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**MASTER'S THESIS**

# Redesign of the layout of AEM's production area at Mainfreight

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# Management summary

Mainfreight is a third-party logistics service provider with a global network for customer specific and preferably integrated warehousing, transport and distribution solutions. Mainfreight offers different kinds of services: transport, European Express Distribution, logistics, air freight services and ocean freight services. Within the logistics services, AEM is one of the customers. Mainfreight takes care of the assembly of agricultural machines to customer specific products in the production area for AEM. We define the vehicles of AEM, which are moved in the production area, as "machines" in this research. All kinds of AEM models are assembled to customer specific products. Due to the increased demand of machines in the production area the last couple of years and more different customer specific options, AEM machines move often between workstations across the production area. Mainfreight believes that due to these movements the production area is not efficient anymore. Next to this, all these movements of machines can cause some serious safety issues which have to be avoided. Furthermore, the performance of the production area is currently only measured by calculating the output every day. Since the layout has a large impact on the efficiency of the production area we design the following research objective to solve this problem:

*How can Mainfreight improve the efficiency of the production area by reducing the total distance driven with agricultural machines such that also a safe environment is created?*

We perform this research only for the agricultural machines in the production area. Currently, the layout is divided into different departments. The machines move through the production area to the desired departments with their workstations. To answer our research objective, we review literature on the improvement of a facility layout and methods to redesign the layout.

After the analysis of the current situation, we conclude that there are five bottlenecks which influence the efficiency of the production area related to the distance. The five bottlenecks are: an inefficient inbound process, poor communication between departments, machines are moved across the same path multiple times, machines are picked up by engineers instead of logistics employees, and searching for the correct machine takes much time. Based upon data of AEM, the demand forecast for the next coming years shows growth. This means that the capacity of the production area is not sufficient anymore to handle this growth, since the current data shows the maximum capacity is reached.

We use Key Performance Indicators to analyze the data of the current situation. We measure the performance based on the production schedule and the actual output. This shows that the production schedule is not accurate: 49% of the time the production schedule is overestimated. It means that the schedule estimated a higher output than the actual production. Another Key Performance Indicator is the distance driven with the machines. We observe the movements of the machines in the production area and draw these movements in the layout to show the flow of machines. Currently 43 km per day is driven with all the machines, inside and outside the production area. The distance outside the production area is taken into account because the storage of machines is outside the facility. If we convert these distances to time, all the machines together are moved 5.9 hours per day. We can conclude that this is inefficient and might cause some safety issues, which have to be avoided.

The improvement of the total driven distance is important to fulfill the future needs and growth of AEM. We use the Systematic Layout Planning of Muther to design the new layout (1961). The relationships between the different departments are determined and filled in a chart. The next step is to determine the required area (in square meters) for each department. Once this data is known, we draw the relationship diagram with arrows between the departments. There are some departments which are at a fixed location and cannot be moved elsewhere. This is considered while designing the new layout. Figure S.1 shows the current and new layout of the production area.

The current layout is the basis for creating the new layout. Based upon discussions with employees of the production area, we rearrange the departments. We create three different alternatives for the current situation which improve the total distance driven with the machines. We use weighted ratings for evaluating the layouts. Based upon this, the new best alternative layout for the production area is shown in the top of Figure S.1.

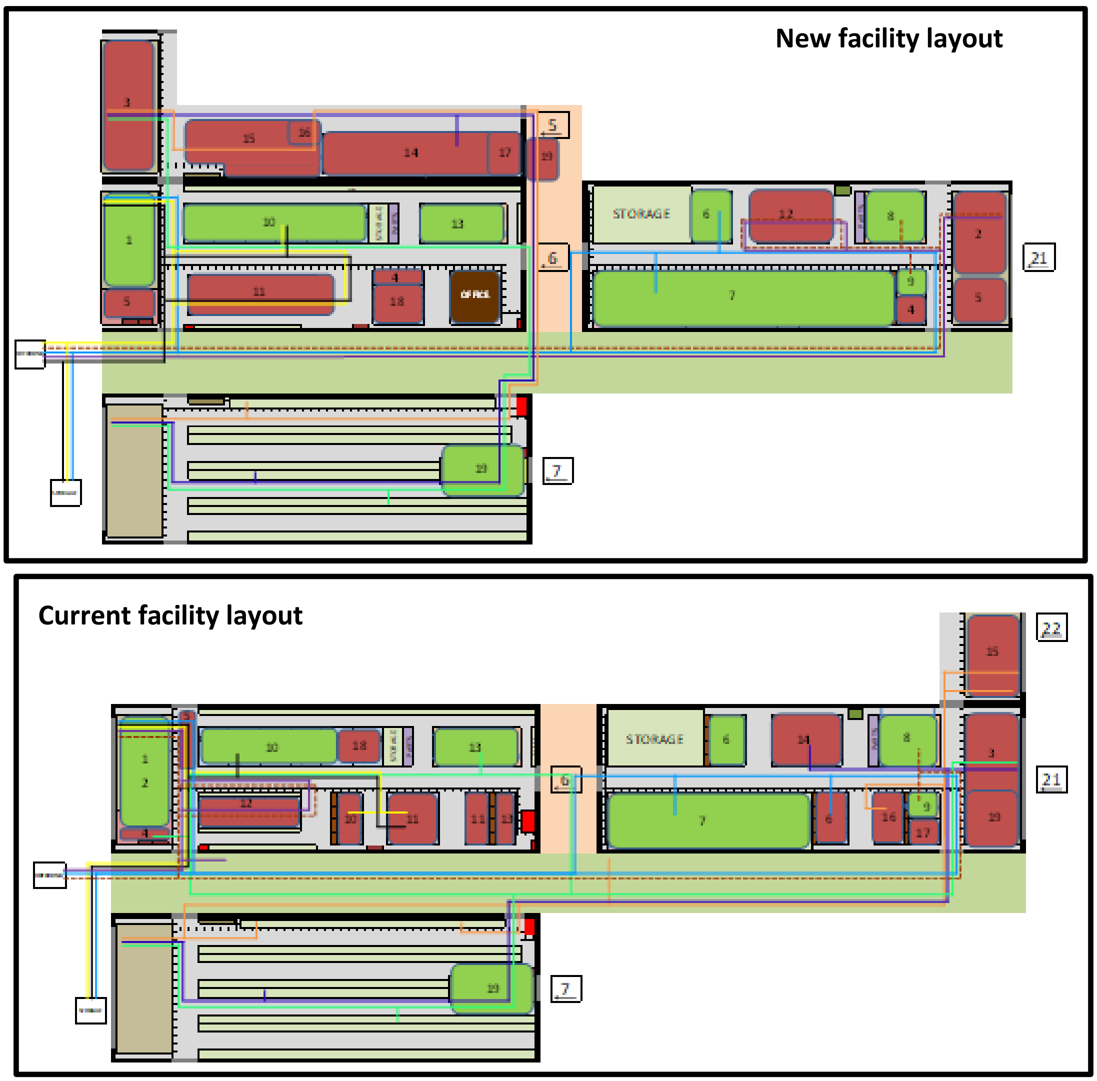


Figure S.1 New (above) and current (below) layout of AEM's production area at Mainfreight with definitions in the table

**Table S.1 Legend of production area layout**

| |
|---|
| ***CONFIDENTIAL*** |

The difference between the current and improved layout are the departments highlighted in red, the departments highlighted green have not changed. The most important change are the departments 1 and 2. These departments are now divided over two separate areas. This makes it possible to reduce the distance driven with these machines, since these machines do not have to drive in both halls anymore. Department 12 has moved closer to the inbound area of the machines, to reduce the distance driven with these machines further. Another change in the layout is the movement of department 14 and 15. Department 14 is moved to the left upper hall to reduce the use of the pathway where these machines are moved. Department 15 has moved and increased in size due to the fact more machines of this type needs to be assembled. Department has 19 moved closer to department 14. With this change employees have to drive less distance with the machines. Department 11 has moved to left to be able to create a smoother flow for the machines. Two other departments that are moved are 4 and 18, these department are more centrally located in the improved layout.

The implementation of layout alternative C can be spread over several weeks. A roadmap is therefore given in table S.2.

**Table S.2 Roadmap implementation improved layout**

<table>
<tr><th>Priority</th><th>Action</th><th>Actor</th><th>Time</th></tr>
<tr><td>1</td><td rowspan="13">CONFIDENTIAL</td><td>Manufacturer of the equipment</td><td>5 weeks</td></tr>
<tr><td>2</td><td>Manufacturer of the equipment / Employees production area</td><td>2 weeks</td></tr>
<tr><td>3</td><td>Employees production area</td><td rowspan="2">1 week</td></tr>
<tr><td>4</td><td>Employees production area</td></tr>
<tr><td>5</td><td>Employees production area</td><td>2 weeks</td></tr>
<tr><td>6</td><td>Manufacturer of the equipment</td><td>4 weeks</td></tr>
<tr><td>7</td><td>Employees production area</td><td>2 weeks</td></tr>
<tr><td>8</td><td>Employees production area</td><td>1 week</td></tr>
<tr><td>9</td><td>Employees production area</td><td>1 week</td></tr>
<tr><td>10</td><td>Manufacturer of the equipment</td><td>2 weeks</td></tr>
<tr><td>11</td><td>Employees production area</td><td>3 weeks</td></tr>
<tr><td>12</td><td>Employees production area</td><td>1 week</td></tr>
<tr><td>13</td><td>Employees production area</td><td>1 week</td></tr>
</table>

Moving departments to new location can be done simultaneously, therefore the sum of the weeks is not the total time needed to have the new layout ready. Based upon discussions with the supervisor of the production area the estimation is that a total of 11 weeks is needed to complete the movement of departments to their new location and the installation of new equipment by the manufacturers.

With the new layout the total distance inside the production area reduces with 18.9% from 11 km to 8.9 km per day for all the machines. The total distance, driven with machines inside and outside the production area, reduces from 43.6 km to 37.2 km per day. This is an improvement of 14.6%. Departments need to be rearranged according to the proposed layout. Recommendations for Mainfreight to improve the efficiency further are improving the communication between departments, let logistics employees move the machines from storage to the production area instead of engineers, and assign storage locations to the storage outside to reduce searching time.

# Preface

This master thesis is written as part of my graduation project, which I performed at Mainfreight in 's-Heerenberg, to finish my master Industrial Engineering and Management. I am very grateful to Mainfreight for giving me this opportunity.

First, I thank Joop Reitsma and Ilse Steverink for their supervision during my time at Mainfreight. Our three-weekly meetings helped me to move forward and provided me with new insights for the project.

Secondly, I would like to thank all the team members of the production area for their help in making me familiar with the processes and their co-operation. In particular I like to mention Marcel Bax, Chris van der Veen, Tom Steverink and Erwin Smitjes. Their roles as supervisor and groupleaders helped me to make the project applicable to a practical situation.

Furthermore, I want to thank Peter Schuur and Wieteke de Kogel – Polak of the University of Twente. Their guidance and feedback really improved the quality of this thesis. I learned a lot from their guidance during the discussions and feedback sessions we had.

I also might not forget to thank Monique Damveld, during my master's we executed every project together to a successful end. Even during this research, we shared our thoughts about the content of our research projects.

Bart Demkes
*March, 2019*

# Glossary

| Abbreviation | Definition | Introduced on page |
|---|---|---|
| AEM | Agricultural Equipment Manufacturer | 1 |
| CRAFT | Computerized Relative Allocation of Facilities Technique | 19 |
| FLP | Facility Layout Problem | 7 |
| IST-situation | Current situation | 2 |
| JIT | Just in Time | 7 |
| KPIs | Key Performance Indicators | 2 |
| MAD | Mean Absolute Deviation | 37 |
| MAPE | Mean Absolute Percentage Error | 37 |
| MARC | Software system used for production and storage | 2 |
| MHC | Material Handling Costs | 10 |
| MSE | Mean Squared Error | 37 |
| MULTIPLE | MULTI-floor Plant Layout Evaluation | 19 |
| QAP | Quadratic Assignment Problems | 18 |
| SFC | Space filling curves | 19 |
| SHA | Systematic Handling Analysis | 9 |
| SLP | Systematic Layout Planning | 13 |
| SOLL-situation | Desired situation | 3 |

# Contents

# 1. Introduction and problem formulation

In the framework of completing my master's study Industrial Engineering and Management (specialization: production and logistics management), I performed research at Mainfreight in 's-Heerenberg to improve the efficiency of the production area.

In this chapter the company is introduced in section 1.1. Section 1.2 briefly describes the research motivation. In section 1.3 the problem description is given. Then, in section 1.4 the research questions are described. In section 1.5 the methodology of the research is explained. Section 1.6 describes the scope of the research and at last, in section 1.7 the deliverables of this research are given.

## 1.1 The company

Mainfreight, based in 's-Heerenberg, the Netherlands, is a third-party logistics service provider with a global network for customer specific and preferably integrated warehousing, transport and distribution solutions. Mainfreight offers different kind of services: transport, European Express Distribution, Logistics, air freight services and ocean freight services. Mainfreight 's-Heerenberg is part of Mainfreight Europe. Together with employees all around the globe, Mainfreight Europe forms Mainfreight. Mainfreight began its operations in New Zealand in 1978. In 2011, Mainfreight acquired the Wim Bosman Group which was located in 's-Heerenberg. By taking over Wim Bosman, Mainfreight became a worldwide logistics provider with facilities in Australia, New Zealand, China, United States of America and Europe. All facilities together have around 7.500 employees, divided over 22 countries around the world.

## 1.2 Research motivation

Mainfreight Europe has three different business units; logistics services, air & ocean and forwarding & transport. One of the customers of the business unit logistics services is an AEM. AEM is an corporation that manufactures agricultural, construction, and forestry machinery, used in lawn care equipment. The partnership intensified more due to the startup of an production area. The production area started by mounting cabins on agricultural machines, executed by two employees working on approximately 50 square meters. The number of different machine types has significantly increased the last couple of years. Due to this the initial layout has changed over the years after evaluating the demand growth on a yearly basis. The area in use for the production area is around 5.500 square meters, divided over two halls. All kinds of models are assembled to customer specific products. Due to the increase of the number of machines in the production area, agricultural machines move often between workstations across the production area. Mainfreight believes that due to these movements the production area is not efficient anymore. The machines that are processed within the production area are shown in Appendix A.

## 1.3 Problem description

Section 1.2 states that Mainfreight increased the number of different machines they can assemble. They are planning to grow further in the production area the next few years. To be able to do this, operational and logistic processes must be optimized. An example of a process where Mainfreight has the feeling that they do not have enough insight in is the movement of the machines through the different workstations in the production area. Since there are different types of machines the route within the production area differs strongly between these machines. For each type of machine, the optimal layout is likely to be different. The layout has a large impact on the efficiency of the production area. Especially when a machine has damage or other functional problems after the inbound, it is not clear what to do with the machine. If there is space at a workstation an engineer could solve the problem immediately, but there is lack of communication between these departments. Due to the fact of this, machines are moved often within the production area which might not be optimal. All these movements of machines can cause some serious safety issues which have to be avoided.

Assembling the machines is a very time (and hence money) consuming task, caused by the fact that machine configurations are customer specific. Next to this, there is no empirical evidence for the performance of the current production area.

