Design of an Assembly System at AERCRETE INDUSTRIES

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Production Systems: Production Development and Management
Design of an Assembly System at AERCRETE INDUSTRIES

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This thesis work is performed at Jönköping Institute of Technology within the subject area of Production Systems. The work is part of the university’s two-year Master’s degree. The authors are responsible for the given opinions, conclusions and results.

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Abstract

The forming of an assembly system is a complex task, which should be considered as never ending. In order to successfully plan and implement an assembly system it is of vital importance that the obstacles and preconditions that have an impact on the system are identified and evaluated. This together with the necessary support activities and the attributes of the product to be assembled constitutes the starting point for the forming of the assembly system. The aim of this thesis is to link the theoretical findings with the issues stated above, and through this explain a best practice approach when forming the assembly system.

The theoretical work aims at describing the nature and activities within assembly and manufacturing systems and explains these in three different levels of strategies divided into Manufacturing strategies, Layout, material flow and design strategies and finally Logistic, material handling and quality strategies. Then the obstacles and preconditions found are discussed and evaluated which set the basis for the forming of the assembly system and by linking these with the relevant theory, conceptual design proposals for the assembly system and the Logistic support system are formed.

These are then evaluated and finally a proposal for the detailed layout of the assembly system is given. This proposal is then to be used as a guideline for the company Aercrete when forming their assembly system.
Summary

In order to create new assembly systems there is a need for the company to assess and know the circumstances surrounding the forming of the system. For an assembly system it is important to consider the products architecture and the need for each part of the product to be assembled and therefore a number of preconditions need to be evaluated in order to find the key factors to consider when forming the actual system.

This thesis purpose is to find these preconditions in order to be able to form a detailed layout of the assembly system. To do so the use of theoretical findings is important in order to be able to identify what is necessary for implementing a successful system. The theory is based upon three different areas namely manufacturing strategies, performance measures and Lean strategies together with logistic, quality and material handling strategies and layout, material flow and design strategies. These areas are chosen in order to cover as many aspects as possible that the assembly system affects and to give a good foundation for the assembly system.

With the aid of this theory, the preconditions and obstacles of the product, the facility and the support system can be found, evaluated and placed into the different areas described in the theory. The preconditions and obstacles are then taken into consideration together with the theory in order to find a customized way of forming the assembly system.

A number of conceptual less detailed suggestions for the assembly line and logistics system layout are then being outlined and evaluated to show that different considerations have been taken and that several different ways of inputs has been examined and evaluated in order to find an optimal or best practice design.

The conceptual designs are then turned into a detailed design which is described as the final and optimal suggestion and serves as a suggestion for the company when starting continuous assembly of the product.

Key Words

Production Development, Assembly system, Assembly line, Production system, Logistics, Material handling.
Acknowledgements

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Jönköping, September 2009

Andreas Adlerborn                                       Henrik Hansson Tengberg
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Introduction

In this chapter, the reader is introduced to the background of this thesis as well as the company and product that the thesis project was involved with. The aim of the thesis is presented as well together with the delimits.

This thesis is carried out in the subject area of Production Systems and is the ending project of the Master programme in Production Systems with a specialization in Production Development and Management. This thesis is particularly touching the production development part of the programme, and is dealing with the matter of how to develop an assembly system from scratch. In today’s Sweden, a lot of production is moved to low cost countries due to the high cost of labour and other resources of production (Aniander et al., 1998).

This fact leads to the importance of keeping the costs of production at a minimum, while keeping the capital invested in the company at a low level (Olhager, 2000). The future’s companies have to be flexible, cost efficient and customer oriented in order to be successful. In addition, the companies also need to be innovative and develop a high spirit of entrepreneurship within the organization (Aniander et al., 1998).

The functions in a company that create value adding activities are normally grouped into a function called the production system. The system is supposed to transform input resources to output products with an increased customer value (Bellgran & Säfsten, 2007). The transformation process can be anything from assembly or machining operations to consultant services. The profit a company creates is the difference between the value the transformation process generates and the cost of the transformation process plus the overhead input resources required to produce output (Olhager, 2000).

1.1 Company background

Aercrete Industries AB is today a small company situated in Bankeryd just outside of Jönköping. The company is a so called “Small and Medium sized Enterprise” with three employees at the moment. Today the company has a main product, Aercrete 625, which is a mobile foam concrete machine aimed at the construction sector. The company has many prospects for its mobile foam concrete machine regarding future sales and services. The mobile foam concrete machine Aercrete 625 has been developed by Aercrete Industries during the last 3 years and is now ready to put into production. The picture below is showing the machine in the way it is supposed to be transported.
As of today, Aercrete Industries has no continuous production of this machine, but instead the focus has been on producing a few prototypes for smaller jobs, and for demonstrations to possible clients. These demonstrations have so far been successful, the company has noticed an increase in the interest of their product, and they have realized that an order of this machine might be possible in the near future. Therefore, the company feels a need of having a finished plan for the future state of the assembly process of the machine. Today the company possesses a facility, which has been lent out to another company, but now this company has moved out and the facilities are now free for the assembly of the machine. The company now wants a production layout and a plan for how to form the assembly system with considerations taken to the facility layout, the material handling and workload balancing between operators. The assembly system should support the product, regarding the facility and other surrounding constraints.

