UNIVERSITY OF TWENTE.

An integrated graph theoretic, manual and analytical hierarchy approach

Master Thesis Industrial Engineering & Management

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Preface

After months of hard work I am proud to present to you the end result: my report describing my research at Siemens into a new facility layout for the Hengelo site. This report is written to attain my master's degree in Industrial Engineering and Management at the University of Twente. It is my final project and therefore my years of studying at the University of Twente have come to an end. I really enjoyed my time as a student at the university and will never forget my experiences. The last period consisted out of a combination between executing my research project at Siemens, job hunting, and traveling to Peru and Indonesia. It has been a exciting and eventful time in which I learned much about myself and others.

This work could not have been realized without the help of many different people. First of all I thank Siemens Netherlands, location Hengelo, for giving me the opportunity to write my final thesis at and about their Hengelo site. I thank my colleagues at Siemens for their efforts to assist me, but also my friends and fellow students for their help. Special thanks to my colleagues Roeland van den Bos and Emil Pietersz, whom I asked for help and advice regularly and who always made time to speak to me and assist me. Also thanks for my friends and fellow (ex)students Freek, Jasper, Jan Willem, Marjon, and Wim for proof reading my thesis.

Above all, I thank my teachers from the university, Leo van der Wegen and Peter Schuur, for their guidance and feedback during my research, without which the quality of the end result would not have been the same. In addition, I thank my supervisors at Siemens Hengelo, Henk-Jan Klaver and Clemens Koster, who answered my many questions and checked my work for consistency with reality at Siemens Hengelo.

Last but not least I thank my parents, my brother and sister, my girlfriend and my brother-in-law for their support and encouragements during my whole study career.

Erik Meijer
2014, October

Management Summary

This report is the result of a research at Siemens to advice on a facility layout redesign of the Hengelo site. Siemens Hengelo requires a new facility layout as the physical availability in buildings changes due to a construction project of the municipality of Hengelo. Moreover, business developments at Siemens Hengelo require changes and additions to current activities. These have to be incorporated into the new layout design. This research is executed for both business units located on the Hengelo site, namely: Packaged Compression Trains (PCT) and Services Oil and Gas (SO).

The **main objective** of the research is: *"A new facility layout design at the Siemens Hengelo site for both PCT and SO which fits the requirements of both business units."* The primary solution requirement is the minimization of the total distance that goods have to travel. Additional solution requirements are: to make the best use of the available space, i.e., place activities at locations such that they make maximal use of available facilities, and to comply with Authorized Economic Operator (AEO) regulations; these rules allow direct shipment of goods across borders. The result of this research are recommendations for the layout of the Siemens Hengelo site for the preferred future (10 year horizon).

The **research question** answered in this research is: "*How can Siemens Hengelo redesign its facility layout to best fit their requirements?*"

We conclude that the so-called **layout alternative PCT2, as depicted in Figure A, best fits the requirements of both business units**. Our research and conclusion is based on the Systematic Layout Planning which consists out of three phases: analysis, search and selection.

In the **analysis phase** we identified and defined the product mix, activities required to build this product mix, the material flow intensity between these activities, the space requirements for these activities, and the available space at the Siemens Hengelo site.

The **search phase**, i.e., the construction of layout alternatives, is based on a two-step approach. First, the material flow is optimized in the unrestricted space, which results in a graph depicting the adjacency preference of activities (i.e., which activities should be located next to each other for a minimal travel distance for goods on site). The second step is a manual assignment of activities in the restricted space We started by assigning the PCT, SO or Logistical activities to building 50 and then adding other activities one by one based on the adjacency graph, space restrictions and space requirements. The result is nine layout alternatives for the Hengelo site.

Finally in the **selection phase**, we identified the most appropriate layout design for Siemens Hengelo. The selection is based on the following criteria and decision makers:

<u>Selection criteria:</u>
- Operational effectiveness
- Space Utilization
- Appearance
- Future readiness
- Investment costs
- Gut-feeling

<u>Decision makers:</u>
- Head Packaging & Testing
- Head Supply Chain Management SO
- Head Workshop SO
- Head Logistics
- Packaging & Testing Support

