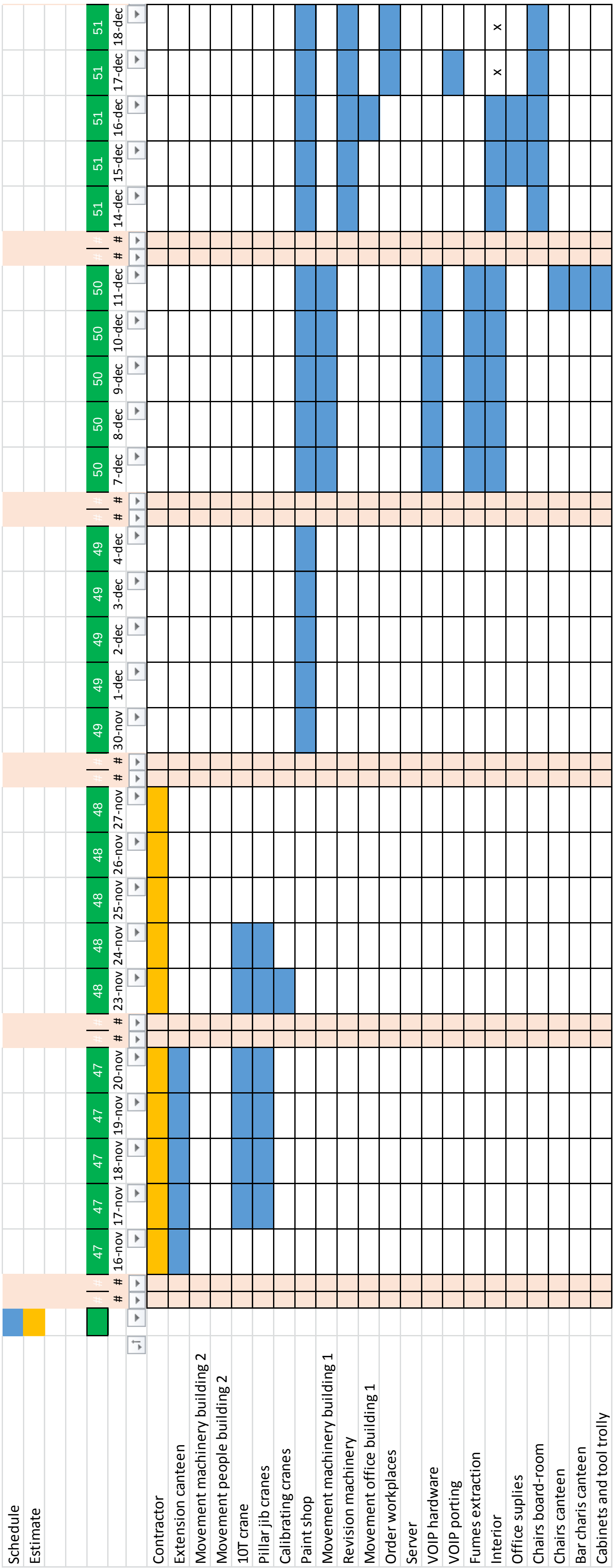

Figure 6.2: The plan for the company's move

6.2.2 Money management

Planning is not the only thing that needs to be accurate; the budget must be correct as well. When a move kicks off, a company allocates a budget to finance it and ensure that excessive costs are not incurred. At the beginning, the project's complexity made it difficult to estimate possible costs. For the sake of comparison, several subcontractors were thus invited to submit quotations. Once a reliable subcontractor is found, price negotiations are recommended. In the case of the company, these negotiations sometimes resulted in savings of 33% of the original price.

As the company decided to cover move costs from their current cash flows, we needed to cooperate closely with the accountant. Financial figures had to be monitored precisely, as multiple subcontractors were contracted for different activities and payments had to be made promptly. Furthermore, management also had to use financial figures to justify its decisions to the company's shareholders. As the move costs exceeded the budget that was allocated by the shareholders, it was necessary to estimate when additional financing was necessary to ensure that the cash flow remained sufficiently high. The estimated budget represented a rough guess on behalf of the stakeholders at the beginning of the project. Most of the additional costs resulted from the changing requirements of different stakeholders. As both stakeholders and management were kept constantly informed of the project, all stakeholders were well aware of the overages.

6.2.3 Quality management

To ensure that the project has the expected quality and fulfils the requirements, the AR approach is appropriate for implementing the layout. Each AR cycle can eventually lead to a new cycle; it is even possible that a larger project consists of multiple smaller AR cycles. The AR cycle was useful for monitoring the move and adapting to changes. As noted previously, time management and planning are important for this type of project. Nonetheless, there are always unforeseen challenges (such as changes in the requirements and delays in planning) that need to be solved directly. The role of the researcher consequently changes constantly within each AR cycle. It is important to understand that the researcher should collaborate with stakeholders as well as with other participants. Furthermore, implementing a layout involves many different subjects and problems, and the master builder must react to changes or disruptions in progress appropriately. Remaining flexible is the key to achieving successful project implementation.

6.2.4 Information and organisation management

The parameters of both information and organisation management are combined within this project. Information needs to be managed and directly influences cooperation and communication with employees or subcontractors. Management makes the decision, but employees can break it (Francis et al., 1992); this sentence summarises how important it is to collaborate with all participants, not just the firm's management. For this study, the scope formulated to narrow the research resulted in human aspects and consequences being excluded; the overall goal was instead to design and create an effective flow. However, it must be noted that human aspects had a major influence on the project, especially during the process of moving to the new production facility. A move will always be more successful with employee cooperation than without. Employees' willingness to participate can be maximised by constantly sharing research results and interacting with them, as well as with managers (Berg, 2001).

6.3 Accomplishments and the 3D model

As subcontractors must be scheduled, it is necessary to expand the layout to include as many details as possible. The layout guides the movers who transport the machines, the electricians who create the electric connections and the warehouse employees who build the racks – all of whom will benefit from a detailed layout. It is therefore recommended that the layout be designed as a 3D model using exact building and machine measurements. The final layout in figure 6.3 includes routes for both people and forklift trucks.