1.2 Purpose and aims

The purpose of this report can be divided into two parts. The First part is the academically part, which is to give the authors the possibility to apply the knowledge that they have been gaining over the last 5 years of education at university level. From the readers perspective the first academically part is to give a clear insight in the conditions and aspects needed for the planning and implementation of an assembly line taking the constraints that surrounds the product and the facility into consideration.
The second part is the practical part, which is to use these conditions and aspects in order to present a real suggestion for the layout, logistics and material flow of the assembly system. This is supposed to be a feasible suggestion that can be implemented in reality at Aercrete Industries. Practical requirements that serve as aims for the design process were specified by the management at Aercrete Industries, and these targets are:

- The assembly system is supposed to produce 20 machines initially with a production target of 80 in the long run.
- The assembly should be as efficient as possible and the facility should be used as efficiently as possible.
- The capital tied up in the assembly system should be as low as possible.
- The throughput time should be less than 100 hours and preferably less than that.

The purpose of the thesis is thus to design an assembly system that will meet these requirements.

A common problem with thesis work is to be able to write an academic report and at the same time satisfy the expectations from the company the thesis is carried out at. It is therefore necessary to balance the report in order to satisfy both the academic goal and the requests from Aercrete Industries about development of an efficient assembly system.

In this particular report the overall aim is to base this suggestion upon theory and to be able to do this, delimitations has been made in order to find the core issues of what is needed. Since forming and development of an assembly system is a huge task, which is never ending, the aim is to present a clear layout of the assembly system explaining the sequence in which the assembly is to occur, and to find a suitable way of handling material and where to place workstations.

Furthermore, the aims are to place and divide tasks to the operators and to balance work between them in order to get an even workload as possible between them. Thus it can be concluded that the main purpose of this report is to give an overall detailed suggestion of a suitable layout based upon facility, product and material handling constraints.
1.3 Delimits

This report's focus will result in a complete layout of the assembly system with regards to the constraints given by the facilities, product, material handling and strategy chosen. Since there are many issues to consider when designing a new assembly system, this report is delimited to the production layout of the factory, the logistics and material handling system, and the flow of material. The management at Aercrete Industries specified a few requirements of the future state assembly system (see section 1.2) and besides these, there were no other limiting factors on the design process.

This report will not include detailed design of workstations, description of assembly techniques and very detailed suggestions, but shall serve as a suggestion for how the future state of the assembly system will be when it is in operation. How to get to that state, was chosen not to be included in the thesis. In other words, the planning for the ramp-up phase of production development will not be included in this thesis.

1.4 Outline

The report is structured into different chapters that are sequentially guiding the reader through the thesis and the implementation of the project.

**Chapter 1 – Introduction**
In this chapter, the company background together with the disposition and purpose/aim is presented. This chapter introduces the reader to the start position of the thesis project.

**Chapter 2 - Theoretical background**
In this chapter, the theory that was relevant for the thesis project is presented and is supposed to help the authors with the project, but also to introduce the reader to the theory behind the work that is carried out.

**Chapter 3 – Methodology**
The methodology chapter presents the reader to the methods and tools that has been used for this thesis. It presents the way the research and development processes have been carried out.

**Chapter 4 - Analysis of the preconditions**
This chapter presents the analysis of the preconditions that exist to the design process and affects the design of the assembly system.
Chapter 5 - Conceptual design of the assembly line
This chapter presents the conceptual assembly line’s design process and the result of the process.

Chapter 6 - Conceptual design of the logistic system
This chapter presents the conceptual logistic system’s design process and the result of the design process.

Chapter 7 - Detailed design of the assembly system
This chapter is presenting the design process of the final detailed design of the assembly system and the result from the process.

Chapter 8 - Conclusions and discussion
In this chapter are the final conclusions of the thesis project presented. Besides, the thesis is reflected about and a discussion of the work is included as well.

Chapter 9 - Glossary
This chapter provides a glossary of words that has the potential of creating confuse for the reader.

Chapter 10 - References
This chapter contains the references steaming mostly from the literature review.

Chapter 11 - Search words
This chapter contains a list of search words to make it easier for the reader.

Chapter 12 - List of attachments
This chapter contains the attachments that have been referred to in the text.

1.5 Clarification and reading instructions
In the thesis the terms manufacturing system, production system and assembly system is used. A production system is in the literature considered to be a part of a manufacturing system, which also are considered to contain some sort of logistic system (Bellgran & Säfsten, 2008). The definition of an assembly system is normally considered to be rather similar to the one of production system, with the exception that a production system can consist of more than 1 assembly system.
In this thesis, the term assembly system is more linked to the definition of the manufacturing system. In this thesis, the term assembly line is rather similar to the one of production system. In the theoretical background, the terms that are used in the reference literature is used and there might be misunderstandings. A reader with scholar in this area may find this approach confusing, but the authors of this thesis found it necessary to make an own definition for the sake of not being inconsistent.