The main objective can be described as:

**How can Mainfreight improve the efficiency of the production area by reducing the total distance driven with agricultural machines such that also a safe environment is created?**

## 1.4 Research questions

In this section the research questions are described. As described in section 1.3 the problem is the fact that the current efficiency of the production area is not optimal. To give answer to the central research question the sub questions stated below will give support.

### IST-questions

1. **What are the characteristics of the facility layout of the production area?**
    - 1.1. What does the process flow look like?
    - 1.2. What relations can we find between the different departments?
    - 1.3. What Key Performance Indicators are currently in place?

To be able to compare the current and improved performance of the production area it is important to know the current layout of the production area, the characteristics of the production area are described in chapter 3. Relations between departments give insight in how departments are connected and how they share information with each other, information that is required to understand the information flow. The Key Performance Indicators (KPIs) currently in place are variables that are measured by Mainfreight, for example throughput time, number of machines produced each day, etc. This data is used as input for the research. The first research question will give the current situation of the production area, the IST-situation.

### Bottleneck-questions

**2. What is the performance of the current layout of the production area (measured by KPIs)?**

2.1. How efficient is the current layout?

The current performance of the production area is measured with the KPIs that are already in place and will be extended with extra KPIs if needed. The performance is related to the output of the production area, efficiency tends to measure results against resources. The second research question will show the bottlenecks in the current process.

### SOLL-questions

**3. How can the facility layout be improved?**

3.1. What is currently known in literature about routing in a facility layout?
3.2. What improvement options are available?
3.3. What are the pros and cons of these improvement options?
3.4. Which improvement method do we choose?
3.5. What does the improved flow of the machines look like?

We need to know how to design an improved layout for the production area, therefore we take a look at methods available in literature that are applicable in our situation. Next, we explain the new layout for the production area which is designed based on the proposed method. The third research question will show the improved layout, the SOLL-situation we want to reach at the end of the research to improve the efficiency.

## 1.5 Methodology

To guide the research, suitable methods need to be examined. In this section the methods that are used to answer each research question are shown. An overview is given in Table 1.1.

**Table 1.1 Data collection method per research question**

| Research question | Data collection method |
|---|---|
| **1. What are the characteristics of the facility layout of the production area?** | Observation |
| 1.1 What does the process flow look like? | Observation / Interviews |
| 1.2 What relations can we find between the different departments? | Observation |
| 1.3 What KPIs are currently in place? | Interviews |
| | |
| **2. What is the performance of the current layout of the production area (measured by KPIs)?** | Observation / Calculations |
| 2.1 How efficient is the current layout? | Observation / Calculations |
| | |
| **3. How can the facility layout be improved?** | Interviews / Literature |
| 3.1 What is currently known in literature about routing in a facility layout? | Literature |
| 3.2 What improvement options are available? | Literature |
| 3.3 What are the pros and cons of these improvement options? | Literature |
| 3.4 Which improvement method do we choose? | Literature |
| 3.5 What does the improved flow of the machines look like? | Tool with improved layout |

## 1.6 Scope of research

The boundaries of the research are described in this section. The improvement of the flow of machines of AEM focuses only on the production area. The flow of parts to the workstations require an additional research since these parts use different kind of transportation. They are not moved by themselves like the machines, but they require a type of transportation such as a forklift to move them. Parts that needs to be assembled to machine are stored inside or closely to the workstation, so if we move workstations the parts will be moved to the same new location. Storing parts outside or to a central stock location is part of another research and currently investigated by the group leaders of the production area and therefore left out of consideration.

To improve the current layout, we use the available data and configuration of the production area. We use improvement methods to change the layout of the production area. The research is focused on the movements of the machines as mentioned before, this includes the traveled distance between workstations, the total distance driven with machines and the time employees are driving the machines.

A first exploration of the current layout does not give a strong indication which departments or machines of the production area are most suitable for tuning. However, our intuition says that changing the sequence of the workstations in the layout has the most influence of improving the efficiency. Since we do not have clear empirical evidence for this thought, we will not choose for this approach now. At the end of the literature review we come back to this question.

## 1.7 Activities and deliverables

This research focuses on providing insights in the current performance of the production area. This is done by means of the following:

### Activities

1. Getting to know the production area;
2. Carrying out the literature study;
3. Analyze current layout and movements;
   - Measure number of machine moves inside production area.
   - Measure distance between workstations.
   - Measure distance traveled with machine.
   - Measure time employee is driving a machine.
4. Developing new facility layout, based on a method found in the literature;
5. Testing new layout;
6. Compare efficiency of current layout with new developed layout;
7. Drawing conclusions from the results.

### Deliverables

The deliverables of this research are:

1. Report;
2. Insights in the current production area layout and flow of machines through the production area;
3. Insights in the movements of the machines and the bottlenecks in the process;
   - For example, traveled distance and time the machines are moved by employees
4. Recommendations about the layout and routing that follow from our analysis;
5. Excel tool with the new improved layout.

# 2. Facility layout: relevant literature

This chapter gives an overview of the literature about the material flow problem and the facility layout problems. In section 2.1 we start with the definition of facilities planning. Next, in section 2.2 the facilities design problem is explained. In section 2.3, the material flow problem is explained. Section 2.4 addresses techniques and algorithms that are used in the field of improving the efficiency of a facility layout with a new design. Section 2.5 describes the evaluation criteria. Next, in section 2.6 a comparison is made between the layout improvement options. In section 2.7 the selected method is explained. The last section, 2.8, gives the conclusion of this chapter.

## 2.1 Facilities planning definition

The facility layout problem (FLP) is a popular topic that has been studied for more than 50 years. The subject is very wide-ranging and according to Tompkins (1996), still one of the most used subjects for publications and research.

*"Facilities planning determines how an activity's tangible fixed assets best support achieving the activity's objectives."*

Tompkins, White, Bozer, Tanchoco, & Trevino (1996) divides the facility layout problem, or facilities planning, into two different fields: facilities design and facilities location. Next, facilities design is divided into three sub components: the design, material handling and layout. These subjects are explained in the section 2.2, 2.3 and 2.4. The facilities location is left out of consideration, since this part focuses on the location of the facility. For example, the number of new facilities have to be located. In our research the location of the facility is fixed.

There are many reasons for a change in the layout (Tompkins, White, Bozer, Tanchoco, & Trevino, 1996):

- Changes in legal requirements;
- Changes of processes or equipment;
- Changes in demand → capacity problem;
- Changes in product design;
- Changes in organization (e.g. JIT);
- Introduction of new products;
- Safety hazards or increase in the amount of accidents reported;
- Too long transfer times.

As a consequence, the design and layout of a facility have a major impact on aspects such as operating costs, material handling costs, maintenance, employee morale and productivity according to Tompkins et al. (1996).

## 2.2. Facilities design problem

The facilities design problem can be divided into three interrelated tasks (Chhajed, Montreuil, & Lowe, 1992; Herrmann, Ioannou, Minis, Nagi, & Proth, 1995):

1. The layout problem – placing the resources such as machines within the available area;
2. The input/output department location;
3. Determination of the network system to support material flow interaction between facilities.

To solve the facility layout problem, one has to find the most efficient arrangement of departments and workstations within the available floor area. The layout problem differs depending on factors as the shape of facilities, material handling systems, the objectives, the constraints and the approaches used to solve them.

The output of the facility problem is a block layout, which specifies the relative location of each department. Once this is known one can analyze the situation more specified to obtain the detailed layout. In this layout all the departments, and machines, path constructions, input/output locations within departments are located (Meller & Gau, 1996).

## 2.3. Material flow problem

One of the important criteria while designing a manufacturing facility is to determine the flow pattern through the system for materials, parts and the work-in-process inventory (Drira, Pierreval, & Hajri-Gabou, 2007). The flow pattern is defined as the pattern in which the materials flow from beginning to the end, while it is transformed from raw material to finished product.

The definition of materials handling is "the art and science of moving, storing, protecting and controlling material" (Tompkins, White, Bozer, Tanchoco, & Trevino, 1996).

The material flow between departments within a manufacturing facility is often used to determine the overall flow in a facility. There are several types of flow patterns, we consider the four general types shown in Figure 2.1. The meaning of the letters is as follow, a): straight-line flow, b): U-shaped flow, c): S-shaped flow, d): W-shaped flow. While determining the material flow between departments it is important where the entrance and exit are located in the facility. The location of the entrance, often used as the receiving department, and the location of the exit, often used as the shipping department, is usually fixed within the facility. The flow of materials within the facility is confirmed to these restrictions.

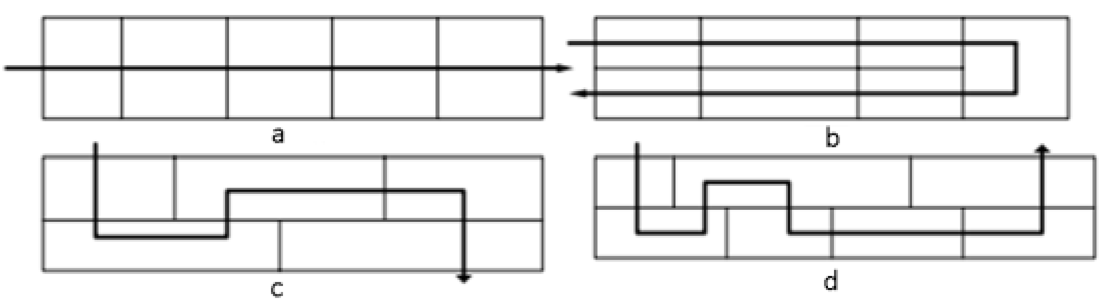


Figure 2.1 Different type of flow patterns within facility (Drira, Pierreval, & Hajri-Gabou, 2007)

The objective of the material flow is to minimize the sum of fixed cost of the path in the facility and the variable cost of flows.

While measuring the performance of a manufacturing facility, the design of the facility is an important aspect of achieving an efficient material handling. If the facility layout is designed well, small transportation times, short paths and a low work-in-process are achieved. In addition, an efficient layout results in an effective material flow without backtracking, congestion, undesirable intersections with other paths, and bypassing (Drira, Pierreval, & Hajri-Gabou, 2007).

The flow of materials aims for maximizing directed flow paths and minimizing the flow between workstations. A directed flow path is an uninterrupted flow from the beginning to the end. The path has no backtracking and does not create congestion, undesirable intersections with other paths, or bypassing. The terms backtracking and bypassing are explained in Figure 2.2.

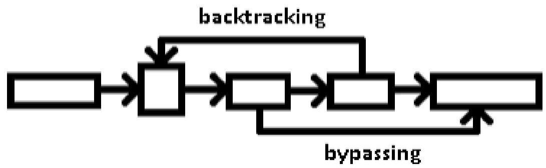


**Figure 2.2 Example of backtracking and bypassing of flows (Drira, Pierreval, & Hajri-Gabou, 2007)**

A method that is frequently used for analyzing material flow within a facility is the Systematic Handling Analysis (SHA) designed by Muther and Haganäs (1968). It is an organized and systematic approach to analyze the material handling problem. With this method you can analyze the movements from and to an area, taking into account external conditions. The focus is on the type of transportation of the materials, it takes into account the transport units that could be used. The Systematic Handling Analysis is explained in the next paragraph.

### Systematic Handling Analysis

The goal of Systematic Handling Analysis (SHA) is to design and implement facility handling plans, which is defined as the movement of materials between departments (Muther & Haganäs, 1968). The analysis consists of four different phases:

| | |
|---|---|
| 1. External integration: | Analysis of incoming and outgoing materials. |
| 2. Overall handling plan: | Construction of the overall facility handling. |
| 3. Detailed handling plans: | Departmental and workplace handling. |
| 4. Installation: | Planning and scheduling the installation. |

Within the SHA there are five elements that influence the material handling analysis. They include the factors P/Q/R/S/T, the definition of these five characteristics are:

| | |
|---|---|
| Product: | The type of product. |
| Quantity: | The volume of goods that are moved. |
| Routing: | The route in which the goods flow. |
| Service: | The aspects that includes personnel and equipment. |
| Time: | Time that is needed for transportation. |

The factors above lead to the Systematic Handling Analysis which can be divided into material analysis, activity analysis and modulus analysis. SHA focuses on minimization of the transportation distances only, while the management of Mainfreight wants to take into account the safety aspect as well. The SHA approach takes into account the transport units and packaging materials, which are not important for this research, since these are provided by the manufacturer of the agricultural machines. Therefore, we will not use this approach to improve the current layout.

## 2.4 Facility layout problem

A facility or factory layout is the arrangement of the area related to the manufacturing process, to allow greater efficiency and productivity. It includes the arrangement of working areas, storage areas, and location of workstations. This is related to the dimensions of the workstations, area of the facility and operational costs. Each movement influences the optimization of the production. Characteristics of an efficient facility layout are as follow (Saerang, 2011):

1. Traveling time of workers and material is decreasing;
2. Minimum operational cost;
3. Zero accident in factory;
4. Employees could work efficiently and effectively;
5. Optimize empty space;
6. Communication among employee are well organized.

Solving a facility layout problem reduces the travel distance. This can be done by eliminating waste in terms of material flows and reducing transportation costs.

A couple of researchers investigated the facility layout in depth (Meller & Bozer, 1997; Meller & Gau, 1996; Heragu, 1997). These will be explained in paragraph 2.4.3 and 2.5.

The facility layout problem (FLP) can be defined as *the placement of facilities in an area, with the goal of determining the most effective arrangement in accordance with some criteria or objectives under certain constraints, such as shape, size orientation, and pick-up/drop-off point of the facilities* (Hosseini-Nasab, Fereidouni, Ghomi, & Fakhrzad, 2017).

The most significant indicator of the efficiency of a layout is the material handling costs (MHC). Around 20-50% of the total operating costs of a company can be assigned to material handling costs (Heragu, 1997). Companies can reduce the costs by at least 10-30% if their facility is designed effectively based on the material flow. Additionally, by having an incorrect layout and location design more than 35% of system efficiency is lost (Heragu, 1997).

In companies it is unlikely that material flows between workstations or facilities remain unchanged during a long period of time. According to Gupta and Seifoddini (1989) one third of US companies have large reorganizations of their production facilities every 2 years. Some of the factors that lead to a change in the material flow between workstations or facilities are as follows:

a. Shorter product life cycles;
b. Changes in design of an existing product;
c. Addition or deletion of products;
d. Changes in production quantities;
e. Replacement of existing production equipment.

### 2.4.1. Facility layout types

The layout of facilities is influenced by the type of production system. Especially the product variety and production volumes are influencing the layout for a large part. We can distinguish four different types of manufacturing systems (Yin, 2009): fixed location layout, product layout, process layout and group layout. Figure 2.3 shows these different types in a matrix where the production volume is on the y-axis and product variety on the x-axis.