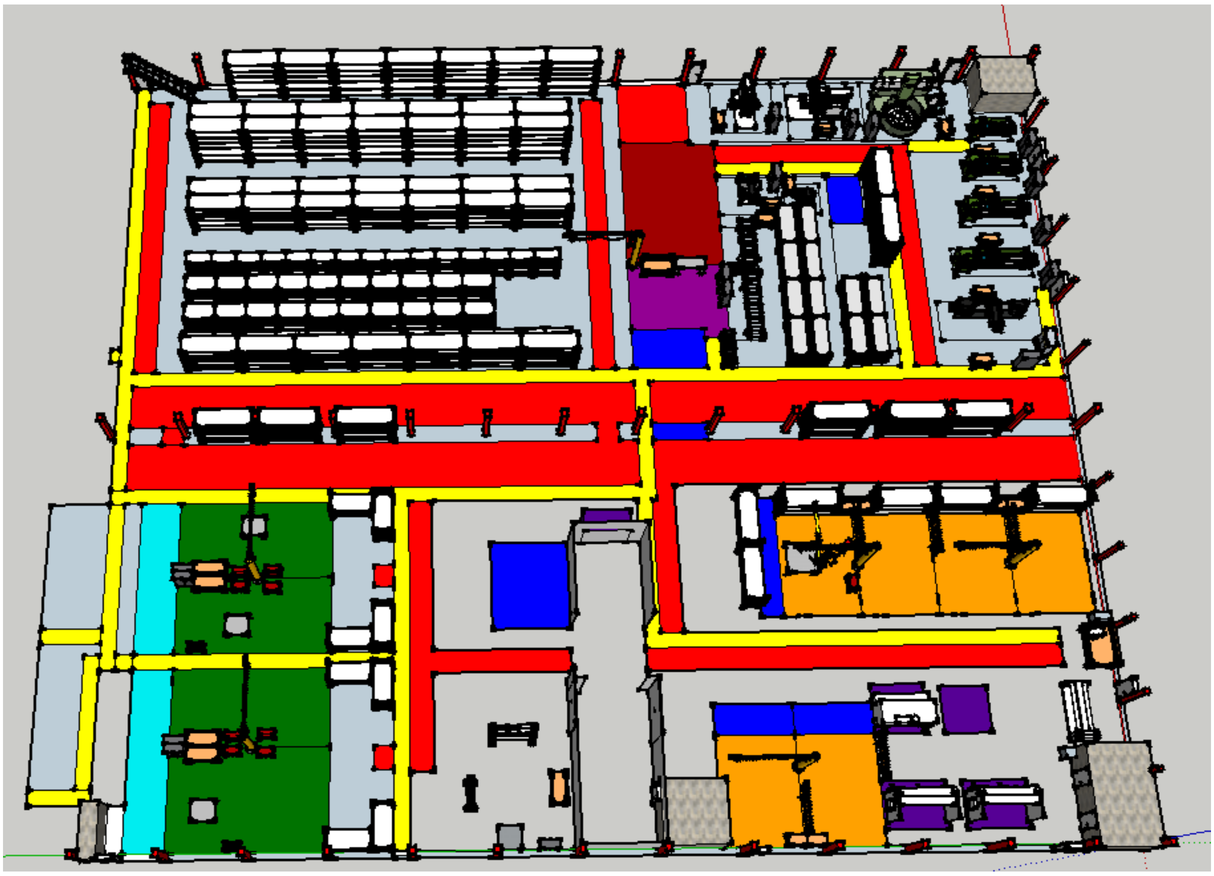

Figure 6.3: Overview of the chosen layout for the company in 3D (see appendix 8 for a more detailed version)

Figure 6.3 shows an overview of the chosen 3D layout; appendix 8 illustrates the same model with more detail for each department. The following brief sketch of the layout's legend is helpful for understanding the figure:

- Yellow line: walkway;
- Red line: forklift trucks path;
- White: Pallet racks;
- Red square (same colour as the path for forklifts): Space reserved for testing;
- Dark red square: Space reserved for storage used machines;
- Purple: Quality control;
- Blue: WIP;
- Light green (left upper corner): Machines within the machinery department;
- Orange: Workplaces for sheet metal department;
- Purple (left lower corner): Machines within the sheet metal department;
- Dark green: Workplaces for assembly department;
- Light blue: Storage of finished machines by produced by the company;
- Grey: Several small rooms within the production facility.

Within the timeframe of the project we introduced/mentioned optimisation techniques as well as change management for the new production facility. In practice we guide stakeholders towards a new thinking, which lead to:

- Introducing a distinction within the assembly line between pre-assembly and final-assembly. Besides, keeping both workplace clean by removing tools as sanding belts. This is the first step in assigning operations towards the right workplaces (e.g., welding is done in the assembly department, while it should be done in the metal sheet department).
- Introducing floor stocks (e.g., bolts and nuts) for the assembly department to reduce the undesirable flow of personnel towards the warehouse.
- In order to reduce the flows for the employees of different departments (e.g., assembly, machining and sheet metal department), the employees of the warehouse become responsible for almost all transportation flows within the production area. Still, some exceptions are formulated, for example the machining department is responsible for transporting the semi-finished goods towards the quality unit.
- Implementing a new working method, by assigning production orders to workplaces by the production manager. This results in a better control of the WIP as well as maintaining the planning and the capacity utilization.
- As noted within this research, one of the recommendations was to design and produce the machines in a modular manner. This recommendation was introduced within the engineering department and to several key players of the company. Besides, as the bolts and nuts inventory is large, reducing the inventory is possible by standardizing different bolts and nuts for the machines.

It is important to understand that more improvement is possible by using the framework of Hicks and Matthews (2010). Furthermore, literature suggests that LM could be used upstream the CODP and the agile approach should be more suitable for downstream operations (Olhager, 2012). The agile approach is consistent with flexibility performance as well as with a differentiation strategy (Hallgren & Olhager, 2009). The strategy chosen by the company is a differentiation strategy and therefore the company should focus on an agile approach. As agile is focused on supply chains (Olhager, 2010, 2012), Suri (1998) suggested to focus on quick response manufacturing (QRM) before targeting agile manufacturing. QRM consist of detailed methodology for implementation as well as detail principles. Therefore this optimisation will be a good foundation before accepting agile. Still, research is required for the company how to implement QRM, LM and agile.

7 Recommendations and conclusions

This research focussed on designing an effective workflow for the company, which eventually became creating an effective workflow for the company. This chapter is structured as follows: section 7.1 discusses the overall conclusions of the research, section 7.1 presents a roadmap that the company can use to facilitate the improvements and section 7.3 describes possibilities for further scientific research.

7.1 Overall conclusions regarding the layout alternatives

Problems within the existing situation

At the moment, the company produces what customers ask for, which aligns with the customer intimacy strategy. This strategy enables the company to add value for their customers by delivering products and services that are specially adapted to these customers' needs. The current work method used by the company focuses on ETO (although MTS is also used). A result of ETO is parts proliferation, which is expensive as it adds costs. A result of MTS is the focus on one piece and cost-per-piece, instead of on the total cost of machines. As the company's operations have mainly focused on in-house production, the supply chain is not fully integrated into the production process. If the MvB discussion changes, the supply chain could become more important. It is therefore recommended that the company use the SCOR model to integrate the supply chain into the production process for non-core components.

While the company does monitor several factors (e.g., quality and lead time), without goals it is impossible to measure improvements. For this research we identified the following four main bottlenecks in terms of efficiency:

1. Transportation costs (which were already tackled due to the move);
2. Other costs due (such as inventory cost, possibly incorrect cost prices and the actual costs of phantom parts);
3. Inefficiencies due to workflows within the existing layout; and
4. The customer order decoupling point.

In order to address these problems, the company planned to move to a new facility (which tackles bottleneck 1). This research is therefore a limited greenfield optimisation project that concerns the retrofitting of a new facility. In addition, the company's management department wishes to increase the company's output. These problems and considerations gave rise to the following central research question for this thesis:

"How can the company's production process be optimised by establishing an effective workflow for a new production facility?"

Results:

The main conclusions of our research are as follows:

- Out of the 28 alternatives that we designed, we discussed the 4 that brought about the greatest changes. These four layout alternatives were then compared on the basis of different criteria (e.g., ease of future expansion and material-handling effectiveness). As layout alternative 4 (figure A) best satisfies the selection criteria, it was selected for implementation.
- Another pre-implementation result was designing a 3D model using exact building and machine measurements.
- Within the timeframe of this thesis, we implemented the most suitable layout for the company. Several tasks were undertaken to ensure a smooth move to the new production facility; this included:
    - Explaining the new layout to the company's employees and stakeholders;
    - Moving the actual production facilities to the new facility;

- Undertaking financial budgeting;
  - Engaging, selecting and supervising different subcontractors; and
  - Starting to introduce change management for further research and implementation.
- With regard to the implementation of the chosen layout, it should be noted that human aspects had a major influence on the project, especially during the process of moving to the new production facility. We created support for the move by keeping stakeholders, managers and employees informed throughout the project. After all, while management makes the decisions, employees can break them.

Recommendations:
On the basis of the above results, we offer the following recommendations:

- A balance between customer satisfaction and operational costs is always necessary. Instead of a combination of ETO and MTS, the company should apply the recommended MTO work method. Furthermore, the process layout should align with the open-field layout. This combination will tackle bottleneck 3.
- When combined with modular design and the standardisation of the production process, the recommended work method will lead to reduced costs, the prevention of obsolete parts, increased machinery utilisation, improved flexibility and shorter lead times (thus tackling bottlenecks 2 and 4).
- Daily activities should be monitored in combination with goals. We recommend using three KPIs to do so, namely: the rate of obsolete inventory, on-time production and supplier fill rate.
- As change management is also introduced and several optimisations are noticed, other optimisation techniques are applicable for the company. To start with, the company should focus on QRM, as this method includes both a detailed methodology for implementation and detailed principles. Further research is necessary to identify the possibilities that QRM may offer the company.