The less subject experienced reader of this thesis can neglect these differences and see it as an interlinked expression for a system in which some sort of value adding activities are carried out, and with material flowing in and out of the system. The term logistic system is describing the activities associated with the in and outflow of materials and how they are transported, handled and used in the assembly system.
2 Theoretical background

This section is supposed to highlight the available theory that can serve as a helping hand when designing the assembly system. The theory is supposed to highlight the available methods and philosophies and create a base for the logical way of carrying out the design.

The theory included in this chapter has been chosen based on its usefulness to the assembly system design process. The theory included is of both a traditional and less traditional nature, thus enabling the use of a “best practice” approach.

The theoretical background chapter can be divided into three major parts. These parts are:

- Philosophies, strategy and guiding factors
- Layout, material flow and design
- Logistics, material handling and quality

The philosophies, strategy and guiding factors part consists of the manufacturing strategy section, which is supposed to be the foundation of the assembly system design. The part also includes a chapter about the performance measures of manufacturing systems, and how to achieve high profitability. A chapter regarding Lean Production is also included in this part. This part is supposed to highlight the pre-design influences normally taken into a manufacturing system development process for manufacturing systems.

The layout, material flow and design part consists of a chapter about a method for systematic layout planning. More, it consists of a chapter about facility layout and flow and, a chapter about product structure and architecture and a chapter about assembly technology. This part is essential for the assembly line and system design process. It provides the necessary structure that the design process requires.

The logistics, material handling and quality part consists of a chapter about the logistics that surround an assembly line and is included in the assembly system. A chapter about quality is also included in order to provide essentially necessary inputs to the design process.
2.1 Manufacturing Strategy

The strategy is acclaimed to be the first step in a manufacturing system development process. The strategy should reflect the business/functions targets set by the management and be the plan for fulfilling those goals (Brown, 1996). Overhead strategy can be broken into strategy for different functions in a business (Hill, 2000a).

2.1.1 Strategy

Strategy is tactical decisions that are compiled into a plan, aiming at achieving some desired goals or targets (Ritson, 2008). The process of strategy (figure 2-1) describes the way a strategy is being transformed from planning to implementing and finally, achievement of the desired objectives that lies behind the formulation of the strategy (Dangayach & Deshmukh, 2001).

Figure 2-1. The process of strategy (Ritson, 2008).

According to Hill (2000a) and Brown (1996) it exist different levels of strategy, in the strategy process, and they have been identified as an overhead corporate/business strategy, which affects the other separate functional strategies. Traditionally, a corporate strategy has been formulated by the senior management.

Then, the corporate strategy is being translated into a marketing strategy by the marketing department. Finally, a manufacturing strategy is being formed based on the previous step (Brown, 1996). This isolated procedure in combination with little functional knowledge, has traditionally led to functional strategies with little involvement in the corporate strategy formulation (Brown, 1996). According to Hill (2000a) another more optimal approach is to link the functional strategies back to the corporate strategy, thus integrating the functional aspects.

2.1.2 Manufacturing strategy

When developing a Manufacturing system, it is emphasized in the literature that formulating a proper manufacturing strategy is essential (Bellgran & Säfsten, 2008).
The theoretical background

The manufacturing strategy is supposed to link the corporate strategy to the strategic planning and decision making regarding manufacturing, in order to reach the corporate targets and goals (Hill, 2000b). The manufacturing strategy is supposed to be the underlying philosophy for the design of the manufacturing system and guide during the development phase (Maynard, 2004).

The question to answer is thus what a manufacturing strategy is? According to Hill (2000a) the definition of a manufacturing strategy is: “Manufacturing strategies comprises a series of decisions concerning process and infrastructure investments, which, over time, proved the necessary support for the relevant order-winners and qualifiers of the different market segments of a company”. Order qualifiers are defined as attributes that qualify a product/service into a marketplace. Order winners are those attributes that actually sell the product/service (Hill, 2000a).

The content of a manufacturing strategy is depending on the competitive factors that a company has chosen, or identified, being necessary for achieving its goal; namely winning orders (Brown, 1996). The areas, or the content, normally considered in a manufacturing strategy are:

- **Capacity decisions**
  - Volume, size, timing
- **Production Process decisions**
  - Equipment, automation, layout
- **Vertical integration decisions**
  - Relationships, networks, sourcing
- **Workforce decisions**
  - Competence, salary, work conditions
- **Customer satisfaction decisions**
  - Speed, deliverability
- **Production planning/materials control decisions**
  - Centralization, “push-pull”, MRP, JIT

- **Organization decisions**
  - Structure, control
- **Flexibility decisions**
  - Volume, product mix
- **Cost decisions**
  - "make-buy”, design, tools
- **Quality decisions**
  - Systems, measurements
- **Technology decisions**
  - Machines, tools
- **Facility decisions**
  - Size, location, specialization

Table 2-1. Decision areas regarding manufacturing strategy. (Based on Brown, 1996; Bellgrann & Säfsten, 2008; Axelsson et al., 2008)
Slack & Chambers & Johnston (2001) have identified other strategically aspects that are important to consider, namely:

**Inventory strategy**

The amount of inventory held in the company and where to position it within the facilities and processes. Besides, controlling the size and composition of inventory is crucial.