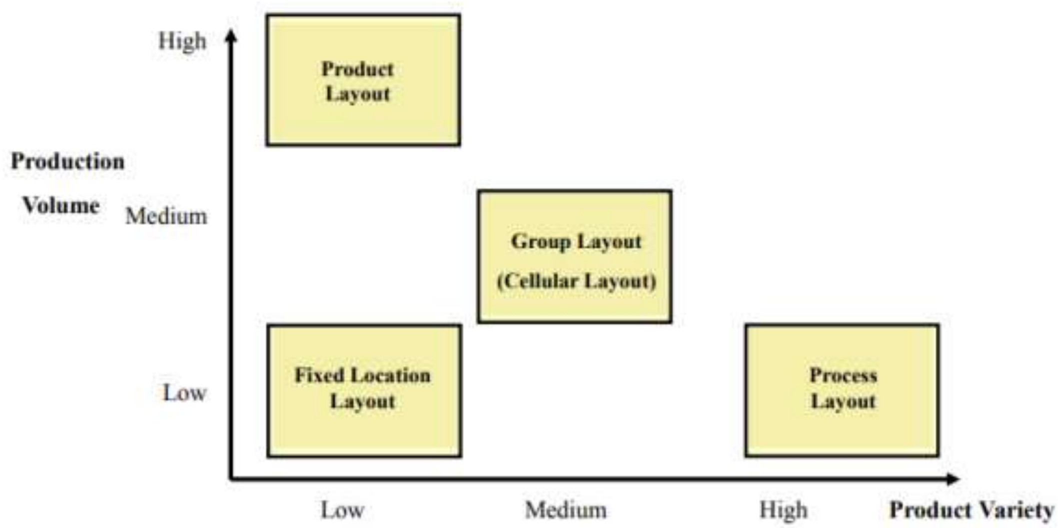


Figure 2.3 Facility layout types (De Kogel - Polak, 2017)

In a fixed layout machines and workers circulate within a production facility, the product does not move, the different resources are moved to perform the operations on the product. Manufacturers of large size products use this type of layout. Product layout is used in facilities with high production volumes and low variety of products. They are organized according to the sequence of successive manufacturing operations, often those factories are make-to-stock and make use of a conveyor system to move the products. Process layout is used in facilities with a wide variety of products, the so-called job shops factories. The products have to move over long distances and have long waiting times. Often these factories are make-to-order. In a group layout or cellular layout, machines are grouped into cells to process similar parts. A cellular layout combines the flexibility of a process layout with the efficiency of a product layout. The biggest difference is the efficiency achieved in the end. Due to the layout of the facility products are closer to each other and grouped together to gain a higher efficiency.

The objective of a facility layout is to utilize the available floor space efficient, provide enough production capacity, reduce material handling costs, utilize labor efficiently. By selecting the correct layout type from Figure 2.3 one is able to improve the layout by making use of the corresponding aspects of that facility type.

### 2.4.2. Layout planning

Layout planning determines the best physical arrangement of resources within a facility. The decisions of a layout are made on the strategic level. The decisions affect the whole organization, and operate over long time spans. Usually it is a capital-intensive change in the layout.

Reasons for changing a layout are changes in products, the introduction of a new product, change in volume or changes in the organization. If an organization decides to change to a Just-In-Time approach the whole process and thus the layout has to change. A change in a layout is interesting if the current layout is not “good” enough. Characteristics of a good layout are amongst others bottlenecks under control, workstations close together, minimum of material handling and predictable production time (De Kogel - Polak, 2017).

There are several factors affecting the layout of a plant (De Kogel - Polak, 2017).

1. Materials;
2. Machinery;
3. Labor;
4. Material handling;
5. Waiting time;
6. Auxiliary services;
7. The building;
8. Future changes.

#### Materials

A layout of a facility depends on the characteristics of the product and on the type of parts and material flows. Factors to be considered are size, shape, volume, weight and physical-chemical characteristics. On the other hand, the sequence and order of the operations will affect plant layout, therefore the variety and quantity to produce has to be considered.

#### Machinery

The information about the process, machinery, tools and the equipment needed is important to design a new layout. The type, total available for each type and quantity of tools and equipment is necessary to consider. Space requirements, shape, height, weight and type of workers required are essential to take into account because it has to fit inside the layout.

#### Labor

In the production process, labor has to be taken into account. It is important to investigate the employees’ safety, light conditions, ventilation, temperature and noise. Also, the number of workers required at a given time and the amount of work they have to perform must be considered before designing a new layout.

### Material handling

The material handling does not give any value to a product, it is waste. It is important to minimize material handling or to combine this with other operations to eliminate unnecessary and costly movements.

### Waiting time – Stock

The goal is to minimize the waiting time of stock, a continuous material flow through the facility. A continuous flow is not always correct, sometimes stock provides safety to protect production or improves customer service. In this case it is necessary to consider the required space for stock in the facility while designing the layout.

### Auxiliary services

Auxiliary services consist of accessibility paths, supervision, safety, quality control and maintenance of machinery. This department represents around 30% of the space at a facility. This space is usually considered as waste area but it is necessary to have this space in a facility.

### Building

The dimensions of the building are the constraints for the layout. If a new building has to be built it is different, in this case you can make the building as large as needed.

### Future changes

Flexibility is important while designing a new layout. Forecasting future changes avoids having an inefficient facility layout in a short term (De Kogel - Polak, 2017).

### 2.4.3. Redesign facility layout methods

This section describes different methods to identify waste and how to redesign a facility layout. The methods spaghetti-diagram, Nadler's ideal systems approach, Apple's plant layout procedure, Reed's plant layout procedure and Systematic Layout Planning (SLP) are explained with the found literature.

### Spaghetti-diagram

A spaghetti-diagram is used to determine an efficient design of a facility layout. This is done by mapping all movements of products and employees. When creating a spaghetti-diagram, every product, service or employee is followed and the movements are drawn on a floor plan of the facility. An example of a spaghetti diagram is given in Figure 2.4. By analyzing all the lines, we can distinguish the length of the paths, production numbers of each product and the overlap and intersections of the lines. With a spaghetti-diagram we can therefore map the inefficient areas and movements, and then adjust the layout of the work floor (Senderská, Mares, & Václav, 2017) to create a more efficient layout.

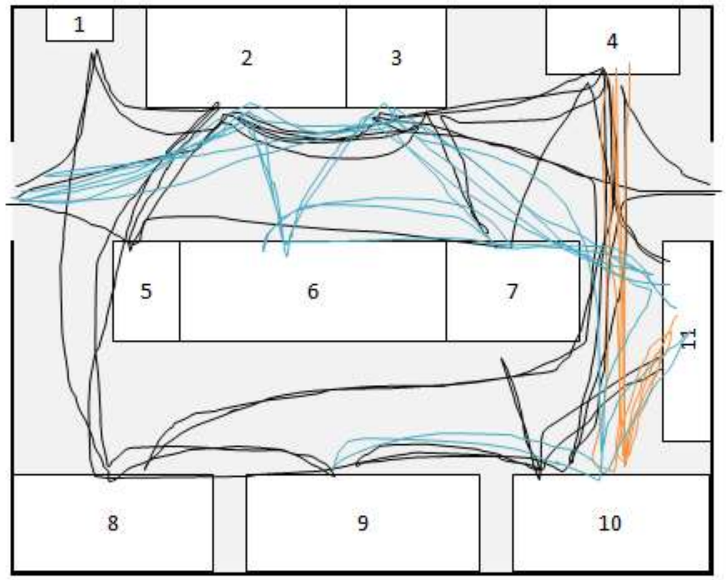

Figure 2.4 Example of a Spaghetti-diagram within a facility (Senderská, Mares, & Václav, 2017)

A spaghetti-diagram is made on a map of the facility that is going to be examined. This map can be reproduced schematically so that it is clear what the relevant workstations are. With the help of a line, the movement of a person or object is shown. Different colors can be used to differentiate between different persons, activities, objects or times (Theisens, 2016).

Before a spaghetti-diagram can be made, several decisions have to be taken. It must be clearly defined what will be investigated and in which manner. During the analysis, the distance covered by the product or the employee and the number of movements made are taken into account. By analyzing these types of transport, the time an employee or product is moving, can be determined. In this way it identifies the possibilities to streamline the process more efficiently (Theisens, 2016).

### Nadler's ideal systems approach

Nadler developed a system approach, to use it for designing work systems. It is also very useful for facilities planning. The approach of Nadler consists of 4 steps (Prasad & Srivastava, 2018):
1. Aim for the "theoretical ideal system".
2. Conceptualize the "ultimate ideal system".
3. Design the "technologically workable ideal system".
4. Install the "recommended system".

The "theoretical ideal system" is a system with zero cost, perfect quality, no safety hazards and no wasted space. The next step is to conceptualize a system that is achievable since the technology exists for its development. The third step is to design a system for which the technology is available, when there are very high costs this may prevent some parts from being installed. The last step is to install the cost-effective system that will work without obstacles. By using this approach, it is possible to design a layout which is beyond the current state of the technology (Prasad & Srivastava, 2018).

## Apple's plant layout procedure

Apple recommended that the following detailed sequence of steps should be used in designing a plant layout (Prasad & Srivastava, 2018).

1. Procure the basic data;
2. Analyze the basic data;
3. Design the productive process;
4. Plan the material flow pattern;
5. Consider the general material handling plan;
6. Calculate equipment requirements;
7. Plan individual workstations;
8. Select specific material handling equipment;
9. Coordinate groups of related operations;
10. Design activity interrelationships;
11. Determine storage requirements;
12. Plan service and auxiliary activities;
13. Determine space requirements;
14. Allocate activities to total space;
15. Consider building types;
16. Construct master layout;
17. Evaluate, adjust and check the layout with the appropriate persons;
18. Obtain approvals;
19. Install the layout;
20. Follow up on implementation of the layout.

## Reed's plant layout procedure

Reed developed a systematic plan of attack for planning and preparing the layout. First the products have to be analyzed, once the products are known you can determine the process required to manufacture the product. It includes all the operations, transportation and storage related to the products. The next phase is preparing layout planning charts, which is shown in Figure 2.5 (Tompkins, White, Bozer, Tanchoco, & Trevino, 1996). Standard times for each operation are used. The next phase is to determine the workstations, and analyze the storage area requirements. If the required area is determined the minimum aisle widths have to be established. The last phase is to determine office requirements to be able to draw a new facility layout (Prasad & Srivastava, 2018).

LAYOUT PLANNING CHART

PART NO. 1 PART NAME PLASTIC CONTACT PAD PCS/ASSY 1 PCS REQ/HR 70.4 SHEET 1 OF 1
ASSY NO. — ASSY NAME — ASSY/PRODUCT 2 PRODUCTION HRS/DAY 6.0 PREPARED BY J.G.D. DATE 1-4-60
MATERIAL PLASTIC SIZE 1 1/2" OD × 3/8" ID (from 4' × 8' × 1/4" SHEETS) PCS/DAY 422 LOT SIZE 1 APPROVED BY DATE

| ST NO. | F M S I | DESCRIPTION | OPER NO. | DEPT NO. | TIME PER PIECE | MACHINE OR EQUIPMENT | MACHINES REQD: MACH FRAC | MACHINES REQD: COMB WITH | MACHINES REQD: MACH REQD | OPER PER MACH | TOTAL MANPOWER: CREQ FRAC | TOTAL MANPOWER: MAN FRAC | TOTAL MANPOWER: COMB WITH | TOTAL MANPOWER: MEN REQD | HANDLING REQUIREMENTS: HOW MOVED | HANDLING REQUIREMENTS: CONT TYPE | HANDLING REQUIREMENTS: LOAD SIZE | HANDLING REQUIREMENTS: DIST MOVED | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | FROM MATERIALS STORAGE | | | | | | | | | | | | | FORK LIFT | PALLET | 4 SHEETS | 100 | |
| 2 | | ON PALLET BY SAW | | 2 | | | | | | | | | | | | | | | |
| 3 | | TO SAW TABLE | | | | | | | | | | | | | | | | | |
| 4 | | SAW INTO STRIPS 2 1/2" × 8' | 10 | 2 | .02 | TABLE SAW | .028 | 9 – 10<br>16 – 10 | 1 | 2 | .028 | .056 | 9 – 10<br>16 – 10 | 2 | | | | | |
| 5 | | TO RACK BY SAW | | | | | | | | | | | 1 – 20<br>14 – 30 | | | | | | |
| 6 | | IN RACK | | 2 | | | | | | | | | 17 – 20<br>3 – 20 | | | | | | |
| 7 | | TO HEATER | | | | | | | | | | | 5 – 30<br>13 – 20 | | | | | | |
| 8 | | IN RACK BY HEATER | | 2 | | | | | | | | | 14 – 20 | | | | | | |
| 9 | | FEED INTO HEATER | | | | | | | | | | | | | | | | | |
| 10 | | HEAT | 10 | 2 | .04 | HEATER | .055 | 9 – 20<br>16 – 20 | 1 | 1 | .055 | .056 | 5 – 20<br>6 – 10 | 1 | | | | | |

Figure 2.5 Layout planning chart example Reed's plant layout procedure (Prasad & Srivastava, 2018)

## Systematic Layout Planning

Over 50 years ago Richard Muther (1961) introduced the Systematic Layout Planning (SLP) as a tool to arrange a workplace in a facility by locating areas with high frequency and logical relationships close to each other. The SLP is best applicable for process or group layout. "The user can identify, visualize and rate the various activities, relationship, and alternatives concerned with the layout project" (Patil, Gandhi, & Deshpande, 2015).

The key elements for solving the plant layout problems according to Muther (1961) are five factors P/Q/R/S/T, these five factors are also used in the SHA of Muther (1968), the explanation of these factors can therefore be found in section 2.3.

The planning procedure of SLP let the user solve the layout problem. The progressive phases of SLP are data collection and its analysis, identify the possible layout solutions and evaluation of alternatives and selection of best layout. On this basis, the SLP was developed and offered to various professional organizations a more practical layout improvement method (1961). The first step of the SLP is creating the relationship chart, which can be created after the data collection of the material flow, between workstations and their requirements. An example of a relationship chart is shown in Figure 2.6.