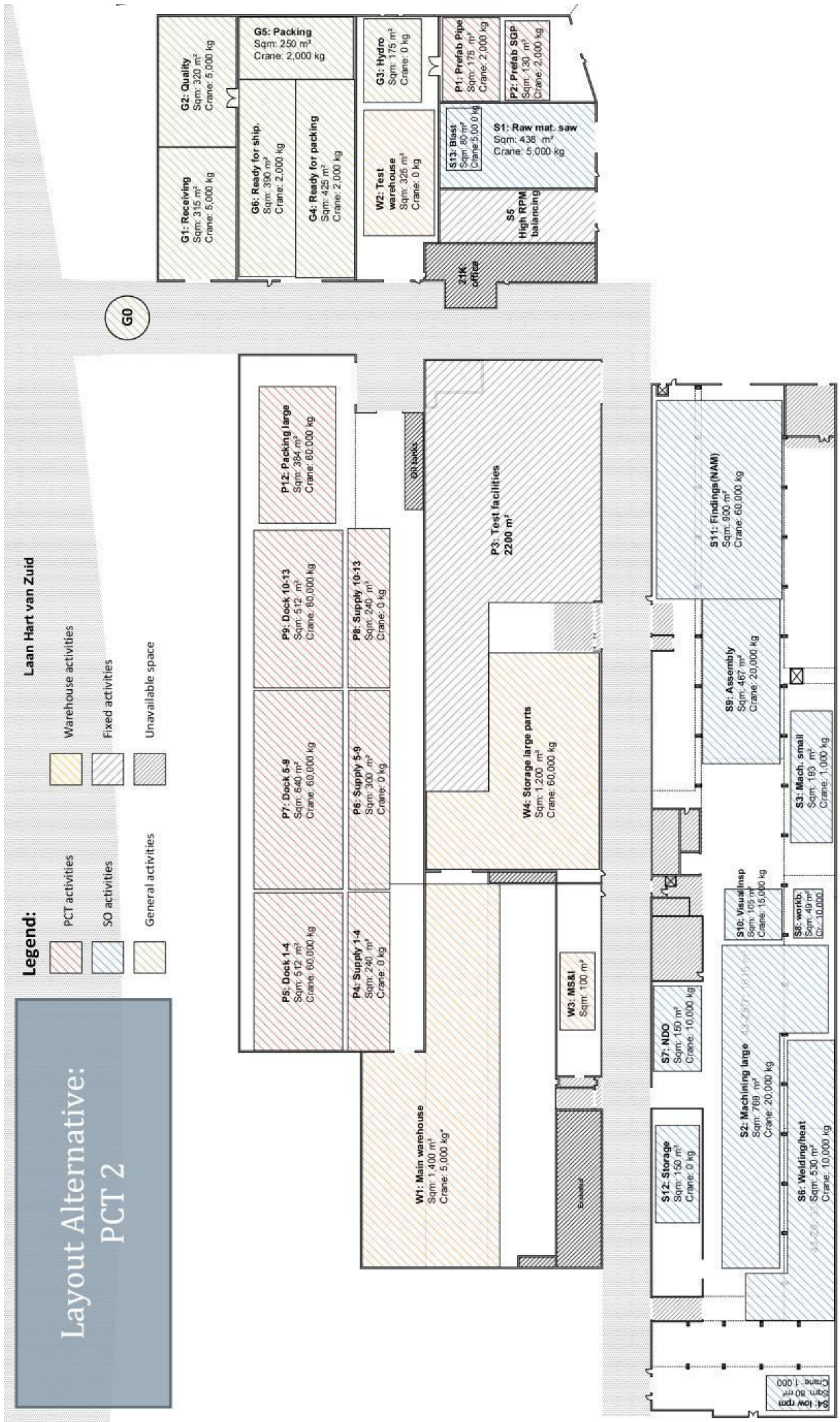

Figure A: most appropriate layout design for the Siemens Hengelo site

Using the expert assessment of the decision makers and several objective measurements, we ranked each layout alternative. This performance measurement was compared to the investment required to gain the measured output level, resulting in an efficiency level (output per euro invested) for each solution alternative. An identical approach was used for the subjective measurement gut-feeling (expert judgment of alternative performance) and the required investment costs. **The pro's and con's for PCT2** as layout design are:

+ PCT2 is the one of the most efficient options given the aggregated performance on the selection criteria per euro invested.
+ PCT2 scores the best based on the gut-feeling of the decision makers.
+ PCT2 is, among the better performing options, the cheapest option (€1,900,000*)
+ Logistical synergy is best realized in PCT2 compared to other PCT options
- PCT2 is not the best in ease of supervision, due to the split in SO activities
- The allocation of W4 (storage of large parts) to building 44 reduces the appearance for visitors
- The allocation of G4, G5 and G6 (shipping) to building 21C is a waste of crane capacity (63,000kg, while only 2,000kg is necessary).

PCT2 might not be representing the exact final alternative. We already made several minor improvement suggestions based on the con's. However, PCT2 contains several **design aspects which should be implemented**:

- PCT activities in building 50
- SO activities in building 43, including Findings(NAM)
- Logistics departments in building 21
- Main warehouse in building 45

Short term recommendations are to further develop and implement a cheaper (€600,000*) layout (similar to alternative LOG2) and the further development of PCT2 (e.g., the suggested improved version). On the **medium term** we recommend developing a detailed layout and the planning and step-wise implementation of PCT2 (or similar layout). **On the long term** implementation should be finalized.