**Improvement strategy**

How to make sure that the company is improving is another strategy that is considered important. In order to improve, the company needs systems that measures the performance and ensures that improvement efforts are carried out.

Hill (2000a) has structured the aspects of manufacturing/operations and marketing strategy into a framework for linking them to the overhead corporate strategy.

<table>
<thead>
<tr>
<th>Corporate objectives</th>
<th>Marketing strategy</th>
<th>Order winners</th>
<th>Process choice</th>
<th>Infrastructure</th>
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<tbody>
<tr>
<td>Growth</td>
<td>Market and segments</td>
<td>Price</td>
<td>Choice of various processes</td>
<td>Function support</td>
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<td>Survival</td>
<td>Range</td>
<td>Quality conformance</td>
<td>Trade-offs embodied in the process choice</td>
<td>Operations planning and control systems</td>
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<tr>
<td>Profit</td>
<td>Mix</td>
<td>Delivery: Speed &amp; reliability</td>
<td>Demand increases</td>
<td>Quality assurance and control</td>
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<tr>
<td>R.O.I</td>
<td>Volumes</td>
<td>Demand increases</td>
<td>Process positioning</td>
<td>Systems engineering</td>
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<td>Financial measures</td>
<td>Innovation</td>
<td>Product/service range</td>
<td>Capacity: Size, timing and location</td>
<td>Clerical procedures</td>
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<td>Leader or follower</td>
<td>Design leadership</td>
<td>Role of inventory in the process configuration</td>
<td>Payment systems</td>
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<td>Standardization vs customization</td>
<td>Technical support supplied</td>
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<td>Brand awareness</td>
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Table 2-2. Framework for linking corporate to operations/manufacturing strategy (Based on Hill, 2000a; Hill, 2000b).

### 2.2 Productivity and performance

The overhaul goal of any business is to generate substantial profit. Besides, the goal of any production or service activity within that business is to achieve high productivity and creating a high level of profitability (Andersson & Audell & Giertz & Reitberger, 1992). The term productivity is about how well a company utilizes its resources and is normally defined as (Helmrich, 2003):
Theoretical background

\[
\text{Productivity} = \frac{\text{Output}}{\text{Input}}
\]

Jirby (1992) states that the numerator in the equation above (Output) is relatively fixed in today’s competitive environment. This means that if the output term is seen as the sales volume, it requires much effort in order to increase the sales. The output factor, however, can be increased by improved quality, flexibility, time-to-market and increased customer satisfaction (Helmrich, 2003). The denominator in the equation (Input) is a variable that can be altered (preferably lowered) relatively easily, which increases the productivity. The input term normally includes resources required to produce the firm’s goods, like:

- **Machines**
- **Material**
- **Labour**
- **Facilities**

In order to achieve a high productivity the firm must operate with a low level of these and other resources in order to stay competitive (Olhager, 2000).

A similar term that is used for determine a firm’s performance is profitability, and is focusing on how well a firm manages to produce profit relatively to the input factors (capital). The term is normally defined as (Helmrich, 2003):

\[
\text{Profitability} = \frac{\text{Revenues} - \text{Costs}}{\text{Capital}}
\]

This performance indicator is linked to the overhaul goal of the businesses (profit) while the productivity indicator is more linked to the production/operations function in a business (Jirby, 1992). The conclusion from the equation above is that a business needs to improve its sales, cut its costs and reduce the capital tied in it in order to increase its profitability (Helmrich, 2003).

Olhager (2000) mentions 4 key strategically attributes that will achieve long term profitability:

- **Quality**
- **Delivery ability and performance**
Theoretical background

- **Cost efficiency**
- **Flexibility**

Andersson & Audell & Giertz & Reitberger (1992) states that it is often difficult to achieve efficiency in every performance target. According to Olhager (2000) is the reality that since the conflict exist, the problem is to make sure that the performance dimensions are balanced in order to achieve the greatest profit for the business as whole.

Olhager (2000) also mentions that there are 3 major dimensions of the profitability concept for the production/operations function, and that they are sometimes in conflict with each other. These 3 performance targets are: Delivery ability, manufacturing cost and low tied up capital in the production function.

![Diagram of conflicting targets in operations](image)

Figure 2-2. Conflicting targets in operations (Olhager, 2000).

The problem is to find an optimal balance of the 3 targets in figure 2-2 above, in order to optimize the financial result of the business. A prioritising of one of the targets may lead to overall inefficiency (Olhager 2000).