7.2 Roadmap

To facilitate the improvements mentioned in the previous section, we propose the following roadmap to guide the company (see table 7.1).

1. Management introduces the three recommended KPIs to monitor daily activities and measure improvements.
2. Different parts are standardised to reduce parts proliferation by eliminating approved but unused parts, parts that have not been recently used and duplicate parts, as well as to encourage engineers to use existing parts when possible.
3. The actual core components within the different machines on which the company truly needs to focus are determined.
4. The costs for phantom parts are improved by the supplier ordering and receiving the raw materials required to make these parts, which allows the company to avoid unnecessary transport costs and prevents the company employees from having to deal with the hassle of buying phantom parts. Using quality control and agreements with the supplier, product quality remains unchanged.
5. Phantom parts are fully outsourced, which makes it possible to apply the SCOR model to integrate the supply chain within the production process for the phantom parts.
6. The engineering department undertakes further research to solve the inefficient work method concerning the assembly of motor support on the product E.
7. The required research on how the company can implement different optimisation techniques (i.e., QRM, LM and agile) in the future is undertaken.

8. A modular design is introduced for the machines produced by the company (with the engineering department first focusing on the product E, as it has the greatest variety of types).

Table 7.1: Roadmap for facilitating the improvements

Phase	Action	Actor
1	Apply the three recommended KPIs within the production process	Management
2	Standardise different parts	Engineering
3	Determine the actual core components	Engineering
4	Improve the costs for phantom parts	Operational manager
5	Apply the SCOR model to integrate the supply chain	Operational manager
6	Further research for reducing inefficient work methods	Operational manager
7	Further research on how to implement different optimisation techniques	Operational manager
8	Introduce modular design for the machines produced	Engineering

7.3 Further research

This research and the design process did not follow the SLP procedure step by step, but rather in a more general manner. Time pressure influenced the design project, and participants and stakeholders had limited availability within their daily jobs. The AR approach and AR cycle were subsequently used as guidelines for designing layout alternatives, which became a process of improvement. The suggestion for science is therefore to undertake a comparative study for this design process. It could also be interesting to redesign the SLP procedure by integrating the AR cycle into the model, which should lead to a more practical approach. Finally, it would also be interesting to study the extent to which employee cooperation influences the success of a move, given the important role it appears to play.

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Appendix 1: Organisation chart of the Group

(CONFIDENTAL)

Appendix 2: Codification of the SCOR Model

Supply Chain Reliability

RL.1.1 - Perfect Order Fulfillment

RL.2.1 - % of Orders Delivered In Full
- RL.3.33 - Delivery Item Accuracy
- RL.3.35 - Delivery Quantity Accuracy

RL.2.2 - Delivery Performance to Customer Commit Date
- RL.3.32 - Customer Commit Date Achievement Time Customer Receiving
- RL.3.34 - Delivery Location Accuracy

RL.2.3 - Documentation Accuracy
- RL.3.31 - Compliance Documentation Accuracy
- RL.3.43 - Other Required Documentation Accuracy
- RL.3.45 - Payment Documentation Accuracy
- RL.3.50 - Shipping Documentation Accuracy

RL.2.4 - Perfect Condition
- RL.3.12 - % Of Faultless Installations
- RL.3.24 - % Orders/Lines Received Damage Free
- RL.3.41 - Orders Delivered Damage Free Conformance
- RL.3.42 - Orders Delivered Defect Free Conformance
- RL.3.55 - Warranty and Returns

Supply Chain Responsiveness

RS.1.1 - Order Fulfillment Cycle Time

RS.2.1 - Source Cycle Time
- RS.3.8 - Authorize Supplier Payment Cycle Time
- RS.3.35 - Identify Sources of Supply Cycle Time
- RS.3.107 - Receive Product Cycle Time
- RS.3.122 - Schedule Product Deliveries Cycle Time
- RS.3.125 - Select Supplier and Negotiate Cycle Time
- RS.3.139 - Transfer Product Cycle Time
- RS.3.140 - Verify Product Cycle Time

RS.2.2 - Make Cycle Time
- RS.3.33 - Finalize Production Engineering Cycle Time
- RS.3.49 - Issue Material Cycle Time
- RS.3.101 - Produce and Test Cycle Time
- RS.3.114 - Release Finished Product to Deliver Cycle Time
- RS.3.123 - Schedule Production Activities Cycle Time
- RS.3.128 - Stage Finished Product Cycle Time
- RS.3.142 - Package Cycle Time

RS.2.3 - Deliver Cycle Time
- RS.3.16 - Build Loads Cycle Time
- RS.3.18 - Consolidate Orders Cycle Time
- RS.3.46 - Install Product Cycle Time
- RS.3.51 - Load Product & Generate Shipping Documentation Cycle Time
- RS.3.95 - Pack Product Cycle Time
- RS.3.96 - Pick Product Cycle Time
- RS.3.102 - Receive & Verify Product by Customer Cycle Time
- RS.3.110 - Receive Product from Source or Make Cycle Time
- RS.3.111 - Receive, Configure, Enter, & Validate Order Cycle Time
- RS.3.116 - Reserve Resources and Determine Delivery Date Cycle Time
- RS.3.117 - Route Shipments Cycle Time
- RS.3.120 - Schedule Installation Cycle Time
- RS.3.124 - Select Carriers & Rate Shipments Cycle Time
- RS.3.126 - Ship Product Cycle Time

RS.2.4 - Delivery Retail Cycle Time
- RS.3.17 - Checkout Cycle Time
- RS.3.32 - Fill Shopping Cart Cycle Time
- RS.3.34 - Generate Stocking Schedule Cycle Time
- RS.3.97 - Pick Product from Backroom Cycle Time
- RS.3.109 - Receive Product at Store Cycle Time
- RS.3.129 - Stock Shelf Cycle Time

Supply Chain Agility

AG.1.1 - Upside Supply Chain Flexibility
- AG.2.1 - Upside Flexibility (Source)
- AG.2.2 - Upside Flexibility (Make)
- AG.2.3 - Upside Flexibility (Deliver)
- AG.2.4 - Upside Return Flexibility (Source)
- AG.2.5 - Upside Return Flexibility (Deliver)

AG.1.2 - Upside Supply Chain Adaptability
- AG.2.6 - Upside Adaptability (Source)
- AG.2.7 - Upside Adaptability (Make)
- AG.2.8 - Upside Adaptability (Deliver)
- AG.2.9 - Upside Return Adaptability (Source)
- AG.2.10 - Upside Return Adaptability (Deliver)

AG.1.3 - Downside Supply Chain Adaptability
- AG.2.11 - Downside Adaptability (Source)
- AG.2.12 - Downside Adaptability (Make)
- AG.2.13 - Downside Adaptability (Deliver)

AG.1.4 - Overall Value at Risk (VAR)
- AG.2.14 - Supplier's/Customer's/Product's Risk Rating
- AG.2.15 - Value at Risk (Plan)
- AG.2.16 - Value at Risk (Source)
- AG.2.17 - Value at Risk (Make)
- AG.2.18 - Value at Risk (Deliver)
- AG.2.19 - Value at Risk (Return)

Supply Chain Costs

CO.1.1 - Supply Chain Management Cost

CO.2.1 - Cost to Plan
- CO.3.104 - Cost to Plan (Deliver)
- CO.3.105 - Cost to Plan (Make)
- CO.3.106 - Cost to Plan (Return)
- CO.3.107 - Cost to Plan (Source)
- CO.3.108 - Cost to Plan Supply Chain