The most important **additional recommendations** are:

- Centralize the logistics departments (i.e., merge logistics SO and PCT) including incoming goods and shipping to improve efficiency in processes and space used.
- Deliver large goods just-in-time to reduce space required for storage of large goods and reduce handling costs.
- Maximize the storage period for ready-for-shipment goods (e.g., maximum of two weeks when finished) to reduce space requirements on site for storage. If customers cause delays in shipment, then the additional costs can be allocated to them.
- Allocate the evaporation storage to incoming goods to reduce material handling.
- Apply the NAM activity also for the regular findings process to increase the utilization rate of space and equipment.
- Set-up standardized processes for prefabbed pipes movement on and off-site, from and to hydro testing, to reduce handling costs and decrease the risk of loss of materials.

**Estimated investment costs are based on an initial investment of €450,000 in building 50*

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1. INTRODUCTION

This report is written to attain my master's degree in Industrial Engineering and Management at the University of Twente. It is the result of a research at Siemens Hengelo to advice on a facility layout redesign of the Hengelo site. Siemens Hengelo requires a new facility layout as the physical availability in buildings changes. Moreover, business developments require changes and additions to current activities on site and these have to be incorporated into the layout design.

Muther (1961) stated: "*Plant layout work is both an art and a science*". This research applies the same vision on the problem. Complex decisions with a significant impact have to be taken with as much information, analysis and reflection as possible to decide on the best possible alternative. However, as plant layout work is also a design problem, creativity is required to attain the best possible layout. Therefore, we apply a combined approach between graph-theory, manual designing and the analytical hierarchy process to advice Siemens Hengelo on the facility layout problem and present them with viable layout alternatives.

The report is divided into seven chapters. Chapter 2 introduces Siemens Hengelo and their facility layout problem. It provides the scope of the research, the research questions and the deliverables.

In Chapter 3 and Chapter 4 we provide the reader with details on the Siemens Hengelo situation. We describe which products are produced, which activities are required to produce these products and how the materials flow between these activities. In addition, we provide the space requirements for the activities and the available space in which we redesign the Siemens Hengelo layout.

The field of research on the topic of facility layout planning is extensive. Therefore, we provide the reader with an overview of the field in Chapter 5. Chapter 6 merges several of these methods into our approach for layout alternative development and evaluation. We execute these methods in Chapter 7, which results in nine layout alternatives and their relative performance to each other.

Finally we conclude the research in Chapter 8. The conclusion includes the recommendations for Siemens Hengelo and describes what further research is required to continue with the further development and implementation of a new site layout.

2. RESEARCH BACKGROUND AND DESIGN

Chapter 2 introduces the research. Therefore, the chapter gives a short introduction to Siemens Hengelo in Section 2.1 and the description of the problem in Section 2.2, which clarifies the reasons for this research. In Section 2.3 we elaborate on our research design including the goal of the research, research questions and the final deliverables. We conclude this chapter with the solution approach and the report outline in Section 2.4.

2.1 COMPANY DESCRIPTION

We split the company description into two subsections. First we discuss Siemens Hengelo as a company (2.1.1) and then we go into more depth about what is built at Siemens Hengelo (2.1.2).

2.1.1 SIEMENS: GLOBAL, THE NETHERLANDS & HENGELO

Siemens calls itself 'a global powerhouse in electronics and electrical engineering' (Siemens, 2014). The company operates in the fields of industry, energy, healthcare and infrastructure & cities. Since the company started over 165 years ago it has grown to a company which employs over 360,000 employees in 190 countries.

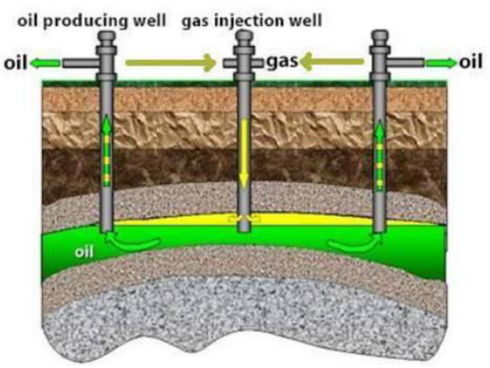
Siemens is operating in the Dutch market since 1879. Siemens Netherlands N.V. has a yearly turnover of €1.5 billion and a total of almost 3,000 employees, which makes it one of the largest organizations on the electronics and electrical engineering market in the Netherlands.