### 2.3 Lean Production

Lean Production is essentially the same concept as Toyota Production System, and is based on the concept of eliminating waste and increase output while being resource efficient. It is suggested that Lean Production is the documented version of the applied Toyota Production System (Liker, 2004). Large increases in productivity and profitability have been seen in companies that have adapted the Lean Production concept (Maynard & Zandin, 2004).
2.3.1 Philosophy

Many companies have since the eighties started to adapt the production philosophies of Toyota Production System (TPS), that was developed by Toyota Motor Company in the early fifties (Shingo, 1981). The reason for this emerging interest in TPS is the outstanding performance seen at the Japanese industry, and especially at Toyota regarding quality and efficiency (Liker, 2004).

The man that is described as the founder of the Toyota Production System, Taiichi Ohno, states that the cornerstone of TPS is the just-in-time philosophy (Ohno, 1988). Just-in-time (JIT) philosophy is, simplified, a guiding system for the planning and execution of the production system’s operations. Ohno (1988) describes JIT as “What you need, only in the quantity you need, when you need it . . . and inexpensively as you can”. According to Womack & Jones & Ross (1990) the development of JIT and TPS to their current designs, has been shaped and influenced by the scarcity of resources that Toyota, and Japan, was facing after the Second World War. In that environment the importance of utilizing the input resources to maximum, was a crucial factor when Toyota planed their operations (Maynard & Zandin, 2004).

Due to the implications of scarcity of resources, Toyota started to minimize “Muda” (waste) in their production system and design away “Muri” (overburden) and “Mura” (inconsistency). Monden (1994) is stressing that the elimination of waste is of greatest importance when operating a production system.

Ohno (1988b) states that it exist seven different kinds of waste that have to be eliminated:

1. **Over-production**. To produce either too much or items not desired by the market.

2. **Waiting**. Products waiting for being processed, workers just stand around or machine break-downs causing idle time.

3. **Unnecessary transport or conveyance**. Movement within the production system that aren’t adding any value.

4. **Over processing or incorrect processing**. Processing that isn’t adding value for the customer, using incorrect tools causing quality problems.

5. **Excess inventory**. Carrying too much inventory is hiding problems in the production system while creating high cost of capital.
6. **Unnecessary movement.** Work that forces the workers to move or bring tools to the workplace is inefficient.

7. **Defects.** Defects are causing several problems to the production system like over-production and time waste.

Liker (2004) has identified an eight waste, namely:

8. **Unused employee creativity.** The workers can contribute to the production system with more than pure hand craft.

Toyota has developed a simple figure that represents the Toyota production System (Ohno, 1988a). The figure shows the two pillars of JIT and Jidoka that are considered the walls that keep the system in function. The roof represents the goals of TPS and the foundation the fundamental elements of the system. The heart of the system is “Kaizen” (continuous improvement), and is the central element that makes the system competitive (Liker, 2004).

![Toyota Production System house](image)

Figure 2-3. The Toyota Production System house (Liker, 2004; Ohno, 1988a).

Liker (2004) has formed fourteen principles that are considered to summarize the extent of Toyota Production System.

<table>
<thead>
<tr>
<th>Continuous Improvement kaizen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Reduction</td>
</tr>
<tr>
<td>Genchi Genbutsu</td>
</tr>
<tr>
<td>5 Why’s</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Jidoka (in-station quality)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic stops</td>
</tr>
<tr>
<td>Andon</td>
</tr>
<tr>
<td>Person-machine separation</td>
</tr>
<tr>
<td>Error proofing</td>
</tr>
<tr>
<td>In-station quality control</td>
</tr>
<tr>
<td>Solve root cause of problems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leveled Production (heijunka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable and Standardized Processes</td>
</tr>
<tr>
<td>Visual Management</td>
</tr>
<tr>
<td>Toyota Way Philosophy</td>
</tr>
</tbody>
</table>
2.3.2 Lean tools and techniques

Even though Toyota Production System and Lean Production are described as a systematic approach by Ohno, (1988a) & Monden (1994) & Womack & Jones & Ross (1990), often the tools and techniques developed by Toyota are used individually without a systems perspective (Liker, 2004). The tools of Toyota Production System where originally solutions to practical problems at the Toyota plants. Therefore are not the tools and techniques in themselves a systematic and holistic approach to the design of a production system (Ohno, 1988b). However, the tools and techniques facilitate the execution of the system (Liker, 2004).

Some of the tools and techniques used in Lean Production are: 5S, Total Productive Management (TPM), Total Quality Management (TQM), 5 Why’s, Just In Time (JIT), Andon, Kaizen, Poka Yoke and Heijunka (Liker, 2004 & Ohno 1988a).

2.3.2.1 5S

One tool of Lean Production that is often used to organize the workplace is the 5S methodology (Ohno, 1988b). The 5S’s stands for five Japanese words that are focused at enhancing the elimination of waste, by making the waste visual through cleanliness (Liker, 2004).
• **Seiri (Sort).** Sort the workplace, only the tools needed for the processes should be present.