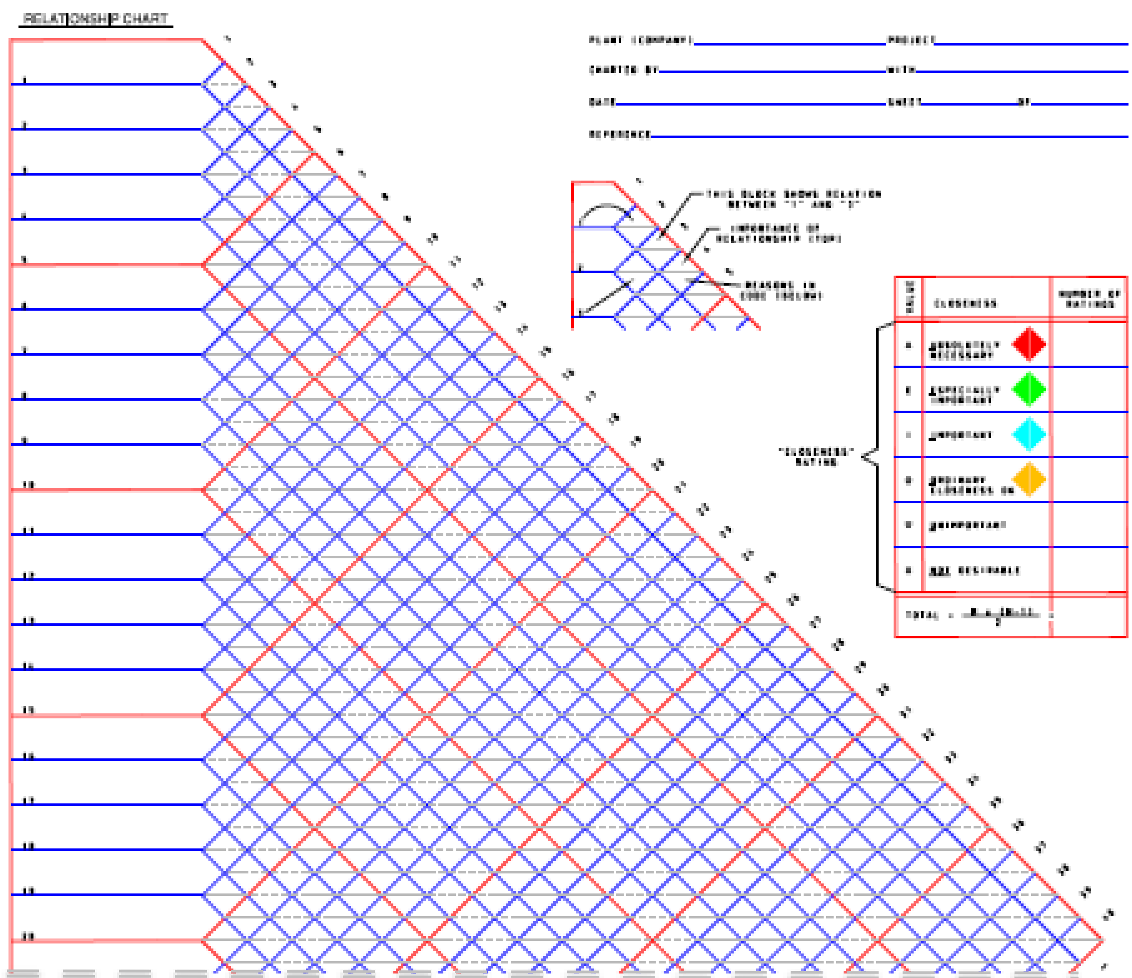


**Figure 2.6 Example of a relationship chart of Muther's SLP procedure (1961)**

In this relationship chart letters are assigned to the different operations, based on how important it is to have the departments close to each other.

A: Absolutely necessary;

E: Especially important;

I: Important;

O: Ordinary;

U: Unimportant;

X: Undesirable.

The second step concerns the determination of the available space. A shop floor has a certain space in which the workstations are limited. In addition to the quantity of the required space, we also need to know the kind of space. To get this space we need to know which physical characteristics are essential conditions for each activity. In this way it is possible to integrate the practical considerations related to the construction into the planning. Moreover, we must have a check on the energy facilities or the special emergency services that are required per activity.

Finally, we must be aware of whether there are imperative requirements with regard to the space required for a given activity in order to be able to comply with the specifically desired configuration. The required space is written in $m^2$ (square meters). In the third step these relationships and the available space are drawn together in one diagram. By schematically drawing the actions and drawing the relationships between them, it becomes visible where long distances are between departments. The diagram can then be moved so that the actions with the most important relationships are placed side by side. The goal is to get as few lines as possible in the diagram.

Step 4 of the Systematic Layout Planning is creating a block layout of the schematically drawn layout in step 3. Each operation gets is own area in which the action must take place.

Step 5 is the evaluation of the created facility layout, the emphasis here is whether all restrictions have been met. Alternative layouts are also taken into consideration and evaluated based on several aspects.

Once the best layout has been determined, a detailed arrangement can be made in step 6. Here, all operations are recorded as it is drawn in step 4.

An overview of all the steps can be found in Figure 2.7.

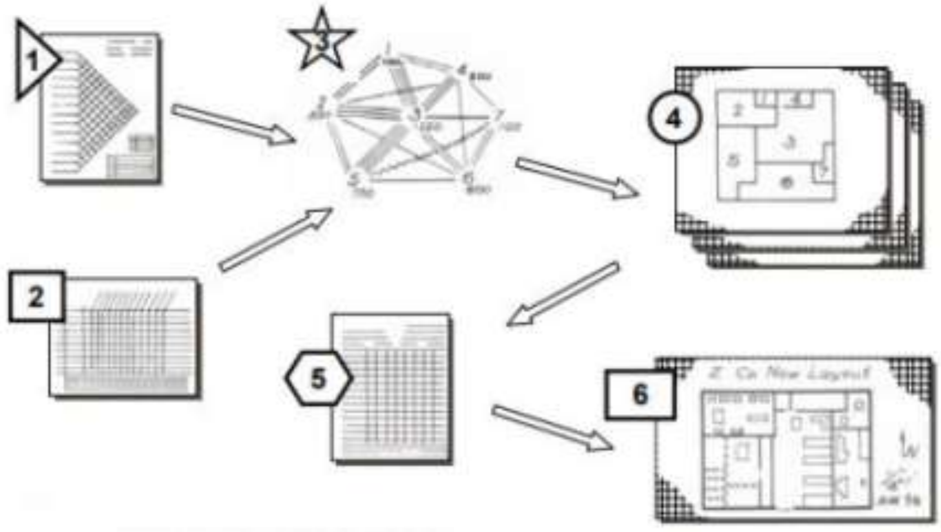


Figure 2.7 Six steps of the Systematic Layout Planning (SLP) method of Muther (1961)

While designing a new layout, each layout has to take into account: relations between the activities, space available for the activities, and the adjustment of the previous two elements while designing a layout plan.

The six steps of SLP are executed in accordance with these three basic elements. The explanation of the six steps in the figure above are:

1. Chart the relationships;
2. Establish space requirements and physical aspects;
3. Diagram with connected activity relationships;
4. Draw space relationships layout and improve this with iterations;
5. Evaluate alternative arrangements based on defined criteria;
6. Detail the selected layout plan on a map of the building.

Once these steps are performed one have a new improved layout established.

### 2.4.4. Layout Improvement Algorithms

The computerized layout algorithms/methods may be used in the method Systematic Layout Planning of Muther. Most of the algorithms are not commercially available. The computerized algorithms generate and evaluate a large number of alternatives in a short time.

There are different types of optimization approaches: exact methods such as branch-and-bound, and approximated approaches such as heuristics and meta-heuristics. The goal of these methods is finding good solutions. Finding these solutions is not easy because the optimal solution leads to large-scale Quadratic Assignment Problems (QAP). The goal of QAP is to assign facilities to locations in such a way to minimize the assignment cost. The assignment cost is the sum, over all pairs, of the flow between a pair of facilities multiplied by the distance between their assigned locations (Quadratic Assignment

Problem, n.d.). Most of the research methods aim at developing heuristic procedures (Meller & Bozer, 1997).

Heuristic algorithms can be considered as a construction algorithm where a solution is constructed from scratch and improvement type algorithms where an initial solution is improved. CRAFT (Computerized Relative Allocation of Facilities Technique) and MULTIPLE (MULTI-floor Plant Layout Evaluation) are improvement algorithms that use pair-wise exchange. Simulated Annealing has been adopted recently as an approach to the layout problem. An advantage of this is to avoid being stuck in a local optimal by accepting changes that worsen the objective function (Chwif, Barretto, & Moscato, 1998).

### CRAFT

The input for CRAFT is a 'from-to chart'. It uses this input for the flow and the algorithm attempts to minimize the material movement cost by pair-wise exchanges among departments. It makes use of the initial layout of the facility and it looks for improvement between the departments by pair-wise exchange.

CRAFT starts by determining the centroids of the departments in the initial layout of the facility. The rectilinear distances between the pair of centroids of the department are calculated, these values are stored in a matrix. Subsequently, there will some exchanges made in two or three directions. The possible changes are examined and the best change is identified, i.e. the one with the largest reduction in layout costs. Once the best exchange has been identified, CRAFT updates the layout according to the best exchange and the new centroids of the department. Next, the new layout costs are calculated to complete the first iteration. The next iteration starts with CRAFT again, it is the same procedure as the first iteration. The process continues until no further reduction in layout cost can be obtained (Tompkins, White, Bozer, Tanchoco, & Trevino, 1996).

The limitation of CRAFT is that only those departments can be exchanged that are adjacent or equal in area. If two non-adjacent sections (with unequal areas) are exchanged, other departments must be "moved", otherwise one of the exchanged sections will be "split" (Heragu, 1997). CRAFT cannot move the other departments since splitting a department is not acceptable in a production facility (Tompkins, White, Bozer, Tanchoco, & Trevino, 1996).

### MULTIPLE

MULTIPLE is an improvement algorithm similar to CRAFT and is a distance-based algorithm. The advantage of MULTIPLE that this algorithm is able to exchange non-adjacent department. It uses space filling curves (SFC) to reconstruct a new layout after each iteration. The space filling curve principle connects all the grids in a layout, each grid is visited exactly once and the next grid visited is always adjacent to the current grid (only horizontal or vertical moves). SFC is generated by a computer.

Another variant of MULTIPLE is conforming curves, these are hand-generated curves. The difference with SFC is that in the conforming curves principle the curve visits all the grids assigned to a particular department before visiting other department. Fixed departments and obstacles are not visited with the conforming curves method. The final costs for the layout of MULTIPLE is lower than for the layout found by CRAFT, since MULTIPLE considers a larger set of possible solutions at each iteration. MULTIPLE is most suitable for creating many alternatives layouts.

### Pairwise exchange

It is an improvement layout algorithm which has a distance-based objective. The objective is to minimize the total cost of transporting materials among all departments in a facility. It is based on rectilinear distance from centroid to centroid. The algorithm evaluates all feasible exchanges in the locations of departments. The pair that leads to the largest reduction in costs is selected. The algorithms assume that all departments are of equal size. Whereas the departments, or the workstations at the production area differ in size and shape, this method is not suitable to the facility layout of the production area.

### Conclusion

The above-mentioned algorithms are improved algorithms. We took a look only at these type of algorithms since the construction algorithms have several drawbacks. No computer-based algorithm can capture all the significant aspects of a facility layout problem. It will not create an optimal layout; a human layout planner will continue to play a key role in developing and evaluating the facility layout. Another drawback is that the layout of a construction algorithm often results in irregular building shapes.

## 2.5. Layout evaluation criteria

Layout's efficiency is typically measured in terms of the material transportation and handling costs *($c_1$)* as expressed by the equation (2.1) (Meller & Gau, 1996; Heragu, 1997):

$$c_1 = \sum_i \sum_j (f_{ij} c_{ij}) d_{ij} \qquad (2.1)$$

Although in our case it is not material transportation and handling that we would like to measure, this equation is applicable to our situation. The movements of machines in the production area can be considered as the 'material transportation'. The machines are transported within the facility. Since it is in this case difficult to determine the exact costs for the transportation ($c_{ij}$) for each pair of departments, therefore we assume the value of each $c_{ij}$ is equal to 1 and we can consider the equation as shown in equation 2.2 (Hailemariam, 2010). Since we set $c_{ij}$ equal to 1, we will use this formula of $c_2$ in our research instead of equation $c_1$.

$$c_2 = \sum_i \sum_j f_{ij} d_{ij} \qquad (2.2)$$

The definition of *f* and *d* are: the average distance machines are transported (*d*), and the quantity of the machines flow (*f*) every day. Distances (*d*) are exact distances between departments.

Other additional criteria for evaluating the efficiency of a layout are:

- Space utilization: space is used for any type of material, personnel needs, aisle space and material movements. Manufacturing facilities are constantly undergoing changes due to market changes. A layout design with maximizing the use of space takes into account the possible future expansion and should therefore keep free space concentrated within a specific area.
- Aisle system: the effectiveness of aisle arrangement to support the flow between departments by materials or personnel. It takes into account the ease of access between departments.
- Safety: safety is an important criterion to take into account when measuring the efficiency. Due to the movements of machines and materials between departments an accident could occur easily.

## 2.6. Comparison of layout improvement options

In this section a comparison is made of the introduced redesign facility layout methods in the previous section 2.4.3. The procedures described in this section has their merits and demerits. For example, Reed's systematic plan consists of ten steps, this approach takes into account the aisle widths and future expansion. Apple developed an approach of twenty steps, which is a time-consuming process. Nadler developed a method with only four steps respectively. Systematic Layout Planning of Muther has eleven steps, but a less complicated version was developed short after the first edition. The Systematic Layout Planning charts are generated during the process implementation. Graphs and charts are easy to analyze and to understand the data. Table 2.1 demonstrates a theoretical comparison among these methods. The qualitative data in Table 2.1 is generated from the literature study. Comparison is evaluated with different type of letters, represented by more (M), medium (ME) and less (L). Factor's absence or presence is represented by no or yes.

**Table 2.1 Comparison of redesign facility layout methods (M: more; ME: medium; L: less)**

| | Nadler | Muther | Apple | Reed |
|---|---|---|---|---|
| **Initial data required** | M | L | Me | M |
| **Use of charts** | L | M | Me | Me |
| **Use of graphs and diagrams** | L | M | L | L |
| **Future expansion considered** | No | No | No | Yes |
| **Constraints considered** | No | Yes | No | No |
| **Procedure implementation** | L | M | Me | Me |
| **Material handling equipment selection considered** | No | No | Yes | No |

If we compare on the basis of future expansion, Reed considered this factor in the developed procedure. Constraints are only considered by Muther, none of the other covers it. Practical implementation of Muther's procedure is much higher than the other approaches.

## 2.7. Selection of improvement option

Based on the literature (Sharma & Singhal, 2016) and the comparison in the previous section, the Systematic Layout Planning (SLP) approach by Muther will be used to develop alternative layouts for the current facility. The authors Bikas Prasad and Ravish Kumar Srivastava have made a ranking on the basis of some selected factors (2018). The ranking indicates that Muther's Systematic Layout Planning (SLP), which we ranked the highest, is the most suitable alternative for solving facility layout design problem according to the authors. The practical implementation of Muther's procedure is much higher compared to other approaches, this is one of the biggest advantages of this approach.

## 2.8. Conclusion

This section will summarize the literature about the material flow problem and the facility layout problem which is discussed in this chapter. It gives answer to the research question: *"What is currently known in literature about routing in a facility layout?"*.

There are several methods to measure and improve the layout of a facility. To redesign a facility layout there are different methods and techniques. Discussed methods in this chapter are: spaghetti-diagram, Nadler's ideal systems approach, Apple's plant layout procedure, Reed's plant layout procedure and Systematic Layout Planning (SLP). The discussed improvement algorithms are: CRAFT, MUTLIPLE and pairwise exchange.

The methods are compared and the most suitable method to analyze and improve the layout is the Systematic Layout Planning (SLP) proposed by Richard Muther (1961). This is mainly due to the fact of the high practical implementation of this method. We will use, next to the improvement of the layout with SLP, the spaghetti-diagram as an input for this method. With this input we have a clear view of what the different flows are within the facility. To create an improved layout we will make use of the improvement algorithm CRAFT in combination with pairwise exchange. With both algorithms we are able to create small adjustments to the layout to improve it further. The CRAFT improvement algorithm is most suitable for improving the layout of the production area since departments are not restricted to rectangular shapes as in the pairwise exchange method.

# 3. Current situation

This chapter describes the current situation of the production area of Mainfreight ‘s-Heerenberg, by answering the first research question: *What are the characteristics of the facility layout of the production area?*

To answer this question, we first describe the current layout of the production area in section 3.1. Section 3.2 describes the process flow of machines through the production area. Section 3.3 describes the relations between the different departments and section 3.4 explains the KPIs that are currently in place. Section 3.5 addresses the problem cluster of this research. Section 3.6 gives the most important conclusions from this chapter.