Since 2001 Siemens Hengelo is part of Siemens Netherlands N.V. and belongs to the energy branch of Siemens. With around 650 employees Siemens Hengelo engineers, assembles and tests oil compressor installations and gas turbines, as well as provides the corresponding maintenance services. Hence the site consists of two business units, namely Packaged Compression Trains (PCT) and Services Oil & Gas (SO) (Siemens, 2014).

2.1.2 APPLICATION OF SIEMENS COMPRESSORS AND GAS TURBINES

The Siemens Turbo Compressors (STCs) from Hengelo (as Siemens location Duisburg has also down- and mid-stream applications) are used to retrieve oil from onshore and offshore oil wells. An oil well always contains a mixture of oil and gas. Recovery of oil can be distinguished in three phases. Primary recovery is possible as long as the natural pressure of the well is high enough to push the oil to the surface. This allows 5 to 10% of the oil to be recovered. When the pressure drops below a certain level secondary recovery methods are necessary. Oil is a thick and heavy fluid so using suction power is insufficient to overcome the static pressure of the oil in the pipeline. One way of retrieving oil in secondary recovery is by using the gas to ease the retrieval of oil. Basically, the gas is pumped back into the well to keep a high pressure in the well (this method is called gas injection). The gas usually has no commercial value, because it is expensive to transport and application is limited. As long as there is a high pressure in the oil field, the oil comes out relatively easy. This is a self-sustaining system that only needs a start-up: by pressing gas into the well a mixture of oil and gas comes out, the gas is separated and pressed back in so this process repeats itself. We illustrate this process in Figure 2.1-left (Siemens, 2014; van der Velde, 2013). Two additional methods during the secondary recovery phase are the injection of water into the oil well and gas lift. An additional 25-30% of the oil can be recovered using secondary recovery. During the tertiary recovery phase all kinds of elaborate methods are used including the injection of different materials and/or chemicals.

The STCs can have three kinds of drivers. If there is sufficient excess gas the customer could use a Siemens Gas Turbine (SGT) to drive the compressor. In other cases the customer could use an electrical motor (e-motor) or a steam turbine (which is rare for up-stream applications) as a driver for the compressor. This combination of driver and compressor is called a Compression Train. Figure 2.1-right shows a SGT driven compression train with and without the noise reduction hood for the SGT. Besides the before mentioned application of the STC, these can also be used for other compression solutions such as the storage, transportation and the refining of oil and gas. The SGT can be used to drive other machinery next to a compressor, such as pumps or generators (Siemens, 2014).



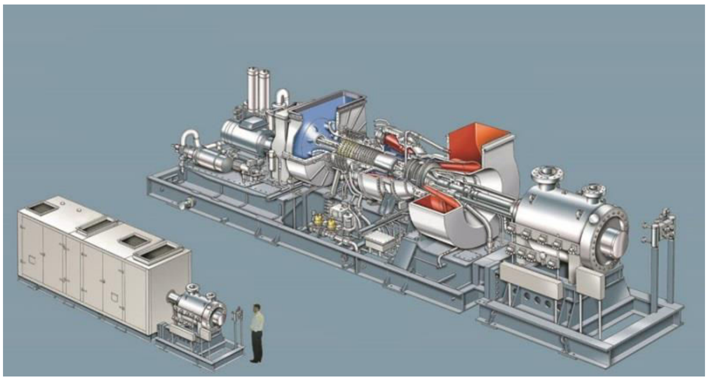


Figure 2.1: Gas injection well (left); A SGT driven Compression Train with and without enclosure for noise reduction (right)

2.2 Problem description

The current layout planning of the Hengelo facility is based on the logic of how a compressor package is assembled. However, the current situation has changed. SO is now a product oriented organization and is completely independent of PCT, while PCT on the other hand focuses on the assembly of complete installations, which includes the compressor and several driver options. Part of these driver options are multiple types of gas turbines. The assembly of gas turbines was added to the core business of Siemens Hengelo in 2009. Assembly of the gas turbines is based on a modular system. The advantages of a more standardized production process became clear, which caused a demand for similar changes in the assembly process of the compressors. Currently a more standardized assembly process is being developed for the compressors. One can say a shift is taking place from an engineering driven organization to an assembly method driven organization. Besides these changes at PCT, SO indicated they would like to expand their current activities as there is an increase in demand.

In addition, the municipality of Hengelo is executing the project "Hart van Zuid", which is to be finished in 2018. Part of this project is a new connection from the A35 to Hengelo Station in the city center of Hengelo. The new road will partly run across the Hengelo site, which requires the demolishment of several buildings on the Hengelo site. Next to Siemens, Stork is situated at the same site in Hengelo, but they are scheduled to move to a new location. Concluding, some of the current buildings will be no longer available, while also new options are created by the departure of Stork.