• **Seiton (Orderliness).** Everything should have a given fixed position.

• **Seiso (Cleanliness).** If the workplace is clean, it is possible to detect errors.

• **Seiketsu (Create rules).** Standardize the workplace and create procedures for the work.

• **Shitsuke (Self-discipline).** Sustain the process and continue with improvements (Liker, 2004).

2.3.2.2  **Kaizen**

Kaizen is described by Liker (2004) as a term for continuous improvement that makes incremental improvements from very small to very big improvements. Its aim is to eliminate all the waste that does not add to value.

Ortiz (2006) describes Kaizen as the never ending improvement. By the use of kaizen Ortiz (2006) states that continuous improvements not only develop the product and the processes surrounding it but it also evolve people’s way of thinking and their creativity.

2.3.2.3  **Just In Time**

Just-in-time is a Toyota production system/Lean production philosophy that aims at reducing the inventory and lead time in the production system (Mito & Ohno, 1988). The foundation of this philosophy is that the right products, in the right quantity and quality should be delivered at the right time, or in other words, when they are needed (Hirano & Furuya, 2006).

Just-in-time is used for planning of the operations by using Kanban cards for triggering the production process and flow of materials. The Just-in-time philosophy is stressing low inventory holding, thus requiring strong relationship within the supply chain (Shingo, 1981). Traditional inventory strategies are using the stock-up approach, meaning that the batch sizes are large and kept in inventory for a longer period. This approach consumes a great deal of space assets and ties capital in the system, due to the long throughput times (Hirano & Furuya, 2006). The Just-in-time philosophy on the other hand focuses on keeping the batch levels small, with more frequent deliveries of supply.
This leads to less inventory carrying cost, less capital tie-up, less waste in the supply chain and ultimately forces the supply chain to achieve a high and stable quality level (Hirano & Furuya, 2006).

2.4 Systematic Layout Planning

The Systematic Layout Planning method has been practised over a long time and is one of the most famous tools for achieving a systematic approach to the layout design. It exist a simplified version of this method called: Simplified Systematic Layout Planning, which is a more practical approach to the layout-arranging problem (Muther, 1973).

2.4.1 Background

According to Muther (1973) there exist two ways of solving the layout planning problem. The first way is to buy all the equipment and material and position them on the shop-floor and then simply rearranging them until their position satisfies the needs. The second way is to use a systematic planning procedure to determine a fairly optimal arrangement of the future layout before the equipment is placed on the shop-floor. It is stated that the large cost of rearranging makes it worth to spend efforts on some pre-installation planning (Muther, 1973).

When facing a layout problem, there are usually two elements that are first facing the designer:

1. Product (P)-The impact of the product on the future production system

2. Quantity (Q)-How many items of each product that is going to be processed

After these previous two issues are dealt with, another three elements are often considered to be important to grasp into consideration by the designer:

3. Routing (R)-How the product will be manufactured

4. Supporting service (S)-The surrounding functions that support manufacturing

5. Time (T)-Time considerations regarding the product, the manufacturing system and the development project

Muther (1973) argues that if followed, these five steps will provide a solid base for an inexperienced layout planner.
In the method called Systematic Layout Planning, developed by Richard Muther (1973), the process of developing a new process layout has been broken down into four sequential phases:

1. **Location**

2. **General Overall Layout**

3. **Detailed Layout Plans**

4. **Installation**

Phase one includes the decision regarding where the new production system will be located, in other words choosing the facility that will be used.

Phase two is dealing with choosing flow patterns and making a rough layout, so called block layout, which considers the space requirements and constraints.

Phase three comprises the act of placing all the physical features, elements and services to their actual placement. This is a detailed version of the general layout.

Phase four is the realization phase, thus meaning creating drawings, seek approval for the detailed plan, planning the installation and eventually make the physical installation of the manufacturing system (Muther, 1973).

### 2.4.2 The framework

According to Muther (1973) is all layout-planning problem resting on three fundamental corner stones:

1. **Relationships** - Closeness, precedence or logical order of the items

2. **Space** - The item’s space or shape constraints

3. **Adjustment** - The search for an practical arrangement of the items

With these three corner stones considered, Muther (1973) has developed a systematic framework for the layout-planning pattern of procedure (see figure 2-4). The logic of the framework is that the process of creating a layout starts with gathering input data. Then all the activities, departments and the area are, without consideration for the space requirements, grouped into a simple layout.
Theoretical background

Next, the space that each activity will cover is matched against the available space of the facility, on some form of layout. Then the implications of practical dimensions and other requirements are met through the adjustment fundamental step. Then the different layouts are evaluated through a systematic approach, which generates the final selected layout plan that will be used as the background for the practical layout (Muther, 1973).