## 3.1. Design of the production area

The production area is the location for assembling and mounting parts and kits to AEM machines. The production area is managed by one supervisor, who is present every working day and responsible for all activities related to the production area. Next to the supervisor, there are several group leaders who are responsible for solving issues and daily operations. At this moment around 90 employees are working in the production area, divided over different departments.

The production area consists of different areas, divided over three halls, namely hall 6, 21 and 22. A very small part of hall 22 is used due the insufficient available space in hall 6 and 21. In Figure 3.1 the production area (hall 6 and 21) is shown, the total area (including aisles and storage) is approximately 5.500 square meters. Appendix I shows the floorplan of the whole area assigned to AEM.

The layout is split into separated areas mentioned with a letter, see Figure 3.1. The letters are explained in Table 3.1. The grey area is the area inside the facility where everybody can walk or drive with machines. The green area is the corridor outside the facility and the orange area is the corridor inside the facility.

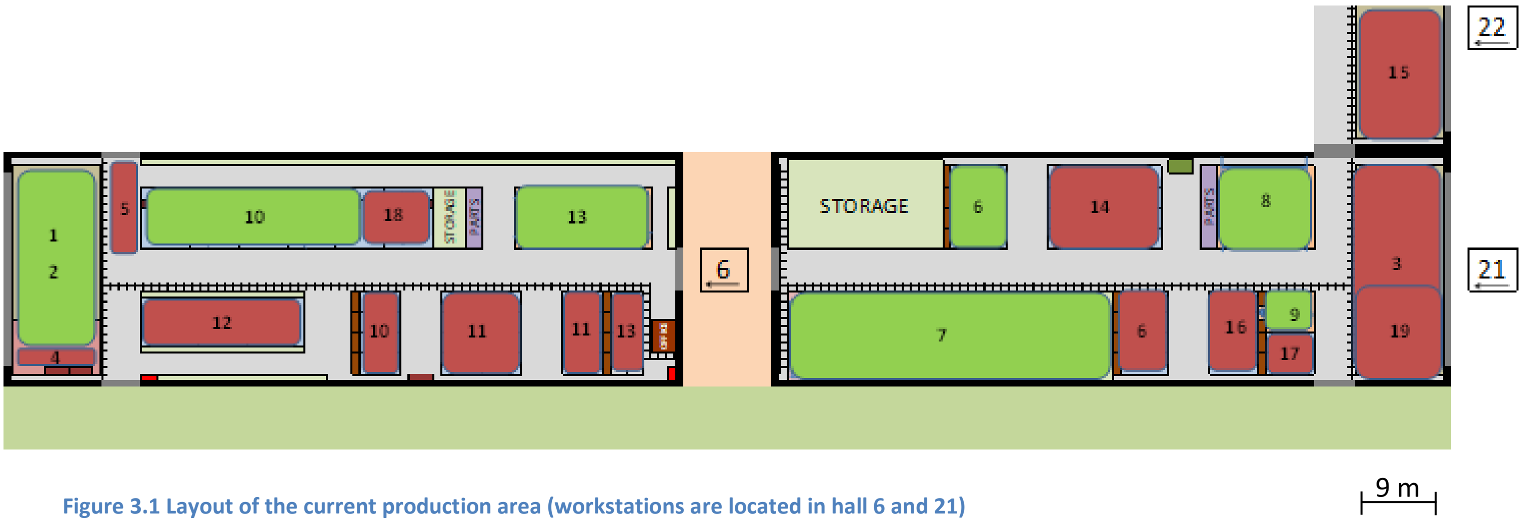


Figure 3.1 Layout of the current production area (workstations are located in hall 6 and 21)

Table 3.1 Legend of production area layout

| |
|---|
| *CONFIDENTIAL* |

## 3.2. Process definition

This section explains the assembly process in more detail. Figure 3.2 shows the process flowchart of the assembly process of machine type *X* (include the circled area) and machine type *Y* (exclude the circled area).

***CONFIDENTIAL***

**Figure 3.2 Process flowchart of machine type *X* (include the circled area) and machine type *Y* (exclude the circled area) in the production area**

*CONFIDENTIAL*

## 3.3. Current routing of machines

This section focuses on the current routing of the machines through the production area. We first introduce our approach to determine the routing of machines. Next, we look at the relations between different departments within the production area. To have insights in the current movements inside the production area, we make use of a floor plan of the facility where the production area is located (the layout is already shown in section 3.1).

The routing of machines in the production area is determined by making use of a Spaghetti-diagram (Senderská, Mares, & Václav, 2017). A Spaghetti-diagram is used to determine an efficient design of a facility layout. This is done by mapping all movements of the machines. When creating a Spaghetti-diagram, every machine is followed and the movements are drawn on a floor plan of the production area. The Spaghetti-diagram of the production area is shown in Figure 3.3. By analyzing all the lines we can distinguish the length of the paths and the overlap and intersections of the lines. With a Spaghetti-diagram we can therefore map the inefficient areas and movements (Senderská, Mares, & Václav, 2017).

Each machine is drawn with a colored line in the layout. We measured the exact distance between workstations in the production area. This is measured by making use of observations, based upon discussions with the supervisor of the production area we needed three weeks to observe all different movements with the machines. The different colors give a clear overview of the different movements in the production area. The process is observed from inbound to outbound. Some machines are stored temporarily in the corridor outside or inside in the production area. Due to this there is no space for other machines that need to use this path. This leads to extra transport of machines because they are moved several times to temporary storage areas. In this overview hall 7 is also shown, this is due to the fact this hall is used for storage of machines after the arrival.


Figure 3.3 Spaghetti-diagram drawn in the current layout of the production area

The relations between departments can obtained from the Spaghetti-diagram. It can be seen that the flow of machines, the brown dotted arrow, after inbound always have to go from the most left part of the facility to the most right part of the facility. These machines have a strong relation between inbound and the their next workstation. The workstation on the other hand has a relation with a different workstation, which is close to the inbound. Therefore, it can be seen that these departments should be close together because they are connected to each other in the current routing.

***CONFIDENTIAL***

**Figure 3.4 Flow frequencies of machines in the production area (thickness of line represents the intensity)**

To create the arrows in Figure 3.4 the flow frequency in number of trips are calculated between any two locations on a route-by-route basis. These frequencies are aggregated and then used to scale the thickness of the flow lines between every pair of locations. The flow lines who have a thick line, has the highest flow within the production area. The aim is to reduce the distance of those lines that have a high flow and long distance; as it influences the total distance driven in the production area the most. A large overview of this flow frequency of machines in production area can be found in Appendix III.

## 3.4. Key Performance Indicators

This section describes the Key Performance Indicators (KPIs) that are currently in place. These are variables that are measured by Mainfreight, for example throughput time and number of machines produced each day. This data will be used as input for the research.

MARC Production SHB 2009 is the software system used as Warehouse Management System, and for production it contains all data related to the machines and orders. It retrieves all relevant data about assemblies, machines, orders and stock from the database. By using this tool data about the current amount of machines in stock and orders can be analyzed. Next to MARC Production SHB 2009, Microsoft Excel is used widely to analyze and have insight in the performance of the process.

The team of the production area uses these data to create insight in how they are actually performing and to create production schedules. The KPIs currently used are explained below together with the reason why these are important for Mainfreight:

1. Throughput of machines: AEM expects to grow more and more the coming years, and Mainfreight want to be able to handle this growth. The KPI shows the total amount of machines which are processed in the production area per year.
2. Production Attainment Performance: Mainfreight wants to have the highest possible outcome to fulfill the needs of AEM, therefore they measure the scheduled production compared to the actual production. The question of Mainfreight is if they deliver the quantity promised to AEM. The KPI is measured as the scheduled production ($S_t$) divided by the actual production ($A_t$) for each product *n*. The production is different than the throughput of the production area, there are machines without assembling parts, these are not taken into account in the production schedule.

$$PAP_n = \frac{A^n{}_t}{S^n{}_t} \tag{3.1}$$

3. Quality of output: Since the quality of the products is not related to the efficiency (total distance driven) of the production area we will not consider this KPI in our research.
4. Number of machines at in- and outbound every day: By measuring the numbers of machines at in- and outbound the planning can be adjusted for the future to have a smoother flow without waiting times for machines.
5. Backlog and open orders: The amount of open orders and backorders are known to be able to change the planning schedule according to these open orders. This is out of scope of the research and therefore it will not be taken into account.

There are some other KPIs which are currently measured by Mainfreight which are not considered in this research because they are out of the scope or they do not give any added value.

## 3.5. Problem cluster facility layout

This section shows the different problems regarding the facility layout as perceived by the employees of the production area, the problem cluster is made in Figure 3.5 (van Winden & Heerkens, 2012).

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**Figure 3.5 Problem cluster of current performance in production area**

From the problem cluster in Figure 3.5 the core problem can be identified, machines are moved many times across the facility. This leads to and inefficient process with risk of collision of the machines. The supervisor of the production area concludes that there are too many movements inside the production area and some movements cannot be completed due to the fact the next workstation is not available yet (the machine has to be stored somewhere else), which does not result in a high efficiency rate. There is a risk of accidents between the machines because there is not much space to move the machines.

Important is to know how to measure the efficiency. The variable ‘distance’ is in this case the most suitable to measure. The variable ‘distance’ can help to reduce the distance traveled by machines or employees. Since the production area has repetitive jobs in the same or similar style multiple times, the benefits achieved are either faster delivery or the same delivery with less effort and a higher safety level.

## 3.6. Conclusion

This section will summarize the current situation of the production area of Mainfreight 's-Heerenberg, by answering the research question: *"What are the characteristics of the facility layout of the production area?"*.

The production area of Mainfreight 's-Heerenberg is the location for assembling and mounting parts and kits to AEM machines. The supervisor is responsible for the activities in the production area, such as the redesign of the layout and improving the overall performance. The layout of the production area consists of 21 different smaller areas, which have their own specific activity.

The machines go from one area to another area depending on the activities they have to follow. The flow of these machines is shown in Figure 3.4. Since the routing is known the relations between the departments are easily obtained.

The KPIs currently in place are; throughput of machines, Production Attainment Performance, Quality of output, number of machines at in- and outbound every day, and backlog & open orders. Not all KPIs are taken into account for the research since not all of them give added value to the research subject.

In the next chapter, chapter 4, the performance of the current layout will be analyzed.

# 4. Performance of the current layout

Analyzing the current situation is necessary to have a clear understanding of the current problems. This chapter describes the current performance of the production area of Mainfreight ‘s-Heerenberg, by answering the second research question: *What is the performance of the current layout of the production area (measured by KPIs)?*

To answer this question, we first describe the measured Key Performance Indicators and their values in section 4.1. Section 4.2 describes the efficiency of the current layout. In section 4.3 this chapter is summarized and the most important conclusions of this chapter are given.

## 4.1. Key Performance Indicators

The management of Mainfreight keeps track of their performance via KPIs of their processes. As explained in the problem description, Mainfreight believes that the production area is not efficient anymore due to the unforeseen growth and therefore the number of machine movements has increased. With the KPIs of the production area, we can analyze if this process performance is below the standard. There are many KPIs currently measured by Mainfreight, the relevant indicators considering this research are, as explained in section 3.4: throughput of machines and Production Attainment Performance. The data of the current KPIs are retrieved from the warehouse management system, MARC.

Since the distance driven with machines, and the time this takes for employees, is important for our research but currently not measured by Mainfreight we add this to the dataset. We will measure the exact distance between workstations in the production area, and the time it takes to move machines to the next workstation/destination. This will be measured by making use of observations, based upon discussions with the supervisor of the production area we need three weeks to observe all different movements with the machines. The four KPIs (throughput, production attainment performance, distance and time driven with the machines) are elaborated in section 4.1.1 to 4.1.4. All these indicators have the same consequence if they are not met, the number of output machines AEM expects will not be achieved. The process in the production area has to be managed adequately to achieve the goal.

To identify the problems in the process, the correct dataset is needed. The current dataset, retrieved from the warehouse management system MARC, is accurate and sufficient to analyze the current process. The dataset contains data of last year (2018) and forecast data for coming year (2019). Based on interviews we can conclude that this is enough data to analyze the current process.

### 4.1.1. Throughput of machines

In Table 4.1, the KPIs of the production area of the past year can be found. However, forecast is not a KPI, we added this to the table to show that AEM expects a growth in the products for the year 2019.

**Table 4.1 Throughput- and forecast of machines in the production area ("-" not determined by AEM)**

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From Table 4.1 we can conclude that the forecast, for the known machines, is higher than the amount of the current year. If we take a look at the previous year, the forecast of AEM for 2018 was accurate since the actual demand was almost the same. The throughput of the production area was lower than the actual demand due to insufficient production capacity. In section 4.1.2 this is discussed in more detail. The production area can expect more demand and should therefore be able to handle this growth.

If we plot the throughput of machines in a graph, see Figure 4.1, we can see the fluctuations of demand throughout the year.

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Figure 4.1 Throughput of machines in the production area (2018)

To analyze the most important machines of AEM for Mainfreight we have made a Pareto Analysis. The Pareto Analysis is also known as the "80/20 Rule", it implies that 20 percent of causes generate 80 percent of results. In our case it would mean that 20 percent of the machines will generate 80 percent of the workload. In Figure 4.2 we can see that this is not true, 62% represents 80% of the workload. The machines that have the most influence on this are three machines, they represent 50% of the workload (based on the amount). Since we focus on the machine movements in the production area we extend the dataset of the Pareto Analysis with the distances driven by the machine.

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Figure 4.2 Pareto-analysis of the throughput of machines in the production area

### 4.1.2. Production Attainment Performance

The production attainment performance is used to measure the degree to which the production is capable of reaching its targeted production output.

The score is calculated by dividing the actual production by the scheduled production according to equation 3.1. It shows the achieved percentage of the goal. By monitoring this score Mainfreight can manage the process and give extra attention to the processes that have a low score.

**Table 4.2 Production Attainment Performance per machine type**

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From Table 4.2 we can see that the weighted average production attainment is 85%. This means that there are some products which are not produced according to the schedule. These products should have extra attention, to plan the production schedule more accurate. A production schedule is used to create a more efficient manufacturing environment. Without this schedule the production department might come across with material shortages or projects rushed through the production facility. The production schedule is also used to show to AEM the expected amount of machines to be ready in the next week. They will plan the amount of orders according to this schedule. The weighted average is calculated based on the average production per day, which can be found in Table 4.7. The sum of the percentages is the weighted average.

Not reaching the 100% production attainment might have several reasons, for example there are not enough orders to complete the production schedule or no parts in stock necessary for the production.

This should in theory be available the week before the schedule, so the schedule could be adapted to this amount of orders. Otherwise too many employees might be scheduled and in the end there are will not be enough orders for all these employees.

## Measurement of performance

The literature suggests a couple of measures to measure the intended production. In this research this accuracy is measured based on the production and not on sales or demand, since the focus is on the production. The measures penalize errors in different ways. The mean square error (MSE) for instance penalizes large errors more than small. Different measures are used to measure the current accuracy. Below three different measures for forecast error are explained (Dilworth, 1999). In each formula *A(t)* are the actual production in period t, *F(t)* are the intended production for period t, and *n* is the total number of periods.