The changes in the business at Siemens Hengelo and the changes at the Hengelo site are the reasons for redesigning the current facility layout to fit the requirements of the new situation.

2.3 RESEARCH DESIGN

Section 2.3 provides an overview of the research design. First the objective of the research is stated in Section 2.3.1. Attaining the objective is limited by the scope of our research as defined in Section 2.3.2. Following the scope we define our research questions in Section 2.3.3 and our final deliverables in Section 2.3.4. In Section 2.3.5 we conclude with our solution approach and the corresponding layout of the report.

2.3.1 RESEARCH OBJECTIVE

This research is part of a larger project at Siemens Hengelo, namely project 'Hart van Zuid', which consist out of five sub-projects of which one is site optimization. Part of the site optimization is the optimization of the production and storage facilities. This subject is the focus of our research. In this research we also optimize the material flow for both business units (PCT and SO) on a general level at the Siemens Hengelo site by redesigning the facility layout. As such the objective of this research is:

> *A new facility layout design at the Siemens Hengelo site for both PCT and SO which fits the requirements of both business units.*

Optimization of material flow in this case is the minimization of the total material handling at the Hengelo site (see Figure 2.2 for an impression of the Siemens Hengelo Site). Material handling is defined as "the act of loading and unloading and moving goods within, e.g., a factory especially using mechanical devices" (TheFreeDictionary.com, 2014). In our research we primarily focus on the minimization of the total distance goods have to travel. Also the number of times goods are stored and picked up could be considered as Siemens wants to optimize material flow, but this is not considered in this research. Two additional solution requirements are:

- Make the best use of the available space, i.e., place activities at locations such that they make maximal use of available facilities.
- Comply with Authorized Economic Operator (AEO) regulations; these rules allow direct shipment of goods across borders.

Figure 2.2: Siemens Hengelo Site

2.3.2 *Research scope*

In this research we are dealing with a Brown Field optimization problem. Brown Field means that we are optimizing in existing facilities. The alternative of Brown Field is Green Field, where a completely new plant is constructed (Investopedia, 2014a). We are limited in optimization by the current constructions, meaning the existing exterior walls are the scope in our research.

The Hengelo Site consists out of several buildings with different applications. An overview of the entire Hengelo site is illustrated in Figure 2.3. One could distinguish four types of space: office, production, testing and storage space. These are all intertwined at the Hengelo site. The facilities relevant for our research are production and storage space, as testing facilities are too expensive to relocate and offices are excluded from our research. This limits our research scope.

Buildings indicated in red are outside of the research scope, as these are mainly offices which cannot be used for production and/or storage (buildings 1, 5, 21K, 24 and part of 45). The area indicated by light blue in building 44 are the compressor and string test facilities. The relocation of these facilities is infeasible due to the infrastructural requirements and the associated large amount of investments necessary. Based on the same reason we exclude building 21G in which the high rpm rotor balancing facilities are located. Finally we exclude storage facilities not located in buildings and the storage of goods on the so called lofts of building 43.The layout illustrated in Figure 2.3 also shows the new developments due to the project “Hart van Zuid”. The part of the new road that forms the new connection between the A35 and the city center of Hengelo, is shown on the map in blue. It is visible that part of the road runs through existing buildings (building 20 and part of building 21) in use by Siemens which will be demolished. These buildings are marked by red diagonal stripes.