CO.2.2 - Cost to Source
- CO.3.27 - Cost to Authorize Supplier Payment
- CO.3.115 - Cost to Receive Product
- CO.3.126 - Cost to Schedule Product Deliveries
- CO.3.137 - Cost to Transfer Product
- CO.3.138 - Cost to Verify Product

CO.2.3 - Cost to Make

CO.2.4 - Cost to Deliver
- CO.3.163 - Order Management Costs
- CO.3.200 - Order Delivery Costs

CO.2.5 - Cost to Return
- CO.3.131 - Cost to Source Return

CO.2.7 - Mitigation Cost ($)
- CO.3.178 - Risk Mitigation Costs (Deliver)
- CO.3.179 - Risk Mitigation Costs (Make)
- CO.3.180 - Risk Mitigation Costs (Plan)
- CO.3.181 - Risk Mitigation Costs (Return)
- CO.3.182 - Risk Mitigation Costs (Source)

CO.1.2 - Cost of Goods Sold
- CO.3.140 - Direct Labor Cost
- CO.3.141 - Direct Material Cost
- CO.3.155 - Indirect Cost Related to Production

Supply Chain Asset Management

AM.1.1 - Cash-to-Cash Cycle Time
- AM.2.1 - Days Sales Outstanding
- AM.2.2 - Inventory Days of Supply
  - AM.3.45 - Inventory Days of Supply (Finished Goods)
  - AM.3.16 - Inventory Days of Supply (Raw Material)
  - AM.3.17 - Inventory Days of Supply (WIP)
  - AM.3.23 - Recycle Days of Supply
  - AM.3.28 - Percentage Defective Inventory
  - AM.3.37 - Percentage Excess Inventory
  - AM.3.44 - Percentage Unserviceable MRO Inventory
- AM.2.3 - Days Payable Outstanding

AM.1.2 - Return on Supply Chain Fixed Assets
- AM.2.5 - Supply Chain Fixed Assets
  - AM.3.11 - Fixed Asset Value (Deliver)
  - AM.3.18 - Fixed Asset Value (Make)
  - AM.3.20 - Fixed Asset Value (Plan)
  - AM.3.24 - Fixed Asset Value (Return)
  - AM.3.27 - Fixed Asset Value (Source)

AM.1.3 - Return on Working Capital
- AM.2.6 - Accounts Payable (Payables Outstanding)
- AM.2.7 - Accounts Receivable (Sales Outstanding)
- AM.2.8 - Inventory

SCOR Online Access

The SCOR framework is also available online to members. The online version features easy navigation through linked definitions, performance metrics, best practices, and skills.

Visit: supply-chain.org/online-access

sP PLAN

sP1 Plan Supply Chain
sP1.1: Identify, Prioritize, and Aggregate Supply Chain Requirements
sP1.2: Identify, Prioritize, and Aggregate Supply Chain Resources
sP1.3: Balance Supply Chain Resources with Supply Chain Require-ments
sP1.4: Establish and Communicate Supply Chain Plans

sP2 Plan Source
sP2.1: Identify, Prioritize, and Aggregate Product Requirements
sP2.2: Identify, Assess, and Aggregate Product Resources
sP2.3: Balance Product Resources with Product Requirements
sP2.4: Establish Sourcing Plans

sP3 Plan Make
sP3.1: Identify, Prioritize, and Aggregate Production Requirements
sP3.2: Identify, Assess, and Aggregate Production Resources
sP3.3: Balance Production Resources with Production Requirements
sP3.4: Establish Production Plans

sP4 Plan Deliver
sP4.1: Identify, Prioritize, and Aggregate Delivery Requirements
sP4.2: Identify, Assess, and Aggregate Delivery Resources
sP4.3: Balance Delivery Resources with Delivery Requirements
sP4.4: Establish Delivery Plans

sP5 Plan Return
sP5.1: Identify, Prioritize, and Aggregate Return Requirements
sP5.2: Identify, Assess, and Aggregate Return Resources
sP5.3: Balance Return Resources with Return Requirements
sP5.4: Establish and Communicate Return Plans

sEP Enable Plan
sEP.1: Manage Business Rules for Plan Processes
sEP.2: Manage Performance of Supply Chain
sEP.3: Manage Plan Data Collection
sEP.4: Manage Integrated Supply Chain Inventory
sEP.5: Manage Integrated Supply Chain Capital Assets
sEP.6: Manage Integrated Supply Chain Transportation
sEP.7: Manage Planning Configuration
sEP.8: Manage Plan Regulatory Requirements and Compliance
sEP.9: Manage Supply Chain Risk
sEP.10: Align Supply Chain Unit Plan with Financial Plan

sS SOURCE

sS1 Source Stocked Product
sS1.1: Schedule Product Deliveries
sS1.2: Receive Product
sS1.3: Verify Product
sS1.4: Transfer Product
sS1.5: Authorize Supplier Payment

sS2 Source Make-to-Order Product
sS2.1: Schedule Product Deliveries
sS2.2: Receive Product
sS2.3: Verify Product
sS2.4: Transfer Product
sS2.5: Authorize Supplier Payment

sS3 Source Engineer-to-Order Product
sS3.1: Identify Sources of Supply
sS3.2: Select Final Supplier(s) and Negotiate
sS3.3: Schedule Product Deliveries
sS3.4: Receive Product
sS3.5: Verify Product
sS3.6: Transfer Product
sS3.7: Authorize Supplier Payment

sES Enable Source
sES.1: Manage Sourcing Business Rules
sES.2: Assess Supplier Performance
sES.3: Maintain Source Data
sES.4: Manage Product Inventory
sES.5: Manage Capital Assets
sES.6: Manage Incoming Product
sES.7: Manage Supplier Network
sES.8: Manage Import/Export Requirements
sES.9: Manage Supply Chain Source Risk
sES.10: Manage Supplier Agreements

sM MAKE

sM1 Make-to-Stock
sM1.1: Schedule Production Activities
sM1.2: Issue Product
sM1.3: Produce and Test
sM1.4: Package
sM1.5: Stage Product
sM1.6: Release Product to Deliver
sM1.7: Waste Disposal

sM2 Make-to-Order
sM2.1: Schedule Production Activities
sM2.2: Issue Product
sM2.3: Produce and Test
sM2.4: Package
sM2.5: Stage Finished Product
sM2.6: Release Finished Product to Deliver
sM2.7: Waste Disposal

sM3 Engineer-to-Order
sM3.1: Finalize Production Engineering
sM3.2: Schedule Production Activities
sM3.3: Issue Product
sM3.4: Produce and Test
sM3.5: Package
sM3.6: Stage Finished Product
sM3.7: Release Product to Deliver
sM3.8: Waste Disposal

sEM Enable Make
sEM.1: Manage Production Rules
sEM.2: Manage Production Performance
sEM.3: Manage Make Information
sEM.4: Manage In-Process Products (WIP)
sEM.5: Manage Make Equipment and Facilities
sEM.6: Manage Transportation (WIP)
sEM.7: Manage Production Network
sEM.8: Manage Make Regulatory Environment
sEM.9: Manage Supply Chain Make Risk

sD DELIVER

sD1 Deliver Stocked Product
sD1.1: Process Inquiry and Quote
sD1.2: Receive, Enter, and Validate Order
sD1.3: Reserve Inventory and Determine Delivery Date
sD1.4: Consolidate Orders
sD1.5: Build Loads
sD1.6: Route Shipments
sD1.7: Select Carriers and Rate Shipments
sD1.8: Receive Product from Source or Make
sD1.9: Pick Product
sD1.10: Pack Product
sD1.11: Load Vehicle and Generate Shipping Docs
sD1.12: Ship Product
sD1.13: Receive and Verify Product by Customer
sD1.14: Install Product
sD1.15: Invoice