Mean Absolute Percentage Error (MAPE)

This measure divides the error by the actual production. The result is a percentage error of total production volume. The formula is:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} |\frac{A_t - F_t}{A_t}|$$

Mean Absolute Deviation (MAD)

This measure is the average absolute error over a certain period of time. The formula is:

$$MAD = \frac{1}{n}\sum_{t=1}^{n} |A_t - F_t|$$

Mean Squared Error (MSE)

This measure penalizes large error more than small ones, by taking the square of the error. The formula is:

$$MSE = \frac{1}{n}\sum_{t=1}^{n} (A_t - F_t)^2$$

The average production attainment can be found in Table 4.3.

**Table 4.3 Performance and intended errors measured in production area**

| |
|---|
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The values are calculated based on the data provided by Mainfreight over 2018 and making use of use of the MAPE, MAD and MSE equations.

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### 4.1.3. Distance driven with machines

We need to measure the distance driven with the machines first. Since this is not a KPI yet, we added this to the dataset. We measured the exact distance between workstations in the production area by observing the movements. We observed the movements for 3 weeks to have an indication where machines move to. In Table 4.4 the distance driven for each machine in the production area is given. A more detailed overview within the production area, is given in Appendix B.

**Table 4.4 Distance driven per machine in production area**

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From Table 4.4 we can see that a large part of the distance is driven inside the production area. If we multiply the data of the total amount of machines in a year and the distance driven for each machine, we have a new dataset which contains the total distance driven inside and outside the production area.

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Figure 4.3 Pareto-analysis based on distance driven with machines in production area

As we can conclude from Figure 4.3 the three different types of machines are responsible for about 50% of the distance driven on machines. The total distance driven is related to the number of machines shipped every day. A higher production volume will have more influence on the total distance, therefore these products have more importance.

### 4.1.4. Time driven with machines

If we convert the distance driven with the machines to time, we can measure the time employees are busy with moving machines. In Table 4.5 and Table 4.6 we measured the time for moving the machines to the next destination/workstation for the three most important machines types (as concluded in the previous paragraph). The time for the other machines types can be found in Appendix F. The column *#Machines per day* is the aggregated amount of machines produced per day, for the machines mentioned in the top of the table.

Table 4.5 Time per activity

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Table 4.6 Time per activity

In total 5.9 hours per day employees drive with the machines to move them to next workstation. Based upon a workday of 8 hours, which is the standard at Mainfreight, we assume 5.9 / 8 = 0.74 employee is per day busy with moving all the machines.

As we can conclude from the tables with the time employees are moving the machines, three machine types have the largest impact. 70% of the total time is used for moving these types of machines.

## 4.2. Efficiency of the current layout

The current performance of the production area is measured in the previous paragraph, and as a summary the output of machines per day, is shown in Table 4.7. The total distance per day is calculated with the formula shown in equation 2.3. An explanation of this equation can be found in chapter 2.3

$$c_2 = \sum_i \sum_j f_{ij} d_{ij} \qquad (4.1)$$

**Table 4.7 Total distance driven per day specified per type of machine (in- and outside production area)**

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From Table 4.7 we can see that per day with all the machines 43 kilometer is driven, in- and outside the production area. This performance is used in section 5.1 to compare the current output of the production area to the desired output with the new layout. In the new output the production area should have a higher throughput of machines and the distance driven with the machines should be less.

During the observation in the production area we saw some bottlenecks, they will be explained below to show to Mainfreight where they should focus on to be able to handle the growth of AEM.

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## 4.3. Conclusion

This section will summarize the performance of the current layout of the production area, by answering the research question: *"What is the performance of the current layout of the production area (measured by KPIs)?".*

In this chapter we defined four KPIs to measure the current performance of the production area. The KPIs are: throughput of machines, production attainment performance, distance and time driven with the machines in the production area.

We found five bottlenecks during our observation, the bottlenecks for the efficiency of the production area are: inefficient inbound process, poor communication between departments, machines are moved across the same path multiple times, machines are picked up by an engineer instead of a logistic employee from the storage located outside and search for the correct machines takes much time.

The conclusion of this chapter is that all machines are moved 43 km per day, inside and outside the production area. This leads to a high risk of safety issues, for example the probability of accidents between machines and employees while there are moved. Due to the unforeseen growth the number of machines has rapidly grown the last couple of years in the production area. The layout has more or less remained the same and therefore the total distance traveled within the production area has increased.

# 5. Improvement options of the layout

This chapter describes the intended situation of the production area of Mainfreight ‘s-Heerenberg, by answering the third research question: *How can the facility layout be improved?*

We need to know how to design an improved layout for the production area, therefore we take a look at methods that are applicable in our situation. Next, we explain the new layout for the production area which is designed based on the proposed method. The third research question will show the improved layout, the SOLL-situation we want to reach at the end of the research to improve the efficiency.

Section 5.1 shows the improved flow of machines in the facility based on the used method of Muther, the Systematic Layout Planning. Section 5.2 summarizes the most important conclusions from this chapter.

## 5.1. Six steps Systematic Layout Planning

The method of Muther, Systematic Layout Planning, is most suitable in our case to design a new facility layout since this method is best applicable for a process layout of the facility. The production area can be seen as a process layout due to the fact of long distances and long waiting times. The time needed to execute an assembly is time consuming.

The method Systematic Layout Planning consists of six steps, it allows you to design an efficient layout based on activities, their relations between each other and the required area and equipment per activity. The six steps are explained in this section.

### Step 1: Relationship chart

The first step is to create the relationship chart. Before creating this chart, the activities have to be described to be able to understand each activity. In Table 5.1 the activities are shown.

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Table 5.1 Relationship chart activities in production area

| |
|---|
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Pictures of these activities can be found in Appendix D.

The activities are filled in the activity relationship chart, the relation between each activity relative to the other activities are determined. In Figure 5.1 it is shown how this relationship chart works. This relation is written in the upper part of the box. To indicate the appreciation of the importance of closeness, letters are used to show this. The description of this valuation can be found in Table 5.2.

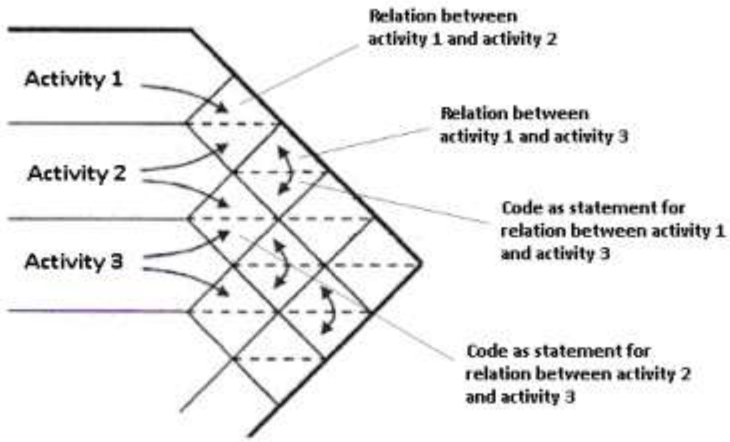


Figure 5.1 Relationship chart explanation

Table 5.2 Importance of closeness for each type of relation

| Importance of closeness | |
|---|---|
| ***Code*** | *Importance of closeness* |
| **A** | Absolutely essential |
| **E** | Especially necessary |
| **I** | Important |
| **O** | Ordinary importance |
| **U** | Unimportant |
| **X** | Undesirable |

Table 5.3 Reasons for closeness in case importance of relation is different than 'U'

| Reasons for closeness | |
|---|---|
| ***Code*** | *Reason* |
| **1** | Work order sequence/flow |
| **2** | Share same equipment |
| **3** | Common personnel |
| **4** | Contact necessary |
| **5** | Hamper |

The reasons for closeness are established based upon discussion with the production area supervisor and group leaders. As a brief explanation, code 1 means that machines have to go from one workstation to another workstation due to the work order sequence, vice versa is not possible. This can be seen as the flow of the machines through the production area. Code 4 means that contact between employees is necessary between the workstations, for example they need to know if the next workstation is available. Otherwise the machine cannot move to the next workstation. For every relation different than 'U' a code with regard to the reason is written in the bottom of the box. Based upon discussions with the production area supervisor and group leaders we present in Figure 5.2 the relationship chart, the first column contains the department numbers. An explanation of these reasons with their code can be find in

Table 5.3.

The complete chart can be found in Appendix H.

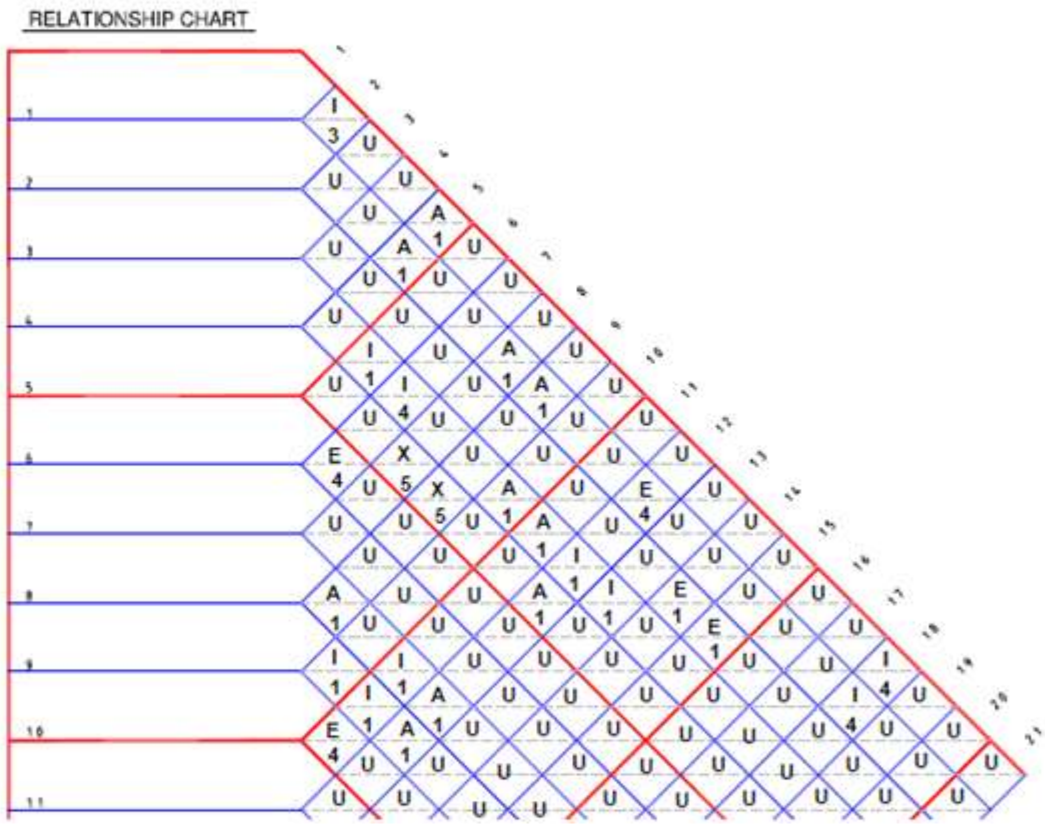


Figure 5.2 Relationship chart for each activity in production area

From Table 5.4 we can conclude that the U's are more than 75% of the total amount of relationships. It means that these departments do not have to be close to each other. This makes a redesign of the layout easier. The adjacency for the departments is important for workstations which process the same type of machine.

Table 5.4 Importance of closeness with amount of occurrence

| Importance of closeness | | |
|---|---|---|
| ***Code*** | *Importance of closeness* | *Amount* |
| **A** | Absolutely essential | 15 |
| **E** | Especially necessary | 6 |
| **I** | Important | 18 |
| **O** | Ordinary importance | 2 |
| **U** | Unimportant | 167 |
| **X** | Undesirable | 2 |

### Step 2: Space requirements

The second step is to determine the space requirements. Based on the planning, the amount and the dimensions of the workstation and machines, the required space is calculated and shown in Table 5.5. The square meters for the activity "Inbound" are separated for the new situation. In the new situation these activities are separated because of the possibility to have inbound at two different locations. Therefore, the required square meters are determined for both activities.

Table 5.5 Space requirements for each activity in production area (current and required situation)

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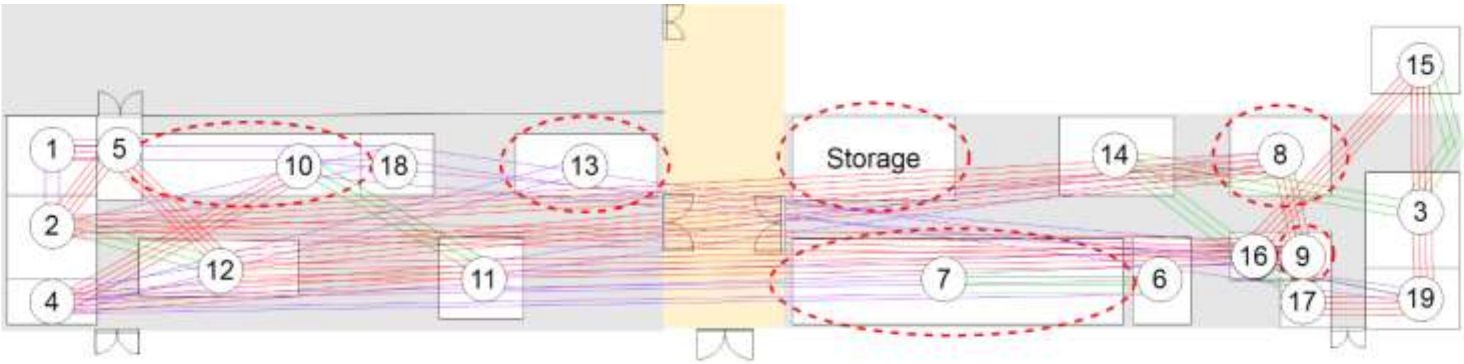
In addition, for each activity you have to check with which facilities the area needs to be equipped. In this case not all facilities are available for every location in the production area. If departments are moved to different locations there might be need of new facilities. There are several activities which cannot be moved to a different location in the production area.

Departments 20 and 21 have no assigned area inside the production area due the fact that these departments are only used when something happens to a machine. The person in charge of solving this issue will look for an empty spot to park the machine and fix the machine at that specific location. By assigning a specific area to these departments most of the time this workstation is not in use, therefore we decided to do not assign an area to these departments.

### Step 3: Activity relationship diagram

To give an indication how the production area is located inside the building of Mainfreight, in Figure 5.4 the dashed line represents the production area. The third step is to create the activity relationship diagram, it is the basis for designing and creating alternative layouts. The pattern is created by the mutual relationships with the ratings from the relationship form. To create this diagram we have to start with the activities with A-relations. These relations are connected with four parallel lines. Afterwards we start drawing the three parallel lines which represent the E-relations (red lines). If necessary, we can start again drawing and then add the I-relations to the diagram (green lines), the I-relations are connected with parallel lines (purple lines). Last step is to draw the O-relationships (black lines), which are connected by means of a single line. The orange area represents the corridor inside the facility, this corridor connects the different halls with each other. The result of the diagram can be found in Figure 5.3.




Departments whose locations are fixed

**Figure 5.3 Activity relationship diagram current layout**

**Table 5.6 Legend of production area layout**

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The current layout is designed based on the initial layout of the production area. It started relatively small and due to the fact that AEM saw opportunities to increase the assembly of more different type of machines, the production area increased in size the last couple of years. This is the cause that workstations are not in a logical order, every time a new type of machine had to be assembled in the production area. The workstation was created in an area that was available, the locations of workstations has not changed over the years.