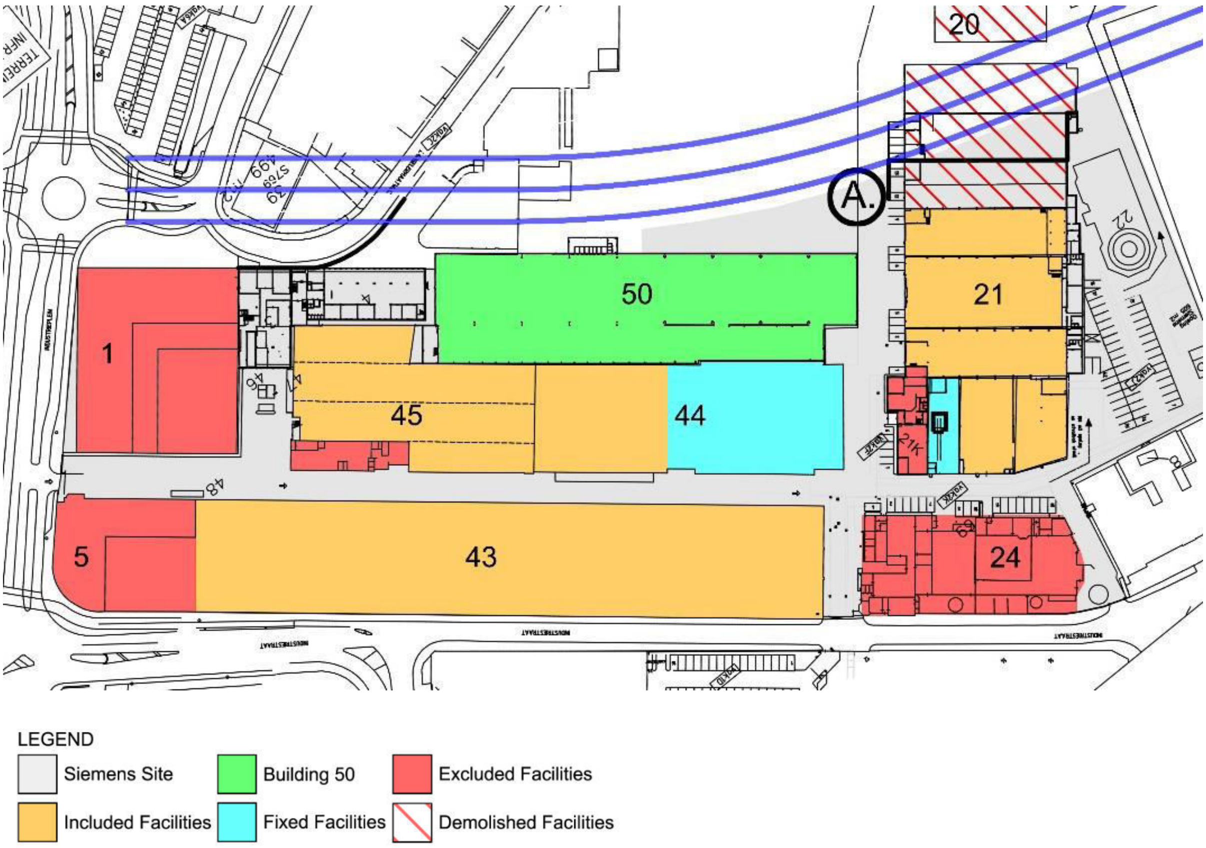


Figure 2.3: Hengelo site layout

Building 50 (indicated by green) is currently in use by Stork. As stated earlier Stork is relocating to a new factory and Siemens Hengelo will acquire the building. Building 50 requires a significant amount of work to make it usable, especially if one wants to use the building for production. Therefore, we distinguish two possibilities: the first in which we limit the usage of the building to non-production activities and the second in which building 50 will be also suitable for production activities.

Besides the above mentioned limitation in building relocations we have several other aspects that limit our research scope. These are:

- The availability of existing crane rails and included cranes with their maximum lifting capacity, which limits the choice of allocation of certain facilities.
- The main entry and exit point to the Siemens Hengelo site will be located at the location marked with A (see Figure 2.3), which limits the starting point of the material flow to one fixed location.

Siemens Hengelo indicated that out of the box ideas which violate a restriction such as the maximum lifting capacity of a crane or an interior wall are allowed. The impact of such violations can be translated to additional investment costs.

The development of layout alternatives should be fit for four demand scenarios. The four different combinations of a consolidation or growth scenario for both PCT and SO.

Summarizing we get the scenarios and research scope displayed in Table 2.1 (the abbreviation Cons. is for consolidation). Green checks indicate applicable to the scenario, red marks mean not applicable to the scenario and orange markers indicate applicability is not as easy as yes or no.

Table 2.1: Research scenarios

Factors:	**Cons. PCT Cons. SO**	**Cons. PCT Growth SO**	**Growth PCT Cons. SO**	**Growth PCT Growth SO**
1. Limited use building 50	⊖	✗	✗	✗
2. Expansion in m2 SO	✗	✓	✗	✓
3. Expansion in m2 PCT	✗	✗	✓	✓
4. Fixed cranes	⊖	⊖	⊖	⊖
5. Main entrance at A	✓	✓	✓	✓
6. Test facilities fixed	✓	✓	✓	✓
7. High rpm balancing fixed	✓	✓	✓	✓
8. Include outside storage	✓	✓	✓	✓
9. Include loft building 43	✓	✓	✓	✓

2.3.3 *RESEARCH QUESTIONS*

The research objective can be translated into our main research question:

How can Siemens Hengelo redesign its facility layout to best fit their requirements?