sD2 Deliver Make-to-Order Product
sD2.1: Process Inquiry and Quote
sD2.2: Receive, Configure, Enter, and Validate Order
sD2.3: Reserve Inventory and Determine Delivery Date
sD2.4: Consolidate Orders
sD2.5: Build Loads
sD2.6: Route Shipments
sD2.7: Select Carriers and Rate Shipments
sD2.8: Receive Product from Source or Make
sD2.9: Pick Product
sD2.10: Pack Product
sD2.11: Load Product and Generate Shipping Docs
sD2.12: Ship Product
sD2.13: Receive and Verify Product by Customer
sD2.14: Install Product
sD2.15: Invoice

sD3 Deliver Engineer-to-Order Product
sD3.1: Obtain and Respond to RFP/RFQ
sD3.2: Negotiate and Receive Contract
sD3.3: Enter Order, Commit Resources, and Launch Program
sD3.4: Schedule Installation
sD3.5: Build Loads
sD3.6: Route Shipments
sD3.7: Select Carriers and Rate Shipments
sD3.8: Receive Product from Source or Make
sD3.9: Pick Product
sD3.10: Pack Product
sD3.11: Load Product and Generate Shipping Docs
sD3.12: Ship Product
sD3.13: Receive and Verify Product by Customer
sD3.14: Install Product
sD3.15: Invoice

sD4 Deliver Retail Product
sD4.1: Generate Stocking Schedule
sD4.2: Receive Product at the Store
sD4.3: Pick Product from Backroom
sD4.4: Stock Shelf
sD4.5: Fill Shopping Cart
sD4.6: Checkout
sD4.7: Deliver and/or Install

sED Enable Deliver
sED.1: Manage Deliver Business Rules
sED.2: Assess Delivery Performance
sED.3: Manage Deliver Information
sED.4: Manage Finished Goods Inventory
sED.5: Manage Deliver Capital Assets
sED.6: Manage Transportation
sED.7: Manage Product Life Cycle
sED.8: Manage Import/Export Requirements
sED.9: Manage Supply Chain Deliver Risk

sR RETURN

sSR1 Source Return Defective Product
sSR1.1: Identify Defective Product Condition
sSR1.2: Disposition Defective Product
sSR1.3: Request Defective Product Return Authorization
sSR1.4: Schedule Defective Product Shipment
sSR1.5: Return Defective Product

sSR2 Source Return MRO Product
sSR2.1: Identify MRO Product Condition
sSR2.2: Disposition MRO Product
sSR2.3: Request MRO Return Authorization
sSR2.4: Schedule MRO Shipment
sSR2.5: Return MRO Product

sSR3 Source Return Excess Product
sSR3.1: Identify Excess Product Condition
sSR3.2: Disposition Excess Product
sSR3.3: Request Excess Product Return Authorization
sSR3.4: Schedule Excess Product Shipment
sSR3.5: Return Excess Product

sDR1 Deliver Return Defective Product
sDR1.1: Authorize Defective Product Return
sDR1.2: Schedule Defective Return Receipt
sDR1.3: Receive Defective Product (includes Verify)
sDR1.4: Transfer Defective Product

sDR2 Deliver Return MRO Product
sDR2.1: Authorize MRO Product Return
sDR2.2: Schedule MRO Return Receipt
sDR2.3: Receive MRO Product
sDR2.4: Transfer MRO Product

sDR3 Deliver Return Excess Product
sDR3.1: Authorize Excess Product Return
sDR3.2: Schedule Excess Return Receipt
sDR3.3: Receive Excess Product
sDR3.4: Transfer Excess Product

sER Enable Return
sER.1: Manage Business Rules for Return Processes
sER.2: Manage Performance of Return Processes
sER.3: Manage Return Data Collection
sER.4: Manage Return Inventory
sER.5: Manage Return Capital Assets
sER.6: Manage Return Transportation
sER.7: Manage Return Network Configuration
sER.8: Manage Return Regulatory Requirements and Compliance
sER.9: Manage Supply Chain Return Risk

Appendix 3: Products information guide the company

(CONFIDENTAL)

Appendix 4: Overview of variety within the Product E

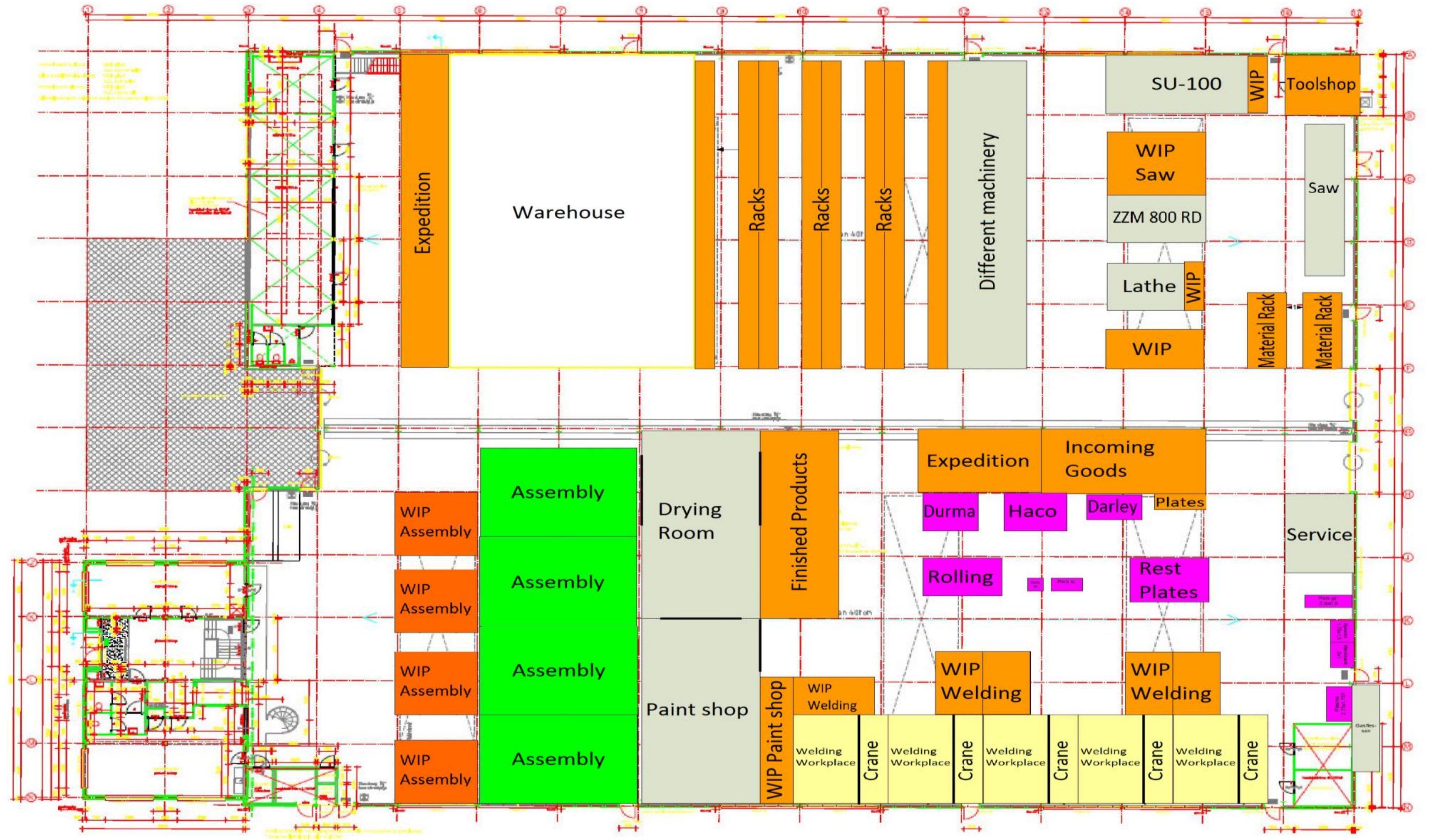
(CONFIDENTAL)