### Step 4: Space relationship layouts

The fourth step is to create the space relationship layout, based on the activity relationship diagram drawn in Figure 5.2. First we need the empty floorplan of the complete area. The scale should be chosen so that the entire space fits on one sheet of paper. Figure 5.4 (dashed red line) shows the area where the machines are processed. Since we have the opportunity to make use of another part of another hall, we use this entire area to show the maximum available space.

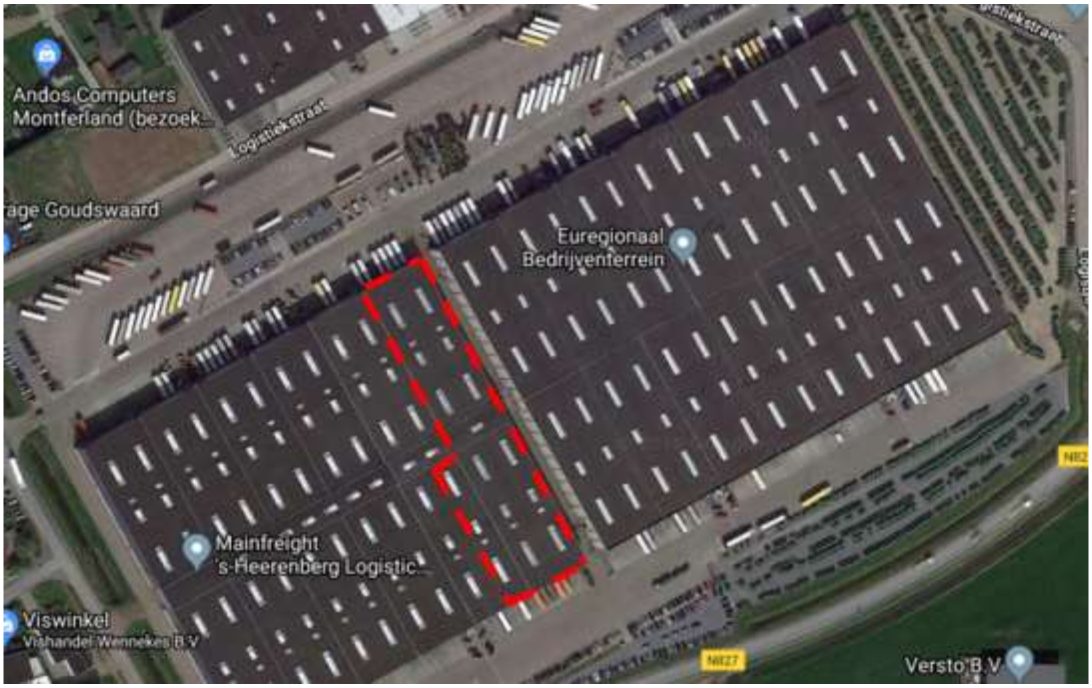


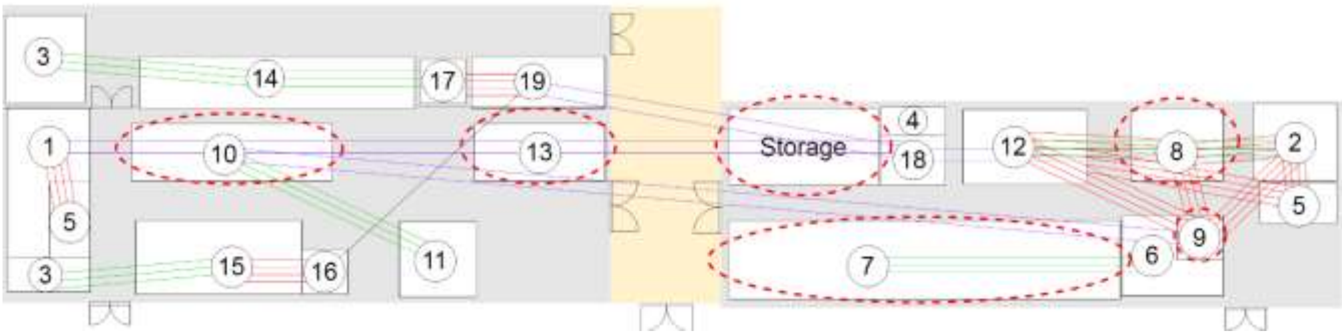

Figure 5.4 Satellite view of the production area (the dashed lines represent the production area)

The assembly process of the machines should take place within the marked area, the production area. The total available area is 6.500 square meters (including corridor and paths). In step 2 we calculated the total required space for the workstations, which is 3551 square meters. We can conclude that the workstations will fit into the total available space.

The next phase is to create new alternative layouts taking into account the closeness ratings from the previous step. By rearranging this multiple times, we are able to create an alternative to the current layout. We made use of the CRAFT algorithm which is discussed in chapter 2 (Heragu, 1997). Within this research, the distance between departments is calculated by looking at the original pathways between workstations. CRAFT is used together with pairwise exchange to develop new layouts, the possible changes are examined and the best change is identified, i.e. the one with the largest reduction in layout costs. Once the best exchange has been identified, CRAFT updates the layout according to the best exchange and the new centroids of the department. For every layout alternative the driving distance is calculated per machine. This new alternative distance is then compared with the current distance of 43 km that was found within chapter 4. Next to the driving distance, the driving time is calculated to see what savings could be made in terms of hours.

## Layout alternative A

In Figure 5.5 the first alternative layout is drawn. The activities are rearranged based on discussions with the employees of the production area and own insights learned from the literature. Alternative layout A is highly different from the current alternative, the activities are rearranged taking into account the priority of reducing the length of arrows. The workstations connected with red arrows have to be close to each other, due to the fact that these are absolutely essential for the process and due to the intensive flow.




– – – Departments whose locations are fixed

**Figure 5.5 Activity relationship diagram alternative layout A**

**Table 5.7 Legend of production area layout**

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Compared to the current layout we can notice that the length of red arrows extremely decreased. This is caused mainly due to the separated workstations 1 and 2. The routing of the machines will follow a short path and are therefore the workstation are allocated efficiently.

### Total distance alternative layout A

Table 5.8 Total distance in- and outside production area for layout alternative A

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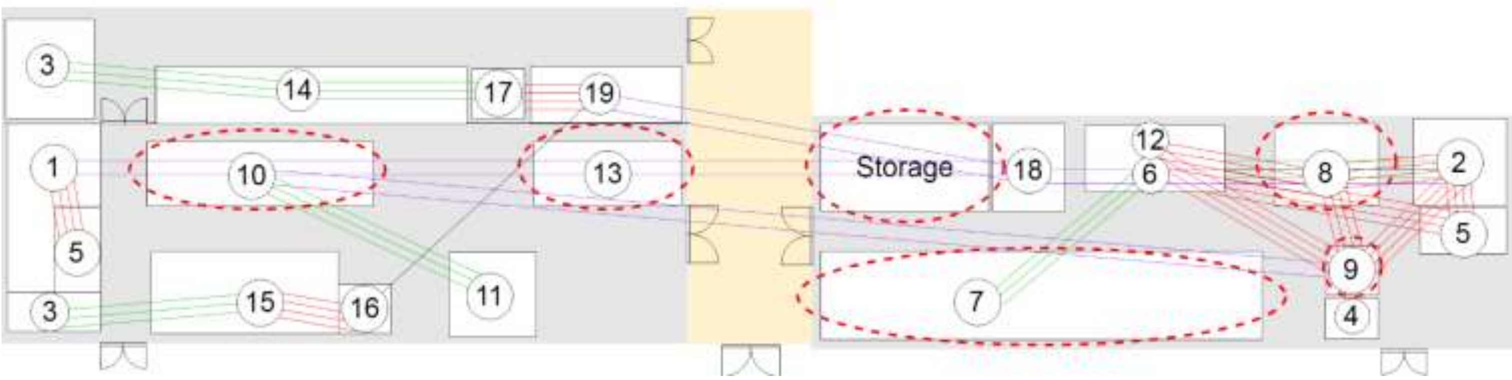
Table 5.9 Comparison current layout and layout alternative A

| Layout | Total per day |
|---|---|
| | Distance [m] |
| **Current layout** | 43616.8 |
| | |
| **Alternative layout A** | 37662.8 |
| **Improvement compared to current** | 13.65% |

In Table 5.8 the exact distance driven with the machines are determined for layout alternative A, we made use of equation 4.1 to calculate the total distance per day. If we compare this this distance with the current layout we obtain an improvement of 13.65%. Based upon discussions with the supervisor the layout can be improved further to save more kilometers.

### Layout alternative B

Based upon discussions with the supervisor of the production area layout alternative A is not the most efficient yet, we developed two alternative layouts. Figure 5.6 shows the alternative layout B. This alternative layout has small adjustments compared to alternative layout A. The workstations that are different in layout B, are workstations 4 and 6. Workstation 4 is moved to the end of the line. Since this area is not a fixed location anymore. Workstation 6 is merged with workstation 12. Since employees of their workstations are interchangeable this leads to an efficient use of space and a higher output. They can switch easily to the other type of machine without having to walk.




Departments whose locations are fixed

**Figure 5.6 Activity relationship diagram alternative layout B**

**Table 5.10 Legend of production area layout**

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### Total distance alternative layout B

Table 5.11 Total distance in- and outside production area for layout alternative B

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Table 5.12 Comparison current layout and layout alternative B

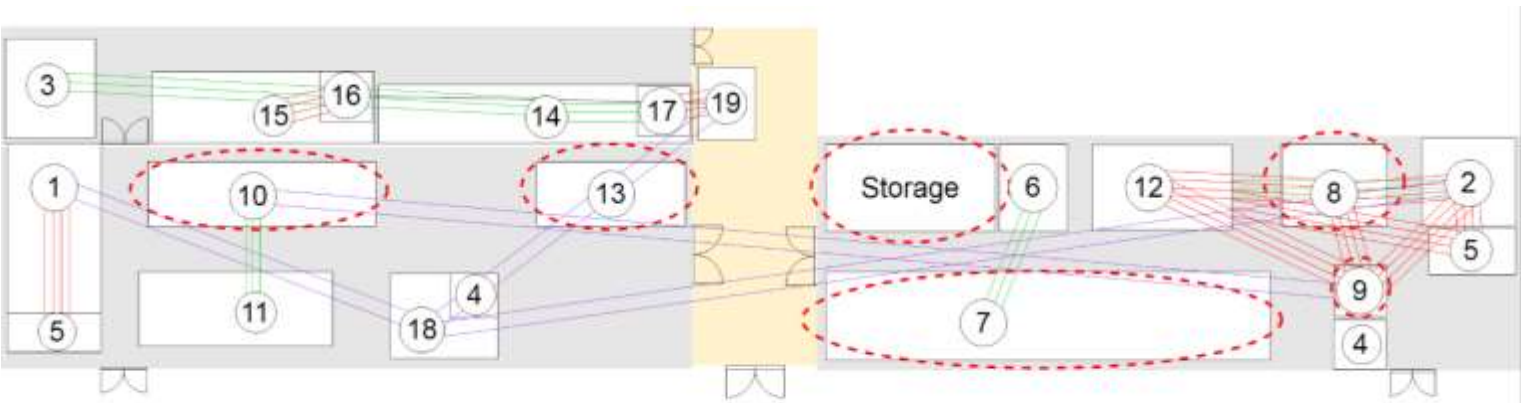
| Layout | Total per day |
|---|---|
| | Distance [m] |
| Current layout | 43616.8 |
| | |
| Alternative layout B | 37988.6 |
| Improvement compared to current | 12.90% |

In Table 5.11 the exact distance driven with the machines are determined for layout alternative B. If we compare these distances with the current layout we obtain an improvement of 12.90%. This is less than alternative layout A, therefore we need to develop another layout to improve the efficiency further.

#### Layout alternative C

The last alternative layout is layout C, which is represented in Figure 5.7. This layout has many modifications compared to the two previous alternatives. The most important is the change of workstation 15 and 16. These workstations are moved to the upper hall. To be able to do this workstation 14 and 17 are moved to the right, to create space for the workstation of this machine. Workstation 19 can in this case be moved to the corridor, since this workstation (area) is only used for temporary storage of machines. These machines are used for assembly whenever an engineer is ready to pick one.

Due to the movement of these workstations to the other halls, we created space in the left hall below. It makes it possible to improve the efficiency further, workstations connected with orange arrows can be located closer to each other. Workstation 18 can be located more central, which is important; since this workstation repair errors of machines which occur during the assembly process. There is more capacity because the available area is larger. Workstation 6 is separated. As stated in alternative layout B, combining these two leads to a higher output. However, if the workstations are still close to each other but separated, there is more space and thus capacity for processing the machines. The consequence is that the layout is able to handle future growth better.




Departments whose locations are fixed

**Figure 5.7 Activity relationship diagram alternative layout C**

**Table 5.13 Legend of production area layout**

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## Total distance alternative layout C

**Table 5.14 Total distance in- and outside production area for layout alternative C**

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**Table 5.15 Comparison current layout and layout alternative C**

| Layout | Total per day |
|---|---|
| | **Distance [m]** |
| **Current layout** | 43616.8 |
| | |
| **Alternative layout C** | 37244.6 |
| **Improvement compared to current** | 14.61% |

In Table 5.14 the exact distance driven with the machines are determined for layout alternative C. If we compare these distances with the current layout we obtain an improvement of 14.61%. This is the best improvement we found for the current layout, based upon discussions with the supervisor we can conclude that this is the best improvement we can find.

### Step 5: Alternative layouts evaluation

In the previous step we created 3 alternatives for the current layout which improve the current situation. In step 5 we evaluate the different layouts relative to each other. First the goals for the final layouts have to be determined. Next phase is to determine the importance of each aspect. The aspect which is the most important will get a '10' as score, the least important will get a '1' as score, in Table 5.16 it's called "weighted factor".

Each alternative layout is evaluated per aspect, the valuation is expressed by hand of a letter. These weighted factors per layout are shown in Table 5.17. Based upon discussions with the group leaders we determined the ratings for each aspect.

**Table 5.16 Weighted factor per aspect used for evaluation of each alternative layout**

| Weighted factor per aspect | | |
|---|---|---|
| **Letter** | **Description** | **Weighted factor** |
| **A** | Excellent | 4 |
| **E** | Very good | 3 |
| **I** | Good | 2 |
| **O** | Satisfactory | 1 |

**Table 5.17 Weighted ratings per layout alternative (multiply weighted factor by A=4, E=3, I=2, O=1)**

| Reasons | Weighted factor | Weighted ratings | | |
|---|---|---|---|---|
| | | *Layout A* | *Layout B* | *Layout C* |
| **1. Use of space** | 6 | A 24 | A 24 | E 18 |
| **2. Routing** | 8 | E 24 | E 24 | E 24 |
| **3. Inbound separated** | 5 | E 15 | E 15 | E 15 |
| **4. Improved flow rate (less traffic per square meter)** | 7 | A 28 | A 28 | E 21 |
| **5. Enough space for busy workstations** | 8 | E 24 | I 16 | A 32 |
| **6. Crossing the path (located in center of production area)** | 3 | E 9 | I 6 | I 6 |
| **7. Passing location twice or more times** | 6 | E 18 | E 18 | E 18 |
| **8. Total distance driven with machines** | 10 | E 30 | E 30 | A 40 |
| **Total** | | 172 | 161 | 174 |

The alternative layouts are discussed with the supervisor and group leaders of the production area. We determined the weighted factors for each reason and decided for each layout alternative what the rating is. A summary of these scores can be found in Table 5.7.