Facility layout design can be compared to solving a complex jigsaw puzzle. Before solving the puzzle we need to know the dimensions in which we puzzle, decide on our puzzle strategy and know when the puzzle is solved correctly. In case of a jigsaw puzzle the latter gives usually only one option, however in the case of facility layout design more than one possible answer exists. This means we should add an additional step at the end where we decide which solution alternative is the best. We transcribe the steps for solving a jigsaw puzzle to a set of four research questions:

1. *What is the current situation at the Siemens Hengelo site, i.e., what are the dimensions of our situation?*

2. *Which scientific methods can we apply to solve the facility layout problem for Siemens Hengelo?*

3. *What are appropriate layout designs for PCT and SO in each building using the theoretical methodology?*

4. *What are the pros and cons of each layout alternative and which alternative is the most appropriate for Siemens Hengelo?*

The answers to these research question leads to an answer to the main research question. How we are going to answer these research questions is discussed in Section 2.4.

2.3.4 Deliverables

The final deliverable to this research as defined by Siemens Hengelo is this report, which includes:

- Visualization of the existing flow between activities
- Recommended alternative layouts for the Siemens Hengelo site including visualization on existing floor plans
- List of assumptions on which the results are based
- Further recommendations on how to improve current processes

2.3.5 Systematic Layout Planning

To aid our solution approach we use the Systematic Layout Planning (SLP) procedure developed by Muther (1961) as framework for our research. SLP presents a simple but proven step-by-step approach for solving facility layout problems. Plant layout, according to Muther, consists out of four phases:

1. Determining the location of the area where facilities will be laid out
2. Establishing general overall layout
3. Establishing detailed layout plans
4. Installing the selected layout

The second and third phase are most important for the facility layout planner (Heragu, 1997). For these two phases a detailed procedure was developed by Muther as shown in Figure 2.4. Tompkins (2010) split Muther's approach into three stages: analysis, search and selection.

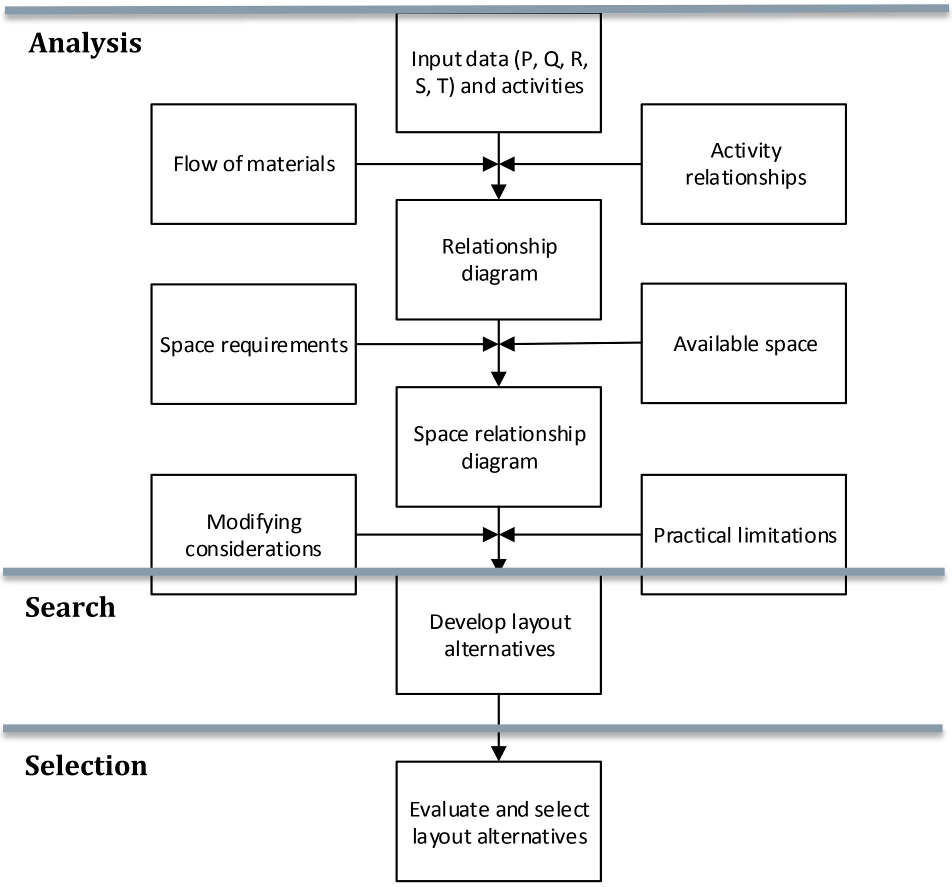


Figure 2.4: Systematic Layout Planning procedure (Muther, 1961)

The analysis stage starts with a PQRST analysis:

- Product: which products does the facility handle?
- Quantity: how much of these products does the facility handle?
- Routing: what series of steps does each product go through?
- Supporting services: which supporting activities do the processes require?
- Time: when and how long do processes have to be executed?