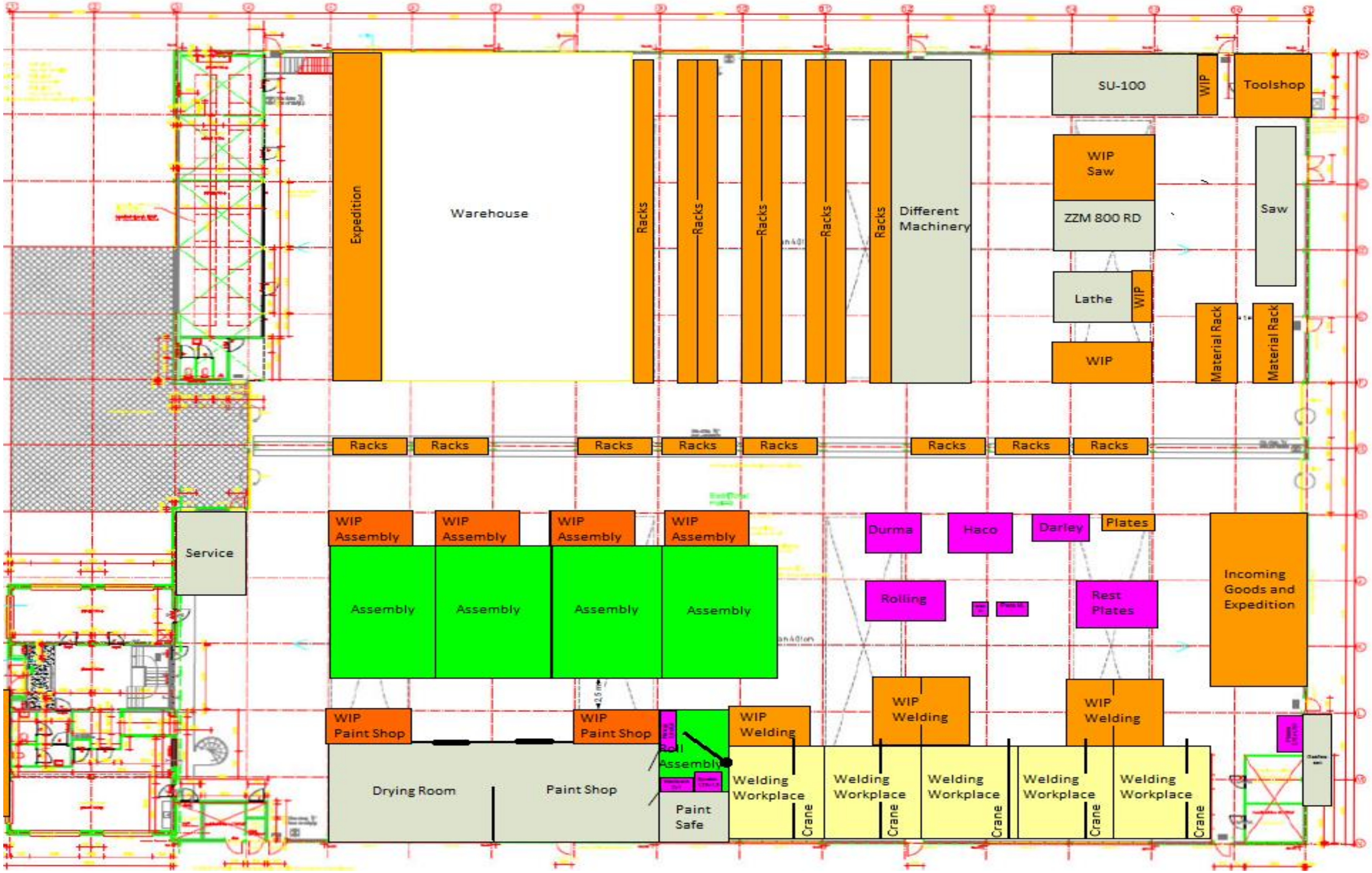
Appendix 5: Proposed layout by Kiens (2013)

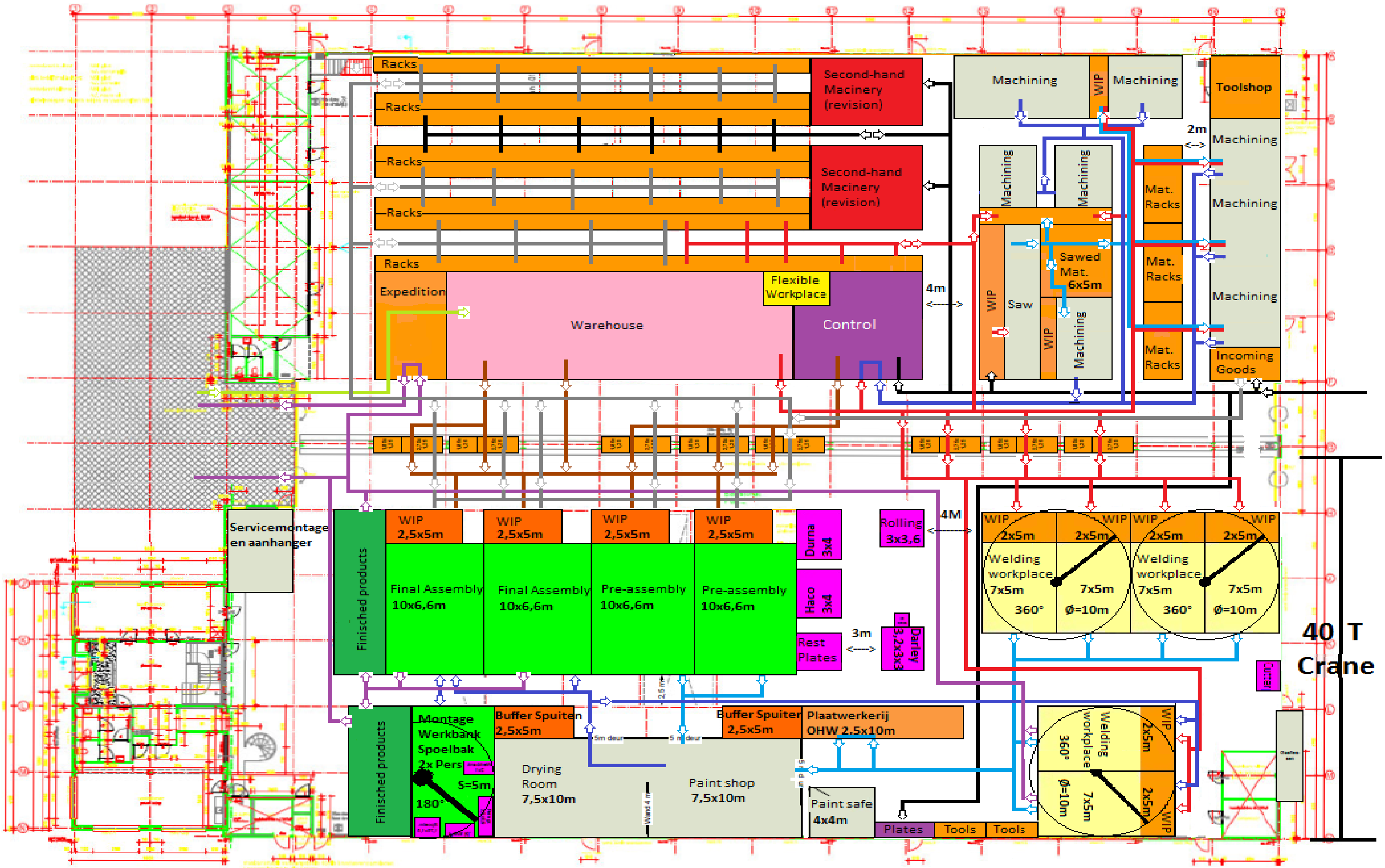
Appendix 6: Detailed overview of the space requirements