Figure 2-4. The Systematic Layout Planning Pattern of Procedures (Muther, 1973)

2.4.3 Selection of layout alternatives

When a few possible detailed layouts have been created, the process of evaluating them starts. Muther (1973) suggests that three basic methods are used for this purpose:

1. Balancing the layout’s advantages versus their disadvantages
2. **Factor analysis rating of the alternatives**

3. **Compare the cost and justification between the different alternatives**

Analyzing the benefits and downsides of each alternative is described as the least accurate, though it is the easiest and most simplified method. If a more systematic approach is desired, the second method of analyzing the factor’s importance is preferred.

<table>
<thead>
<tr>
<th>Ease of future expansion</th>
<th>Effectiveness of supporting-service integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptability and versatility</td>
<td>Fit with company organization structure</td>
</tr>
<tr>
<td>Flexibility of the layout</td>
<td>Working conditions and employee satisfaction</td>
</tr>
<tr>
<td>Flow of materials effectiveness</td>
<td>Ease of supervision and control</td>
</tr>
<tr>
<td>Materials handling effectiveness</td>
<td>Appearance, promotional value, public or community relations</td>
</tr>
<tr>
<td>Storage effectiveness</td>
<td>Equipment utilization</td>
</tr>
<tr>
<td>Space utilization</td>
<td>Utilization of natural conditions or surroundings</td>
</tr>
<tr>
<td>Safety and housekeeping</td>
<td>Ability to meet capacity or requirements</td>
</tr>
<tr>
<td>Quality of product</td>
<td>Plant security and pilferage</td>
</tr>
<tr>
<td>Maintenance problems</td>
<td>Compatibility with long-range company plans</td>
</tr>
</tbody>
</table>

Table 2-4. Weighting factors of the layout alternatives (Muther, 1973).

The factors above are listed and then the layouts are being ranked based on the importance of the factors and how well the layouts fulfill these. The result is presented as a comparable number that indicates which of the layouts that is the most appropriate one. The third method, cost comparison, encompasses calculating the total cost for the alternative layouts that are being compared. When designing an entirely new manufacturing system, the cost that is being computed is the total cost involved with the project (Muther, 1973).

**2.5 Facility layout and flow**

When designing a manufacturing system there is a need to choose what kind of layout to use. According to Slack & Chambers & Johnston (2004) is the preceding step to choose a layout, to decide what kind of process type to use. The two factors that decide what kind of process type to choose is; volume and variety (Hill, 2000b). Slack & Chambers & Johnston (2004) state that in the manufacturing environment there exists five types of process types:

- **Project processes** - Normally characterized by low volume and high variety, often used for shipbuilding.
• **Jobbing processes** - Normally characterized by low volume and very high variety, often specialized “one-offs”.

• **Batch processes** - Normally characterized by moderate variety and volume, and due to its long-range scope it can be used for a long range of operations.

• **Mass processes** - Normally characterized by high volume and low variety, often used for automobiles and consumer goods.

• **Continuous processes** - Normally characterized by extremely high volume and low variety, used for paper, brewing and similar industries.

When the process type is selected, the next step is to choose the actual layout type (Slack & Chambers & Johnston, 2004). There exist four basic layout types that are used in general for when designing a production layout (Krajewski & Ritzman, 2002):

1. **Fixed-position layout**

The fixed-position layout is used when the object that is transformed in the manufacturing system is manufactured in small quantities. The product is normally produced in a project environment and is, in comparison, an immense product (Olhager, 2000). The flow principle is that material is brought to the position where the product is assembled or constructed. The product is thus fixed, or not transported, during the time it is being processed (Fogarty & Hoffman & Stonebraker, 1989).

2. **Process layout**

The process layout, or functional layout, is used when a product is to be produced with equipment or resources that are shared with other products. The resources are normally, grouped with similar entities, thus creating greater utilization of the resources (Slack & Chambers & Johnston, 2004). The material is flowing through the floor shop in a complex pattern, thus requiring great planning of the production (Fogarty & Hoffman & Stonebraker, 1989).

3. **Product (Line) layout**

The product layout is used for production environments when there is constant and high demand, and low variety of the product mix (Olhager, 2000). The equipment for the transformation of the product is dedicated to the specific product variant, and the product is following a dedicated product flow (Slack & Chambers & Johnston, 2004).
Theoretical background

The flow of materials is based on that the transformation of the product is made in following workstations that transform the product with a balanced amount of work at each station (Fogarty & Hoffman & Stonebraker, 1989).

4. Cell layout

The cell layout is used for products that are suited for manufacturing in a dedicated environment with the flow principle, but with the requirements of the process layout. The cell layout is thus an attempt to rationalize the process layout, creating shorter lead times and more structure to the manufacturing (Slack & Chambers & Johnston, 2004).

When the basic layout principles presented above is to be chosen, they should be linked to the strategic choice of the process type (Slack & Chambers & Johnston, 2004). A simplifying figure of the interrelationships between the different process and layout types are presented below. It should be noted that the boarders between them is less strict than the figure implies.