Reason 8 is important since the goal of the research is to reduce the total distance. For this purpose the total distance between workstation is manually calculated with the use of the layout in Excel. When the distance between workstations is known we have to multiply this with the total amount of machines processed per year. The sum shows the weighted average distance, based on this the efficiency is determined, a lower value means a higher efficiency. The total distance for each alternative layout can be found in Table 5.8, Table 5.11, and Table 5.14.

### Comparison time driven with machines

Layout alternative C reduces the distance driven with the machines the most, compared to the other alternatives. If we convert the distances to time, we know how much time it costs every day to move the machines to the next workstation or destination.

In Table 5.18 the savings/increase per day are calculated. We assume that the savings in distance are the same for the time. We take the percentage reduction for the distance and apply this reduction to the current time machines are moved.

**Table 5.18 Time savings per day per machine type current layout compared to Layout C**

| Machine | Saving/increase per day [sec.] |
|---|---|
| *CONFIDENTIAL* | 164 sec |
| | 80 sec |
| | 64 sec |
| | +621 sec |
| | +704 sec |
| | 261 sec |
| | 1254 sec |
| | 235 sec |
| | 535 sec |
| | 60 sec |
| | 344 sec |
| **TOTAL** | **28 min**<br>**0.46 h/per day** |

With the new layout the savings are 28 minutes per day. Next to the time savings, the safety has improved due to the fact that less kilometers are driven every day. Pathways are used less often to move machines across the production area, workstations that are needed for the machines are close to each other and in a logical order. This decreases the amount of machines using the pathways, where employees are walking, and therefore a safer environment is achieved. Another improvement is the increase of the available space for the production area, since the production area is expanded to another hall workstations have increased their capacity. This makes sure the production schedule can be more accurate and the production area is able to achieve the forecasted demand by AEM for the machines in the production area.

### Step 6: Detailed selected layout plan

During the final step, the chosen layout is drawn in detail. This means that all the necessary equipment, workstations, and other used tools, per activity in the layout are drawn. Layout C is drawn in detail in Figure 5.8, this layout is the most efficient compared to the other alternative layouts. All the halls; 5, 6, 7, 21 and 22 are shown. In Appendix V a larger version of Figure 5.8 is shown. Appendix IV shows the detailed new improved layout plan without the flow of machines.

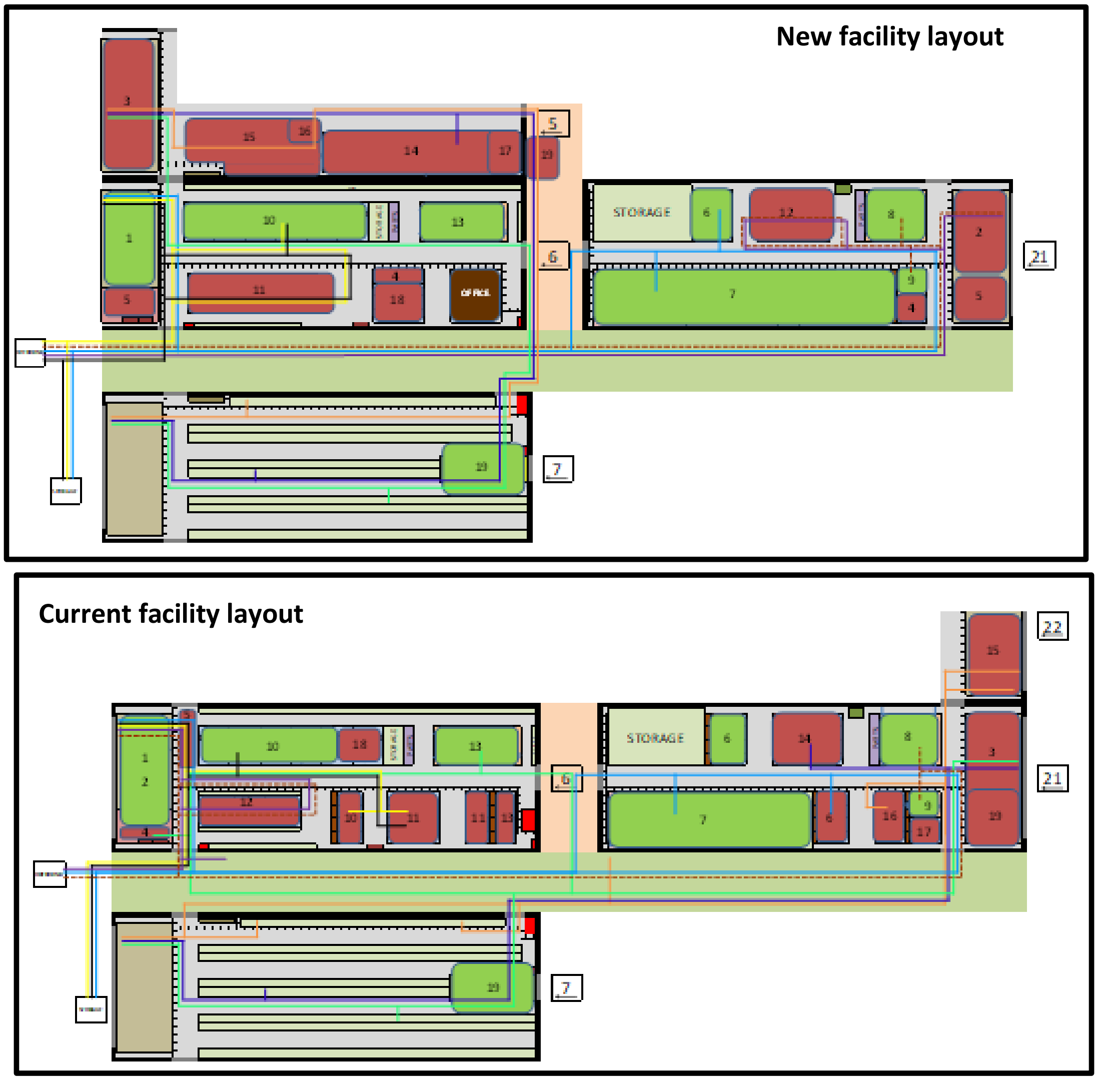


Figure 5.8 Detailed layout plan for the production area (above new and improved; below current)

Table 5.19 Legend of the production area layout

| |
|---|
| ***CONFIDENTIAL*** |

The difference between the current and improved layout are the departments highlighted in red, the department highlighted green have not changed .The most important change are the departments 1 and 2. These departments are now divided over two separate areas. This makes it possible to reduce the distance driven with these machines, since these machines do not have to drive in both halls anymore. Department 12 has moved closer to the inbound area of these machines, to reduce the distance driven with the machines further. Another change in the layout is the movement of department 14 and 15. Department 14 is moved to the left upper hall to reduce the use of the pathway where the machines are moved. Department 15 has moved and increased in size due to the fact more machines of this type needs to be assembled. Department has 19 moved closer to department 14. With this change employees have to drive less distance with these machines. Department 11 has moved to left to be able to create a smoother flow for the machines. Two other departments that are moved are 4 and 18, these department are more centrally located in the improved layout. In Appendix V this is shown in a larger layout. The implementation of layout alternative C can be spread over several weeks. A roadmap is therefore given in table 5.16.

Table 5.20 Roadmap implementation improved layout

| Priority | Action | Actor | Time |
|---|---|---|---|
| 1 | ***CONFIDENTIAL*** | Manufacturer of the equipment | 5 weeks |
| 2 | | Manufacturer of the equipment / Employees production area | 2 weeks |
| 3 | | Employees production area | 1 week |
| 4 | | Employees production area | |
| 5 | | Employees production area | 2 weeks |
| 6 | | Manufacturer of the equipment | 4 weeks |
| 7 | | Employees production area | 2 weeks |

| Priority | Action | Actor | Time |
|---|---|---|---|
| 8 | CONFIDENTIAL | Employees production area | 1 week |
| 9 | | Employees production area | 1 week |
| 10 | | Manufacturer of the equipment | 2 weeks |
| 11 | | Employees production area | 3 weeks |
| 12 | | Employees production area | 1 week |
| 13 | | Employees production area | 1 week |

Moving departments to new location can be done simultaneously, therefore the sum of the weeks is not the total time needed to have the new layout ready. Based upon discussions with the supervisor of the production area the estimation is that a total of 11 weeks is needed to complete the movement of departments to their new location and the installation of new equipment by the manufacturers.

## 5.2. Conclusion

This section will summarize the intended situation of the production area of Mainfreight ‘s-Heerenberg, by answering the research question: *“How can the facility layout be improved?”*.

First the importance of relations between departments are determined based upon discussions with the supervisor and group leaders of the production area. Based upon those relations the relationship chart is created. After this is created we determined the required space for each department. With this data together we draw the activity relationship diagram. In this diagram arrows represent the flow between the different departments. The objective is to reduce the length of these arrows to make sure departments who have an intensive flow between each other are close together.

In the next step we developed three alternative layouts to the current layout to improve the efficiency. To select the most promising alternative layout we evaluated the layouts based on eight criteria with corresponding weight factors. The criteria are determined to take into account the objective of this research to reduce the distance driven with the machines. Next to reduce the distance, the time driven with machines needs to be reduced. This has been taken into account and computed. The most suitable layout to reduce the distance was layout C, which improved (reduced) the total distance with 14.6%. Per day this leads to a savings of 0.46 hour. The improved layout can be found in Appendix IV. The two other KPIs, throughput of machines and production attainment performance have improved in accordance with the objective. The available area for the production area has increased and the workstations have more capacity to process the machines. The production schedule can be achieved more easily since in the current layout the problem was not enough capacity, due the fact machines are moved less often and in a more efficient way, the capacity of the workstations has increased.

# 6. Discussion

This chapter discusses the limitations of the research.

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# 7. Conclusions and recommendations

In section 1.2 it was described that due to the increase of the number of machines in the production area, agricultural machines of AEM move often between workstations across the production area. The management of Mainfreight *believes* that due to these movements the production area is not efficient anymore. To analyze the efficiency, we outlined our objective in section 1.3: How can Mainfreight improve the efficiency of the production area by reducing the total distance driven with agricultural machines such that also a safe environment is created. In section 6.1 we conclude to what extent we succeeded in achieving this objective. Moreover, we give recommendations in section 6.2 to Mainfreight and directions for further research in section 6.3 which came across during the analysis of the efficiency of the production area.

## 7.1. Conclusions

The objective was to improve the efficiency of the production area by optimizing the number of movements of machines to a minimum. To be able to improve the efficiency we first identified the current situation and efficiency. Next, we performed a literature study that focused on the redesign of a facility layout. Then we proceeded with the steps to redesign the layout of the facility.

### Current situation

For the current situation we conclude that the movements of machines is not optimal. Based on the drawn flow of machines within the layout we conclude that machines are moved often. The current performance is not enough to handle the expected growth.

We measured the production attainment and we can conclude that the current production schedule is not accurate. Often the production schedule is either too low or too high. This affects the amount of employees needed for the jobs to complete. Since the schedule is not accurate the targets cannot always be achieved. This leads to a lower efficiency.

There are five bottlenecks which affect the efficiency in the current situation: an inefficient inbound process, poor communication between departments, machines are moved across the same path multiple times, machines picked up by an engineer from outside storage and search for the correct machine takes much time.

### Improvement of the layout

During our research we found out that the layout of the facility needed a redesign, able to handle more machines and future growth. To redesign the layout, we made use of the method ‘Systematic Layout Planning’ developed by Muther (1961). The approach of Muther is used very often and has been proven to work effectively in designing a new layout.

The new layout is based upon discussions with employees from the production area. As chapter 5 revealed, we indeed designed a layout that matches our objective: the new layout improves the efficiency of the production area. The results we achieved with the new design were very promising: we improved the total distance driven per day for all machines with 14.61%. To gain less disruptions in the process of assembling machines employees should communicate clearly between each other.

An important aspect of the new layout is that it not only performs well for the current amount of machines, but also for growth in the future. Due to the expansion to an extra hall, there is more capacity to handle each type of machine. There is enough space to meet the expected growth of AEM for the next coming years. By this, Mainfreight can continue their relationship with AEM.

In addition, we showed that there are some bottlenecks in the production area. The new layout resolves most of these bottlenecks. The bottlenecks that are not solved with the new layout are part of further research, this is discussed in section 6.3.

With this research we proved that the new layout can successfully be employed in the production area. The redesign outperformed the other alternative layouts based on the total distance that is needed to drive between workstations.

## 7.2. Recommendations

This research does not only give insights in the current performance of the layout in the production area, it also offers a structured facility layout approach. This section gives the layout solving structure Mainfreight can learn from.

The research shows a structured approach to the facility layout problem, the method used for improving the current layout is the Systematic Layout Planning of Muther. It consists of six steps to be able to design alternative layouts. After the design of several alternative layouts, they are evaluated based on the current situation. By weighted-factors the best layout is selected and drawn in detail with the tools and equipment.

In section 5.1 we created stepwise a new layout to structure the recommendation. We recommend to start with these steps to understand the new layout. Mainfreight should rearrange the workstations in the production area according to the layout shown in Appendix IV. This new layout reduces the total distance driven with 14.61%. The total distance for all machines reduces from 43616.8 meters to 37244.6 meters per day.

Lastly, the complete research has given us insight in the actual problems in the Late Configuration Center at Mainfreight, and what their possibilities are to improve their situation. We recommend to read the full research and enjoy the clarity in the problem it provides us.

## 7.3. Further research

During our research we excluded some subjects we came across in our analysis. In this section, we discuss some of these excluded subjects.

In section 4.2 we discussed the communication between departments. It is unclear for employees in certain scenario's what they should do, for example if something goes wrong during the process in the production area. They do not exactly know how to handle and to communicate with whom. In this specific case it might occur that several employees are busy with one relatively small issue, which causes a lot of disruption in the assembly process for other employees. During our research, we left this bottleneck out of the analysis. The process can be analyzed without taking this into account.

Another bottleneck is discussed in section 4.2: the machines are picked up by an engineer from the outside storage. During the research we observed that employees walk often and long distances. One of the reasons is that the storage of machines, that still needs to be assembled, are stored far away from the production area. It happens often that an employee from inbound moves a machine to the storage outside and walks back to the production area. At the same time an engineer walks from the production area to the storage outside and picks up a machine. These employees should work together to save unnecessary walks to the storage outside. During our research, we left this bottleneck out of the analysis due to the fact it is currently impossible to move this storage area outside to another location. The calculation of the efficiency of the production area does not suffer from this on this since we set the starting point of the calculation at the entrance of the production area.

In section 4.2 we discovered another bottleneck: searching of machines takes a lot of time. We observed during the analysis that there are no assigned storage locations outside for the finished machines. They are sorted based on type of the machine, in case there are more than 100 machines of the same type stored at the location, finding the correct machine takes much time. In order to find fast the correct machines, assigning the machines to an area which have a location (for example A1), reduces the area to seek for the machine.

Avoiding above bottlenecks will give a higher efficiency and increases the performance of the production area significantly.

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# Appendices

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