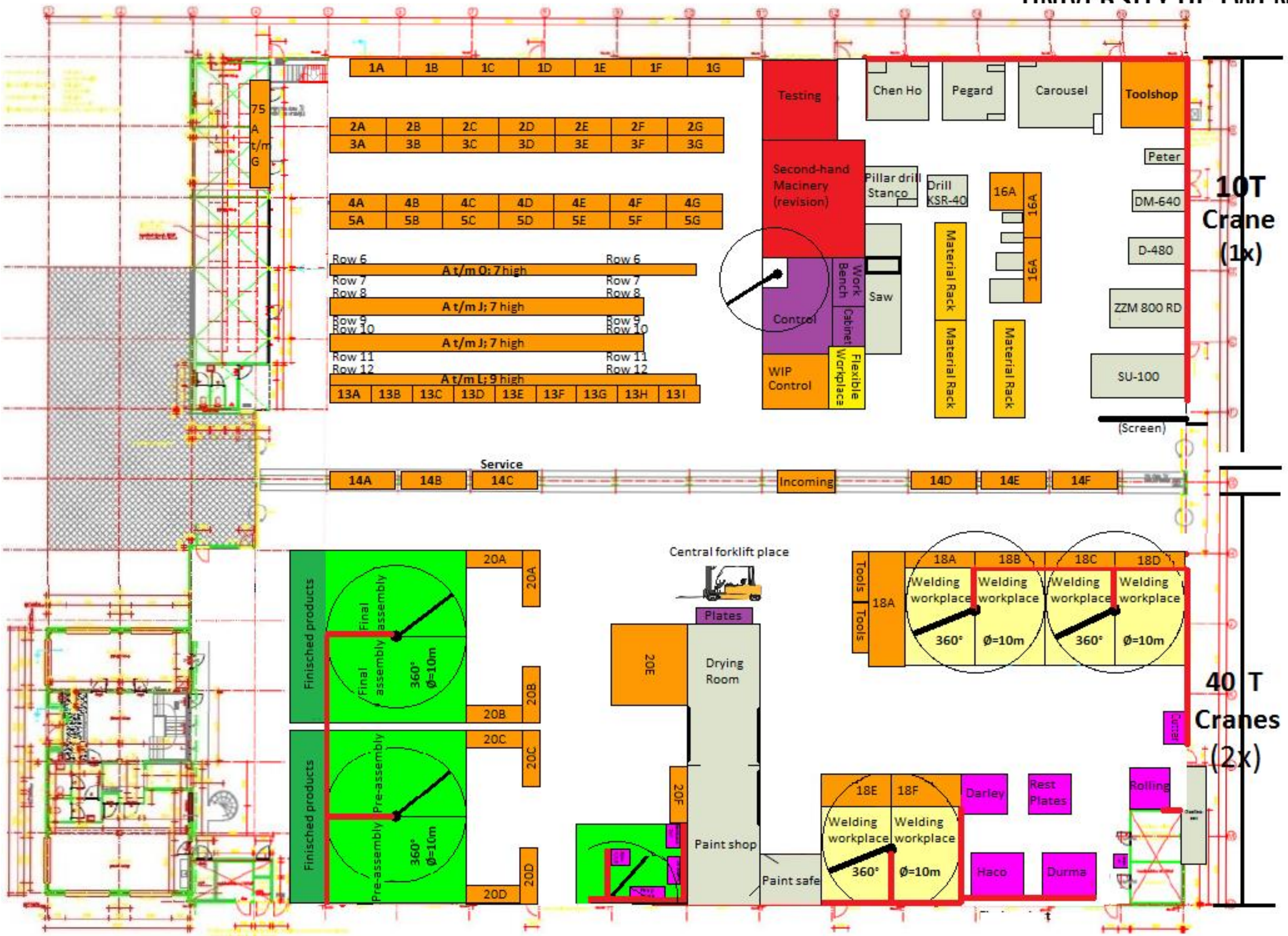
Department	Current	Amount		Needed	Amount
Warehouse	14x17	1		20x15	1
Incoming goods	46	1			1
Outgoing goods	50	1			1
Half-fabricates	30	1			
Racking Company 1	121 S	1		6x6x5?	
Racking Company 2	98 S	1			
Quality control				4x6	1
Machining dep.	25x20				
SU-100				3,10x6,75	1
Chen Ho TCCB				4,20x4,50	1
Carousel SC-2000				5x6	1
VDF D-480				2x4,1	1
VDF DM-640				1,6x3,8	1
Cazeneuve				1,4x3	1
Pegard				4,5x4,8	1
ZZM 800 RD				2,4x5,5	1
KSR-40				2,5x2,5	1
Stanco 2 A 554				3,1x4,2	1
Idice-200				1,8x1,3	1
Chisel sharpener				1,15x0,55	1
Farman				1,4x1	1
Trashbin Steel				1,4x1,4	
Sawing dep.					
Storage finished goods	3x3	1			
Racking materials				1,1x6	2
Racking materials				1,5x6	1
Racking materials	2,5 x6	2		2,5x6	1
Saw incl. roller convoyer	1x6	1		2,3x9	1
Sheet metal dep.					
Welding workplaces	6x7	5		7x5	5
Storage WIP	5x3	5		2x5	5
Durna				3x4	
Haco				3x4	
Darley				3,20x3,3	
Rounda PS-205				1,1x3,6	
Small weller				1x1,5	
Racking materials				1,4x2,9	
Storage materials				3x3	
Place for laser cutting				1,8x2,6	
Paint shop					
Paint shop				7,5x10	1
Drying room				7,5x10	1
Paint safe				4x4	1
Storage WIP				2,5x5	2
Assembly dep.					
Montageplekken	7x9	2		10x6	4
Opslag onderdelen	7x3,5	2		5x2,5	4
Rol assemby					
Presser 1 (big)				1,1x2,7	1
Presser 2 (small)				0,8x1,7	1
Rinsing machine				1,4x1,4	1

Appendix 7: Detailed overview of the layout alternatives




Expedition
Warehouse
Racks
Racks
Racks
Racks
Racks
Different Machinery
SU-100
WIP
Toolshop
WIP Saw
ZZM 800 RD
Saw
Lathe
WIP
WIP
Material Rack
Material Rack
Racks
Racks
Racks
Racks
Racks
Racks
Racks
Racks
Service
WIP Assembly
WIP Assembly
WIP Assembly
WIP Assembly
Assembly
Assembly
Assembly
Assembly
Durma
Haco
Darley
Plates
Rolling
Rest Plates
Incoming Goods and Expedition
WIP Paint Shop
WIP Paint Shop
Roll Assembly
WIP Welding
WIP Welding
WIP Welding
Drying Room
Paint Shop
Paint Safe
Welding Workplace
Welding Workplace
Welding Workplace
Welding Workplace
Welding Workplace
Crane
Crane
Crane
Crane
Crane