Using this input, the activity relationships and the flow of materials, the planner can construct a relationship diagram. The relationship diagram can best be represented by a node and arc structure in which arcs represent the relation between activities, nodes represent activities and arc-thickness represents the size of the relation between activities.

The next steps, “space requirements” and “available space”, determine respectively the floor space to be allocated to each department and the space to which each department can be allocated. Adding this data to the relationship diagram the planner can construct a space relationship diagram, completing the analysis stage.

The search stage consists out of the development of layout alternatives, while taking into consideration additional design constraints and practical limitations.

In the final step, the selection stage, alternatives are evaluated and the most fitting alternative is selected. The exact methods for the search and selection stage are chosen during the research.

2.4 Solution approach & report outline

We can use Muther's approach to answer our research questions. Of the four phases the first is completed, as we already determined the location of the area where facilities will be laid out (see Section 2.3.2). In the rest of our research we focus on the second phase: establishing general overall layout. As such we can use the SLP procedure. The division in stages by Tompkins looks similar to our division in research questions and as such we discuss our approach and report layout per stage, i.e., analysis, search and selection stage discussed in Sections 2.4.1, 2.4.2 and 0 respectively. We conclude this section with an overview of the report outline in Section 2.4.4.

2.4.1 Analysis stage

Completing the analysis stage of the SLP procedure provides an answer to our first research question. We split the analysis stage into two chapters. In **Chapter 3** we discuss the input data (PQRST), the activities and their relations. We answer the following three questions (which partly answers our first research question):

1.1 What products and in which quantities need to be produced at Siemens Hengelo?
1.2 What activities and supporting services are required to facilitate the production?
1.3 What is the relationship between these activities?

Included in this chapter are several improvements to the current situation, which we incorporate in our final solution. We conclude this chapter with a relationship diagram. In **Chapter 4** we elaborate further on the space requirements and available space, thus provide an answer to the following two questions (which partly answers our first research question):

1.4 What space requirements do these activities have?
1.5 What is the available space to which we can (re)locate these activities?

Using the information from Chapter 3 we can project the space relationship diagram on the current facilities. The information gathered from the above five questions results in an answer to our first research question ("*What is the current situation at the Siemens Hengelo site, i.e., what are the dimensions of our situation?"*).

2.4.2 Search stage

During the search stage we develop layout alternatives based on scientific methodologies. So we first need to answer the second research question ("*Which scientific methods can we apply to solve the facility layout problem for Siemens Hengelo?"*). **Chapter 5** contains our literature research on the facility layout problem and available methods to develop solutions. Using one or several of these methods we continue in **Chapter 6** with the formulation of our solution approach. The conclusion to Chapter 6 gives an answer to our second research question. Next, in **Chapter 7,** the development of appropriate layout alternatives for Siemens Hengelo is discussed and we answer our third research question ("*What are appropriate layout designs for PCT and SO in each building using the theoretical methodology?"*).

2.4.3 SELECTION STAGE

Our fourth research question ("*What are the pros and cons of each layout alternative and which alternative is the most appropriate for Siemens Hengelo?*") requires a selection of the most appropriate layouts for Siemens Hengelo based on pro's and con's, which is similar to the final selection stage of SLP. We discuss the selection stage in **Chapter 7**. Final evaluation and selection is done at the end of Chapter **7**. The final selection is the answer to the fourth and final research question.

2.4.4 REPORT OUTLINE

Figure 2.5 provides an overview of the above information. The first column shows the research questions of our research. We linked these questions with the three stages of SLP and the chapters of this report in which these questions and stages are discussed. We want to note that we have divided research question 1 into five sub-questions based on the five questions in the analysis stage of SLP. In the next chapter we elaborate on the first three of these five sub-questions.

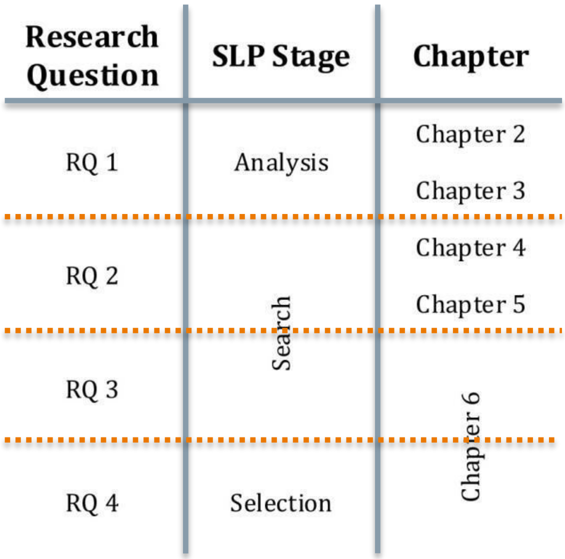


Figure 2.5: Report layout