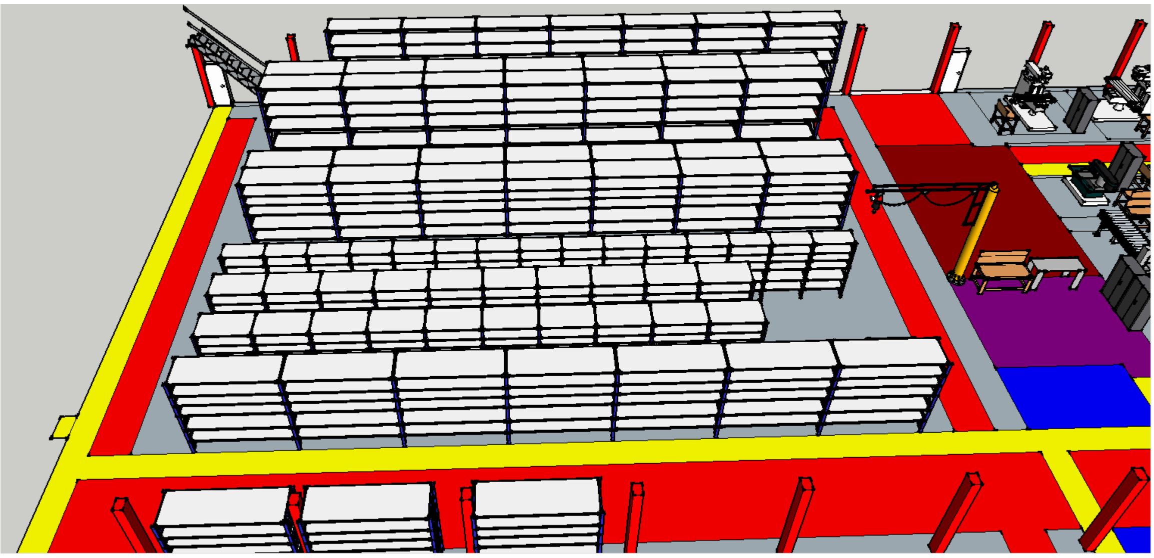

Racks
Racks
Racks
Racks
Racks
Second-hand Macinery (revision)
Second-hand Macinery (revision)
Machining
WIP
Machining
Toolshop
2m
Machining
Machining
Machining
Incoming Goods
Machining
Machining
Mat. Racks
Mat. Racks
Mat. Racks
Sawed Mat. 6x5m
WIP
Saw
WIP
Machining
4m
Expedition
Warehouse
Flexible Workplace
Control
Servicemontage en aanhanger
Finisched products
WIP 2,5x5m
WIP 2,5x5m
WIP 2,5x5m
WIP 2,5x5m
Final Assembly 10x6,6m
Final Assembly 10x6,6m
Pre-assembly 10x6,6m
Pre-assembly 10x6,6m
Durna 3x4
Haco 3x4
Rest Plates
Rolling 3x3,6
4M
3m
Darley 3,2x3x3
WIP 2x5m
WIP 2x5m
WIP 2x5m
WIP 2x5m
Welding workplace 7x5m 360°
7x5m Ø=10m
Welding workplace 7x5m 360°
7x5m Ø=10m
40 T Crane
Finisched products
Montage Werkbank Spoelbak 2x Pers
S=5m
180°
Buffer Spuiten 2,5x5m
Buffer Spuiten 2,5x5m
Plaatwerkerij OHW 2.5x10m
Drying Room 7,5x10m
Paint shop 7,5x10m
Paint safe 4x4m
Plates
Tools
Tools
Welding workplace 360° Ø=10m 7x5m
2x5m
2x5m
WIP
WIP



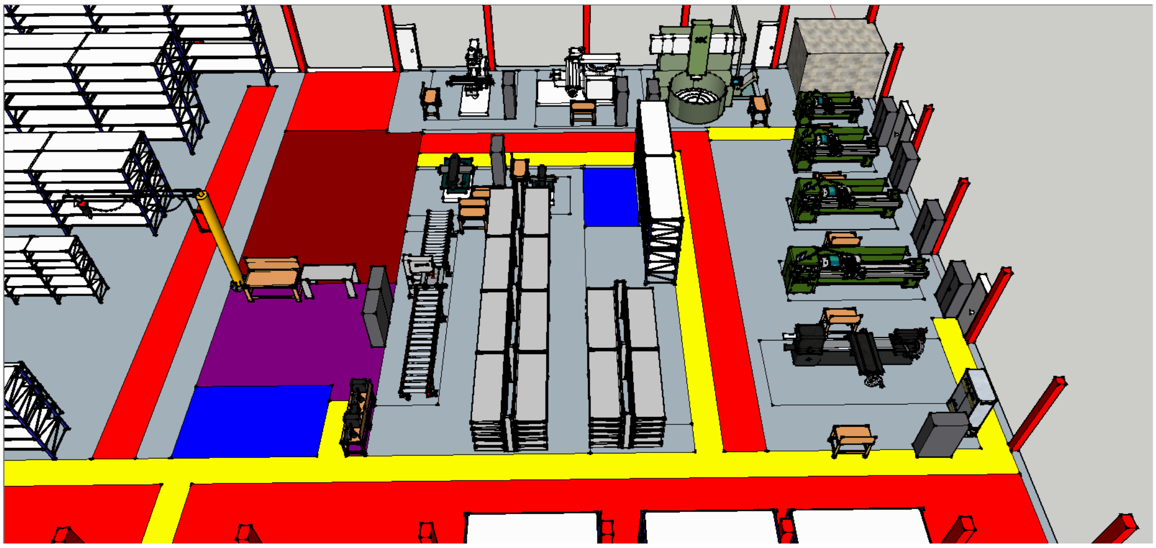
1A 1B 1C 1D 1E 1F 1G
2A 2B 2C 2D 2E 2F 2G
3A 3B 3C 3D 3E 3F 3G
4A 4B 4C 4D 4E 4F 4G
5A 5B 5C 5D 5E 5F 5G
75 A t/m G
Row 6
A t/m O: 7 high
Row 7
Row 8
A t/m J; 7 high
Row 9
Row 10
A t/m J; 7 high
Row 11
Row 12
A t/m L; 9 high
13A 13B 13C 13D 13E 13F 13G 13H 13I
Testing
Second-hand Macinery (revision)
Control
Work Bench
Cabinet
Flexible Workplace
WIP Control
Chen Ho
Pegard
Carousel
Toolshop
Pillar drill Stanco
Drill KSR-40
Saw
16A
Material Rack
Material Rack
Material Rack
Peter
DM-640
D-480
ZZM 800 RD
SU-100
(Screen)
10T Crane (1x)
Service
14A 14B 14C
Incoming
14D 14E 14F
Central forklift place
Plates
Drying Room
20E
20F
Paint shop
Paint safe
Finisched products
Final assembly
360°
Ø=10m
Pre-assembly
20A 20B 20C 20D
18A 18B 18C 18D
Tools
Welding workplace
18E 18F
Darley
Rest Plates
Rolling
Haco
Durma
40 T Cranes (2x)

Appendix 8: Detailed overview of the 3D model

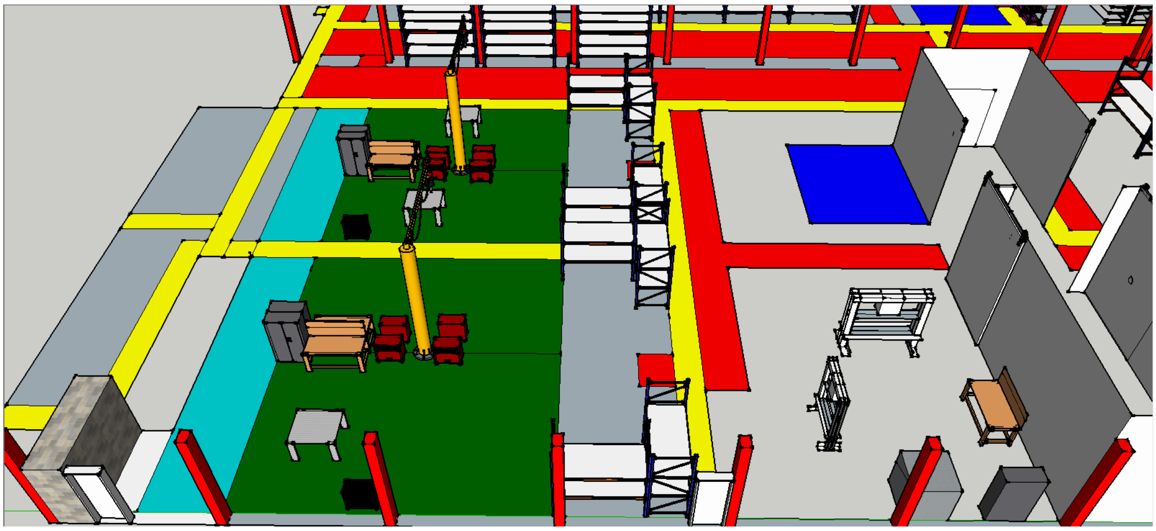
The warehouse



The machining department



The assembly department



The sheet metal department