![Figure 2-5. How to relate process to layout types (Slack & Chambers & Johnston, 2004).](image)

Slack & Chambers & Johnston (2004) suggest that after selecting the basic layout type, the detailed design of that specific layout type should be designed.
2.6 Product structure and Architecture

A product that is designed, either being designed or going to be designed consists of constituent component parts that make up the product. A product structure is describing in which order the component parts are put together to the end product. The bill of materials is a list that specifies the quantity of each component parts that make up the end product (Slack & Chambers & Johnston, 2001).

2.6.1 Bill of Material

As described above, the bill of material is essential when a product is going to be manufactured. This is due to the fact that most products exist of several components and different quantities of these. To be able to manufacture a product requires knowledge and understanding regarding the structural relationship between the subordinate components, the sub-assemblies and the final product, so called dependent demand (Fogarty & Hoffmann & Stonebraker, 1989).

According to Vollmann et al. (2005) it exist two types of bill of materials. The first one is a single-level bill of material; the second is the intended bill of material. The intended bill of material is structured to show all the subordinate components, at all levels, to an end product. Due to this fact, it is often used for making assembly schedules for how to put the product together (Vollmann et al., 2005).

2.6.2 Product structure and manufacturing environment

The product structure and the manufacturing environment affect the flow of materials when building and operating a manufacturing system. The shape of the product structure is reflected by the design of the product, but also the amount of components that are made in-house (Slack & Chambers & Johnston, 2001).

![Shapes of product structures](image)

Figure 2-6. Shapes of product structures (Slack & Chambers & Johnston, 2001; Olhager, 2000).
The A-shape is describing an end product that is being made from a lot of items. The V-shape is a limited number of materials that are being transformed into a large number of end products. The X-shape contains modular sub-assemblies that are mixed together in order to generate a large number of end products. The T-shape is symbolizing the product structure shape for a product that is standardized in the beginning, but highly differentiated in the end of the manufacturing process (Slack & Chambers & Johnston, 2001 and Fogarty & Hoffmann & Stonebraker, 1989). According to Fogarty & Hoffmann & Stonebraker (1989) the A-shape is used for Make-to-stock manufacturing, while the X-shape and the V-shape is used in assemble-to-order and make-to-order, respectively, manufacturing environments.

2.7 Assembly Technology

Learning curves are a fact that has to be considered when the assembly system is designed, due to the fact that it will create differences between the planned scenario and the reality after some time (Fogarty & Hoffman & Stonebraker, 1989). Line balancing is the main problem when making the design of an assembly line, and is strongly affected by learning curves (Fogarty & Hoffman & Stonebraker, 1989).

2.7.1 Learning curves

Due to the nature of the human, it is important to consider how the performance of her changes over time (Hill, 2000a). According to Helander (2006) it is a well known factor that human performance of carrying out an activity or task, is increasing over time, and also that predicting the level of improvement is possible. The term that is used to describe these effects when it comes to manual assembly work, is learning curves or experience curves. Olhager (2000) consider three assumptions regarding learning curves:

- The assembly time per unit is decreasing accordingly with increased number of items produced
- The ratio of decrease in assembly time is levelling out as the number of produced items increase
- The ratio of decrease in time per item produced, is possible to predict

The implications of learning curves on manufacturing systems is thus that the times and assumptions used for designing the system might not be relevant when the system been in use for some time.
This fact could lead to an unbalanced assembly line with either overproduction or disturbances in the production (Fogarty & Hoffman & Stonebraker, 1989). The positive factors of learning curves are that the quality level increases over time and that the decreased assembly time leads to lower costs (Hill, 2000a).

![Different learning curve shapes](image)

Figure 2-7. Different learning curve shapes (Fogarty & Hoffman & Stonebraker, 1989).

As can be seen in figure 2-7, the assembly time per unit decreases over time when the experience of the operator increases. When designing a manufacturing system it is therefore important to consider the impacts of learning curves and plan for future changes of the assembly times. In the case of the start up of a new assembly line, it is recommended to measure the real times after the system been up running for a while, in order to look for changed conditions (Fogarty & Hoffman & Stonebraker, 1989).

### 2.7.2 Detailed design of assembly systems (Line balancing)

As described in section 2.5, after the basic layout type is selected it is recommended to start with the detailed design of the layout. For the product layout type, the fundamental problem is to decide what and where to position the production tasks in the transformation process of the product (Slack & Chambers & Johnston, 2004). The development of a detailed design layout has, according to Fogarty & Hoffmann & Stonebraker (1989), three main considerations:

- **Process efficiency**
Theoretical background

- **Line Capacity and utilization**
- **Line-Balancing efficiency**

Slack & Chambers & Johnston (2004) have identified some decisions that are crucial to consider when designing the detailed layout:

- **What cycle time is needed?**
- **How many stages are needed?**
- **How should the task-time variation be dealt with?**
- **How should the layout be balanced?**
- **How should the stages be arranged?**

The way to deal with the described considerations is to calculate the capacity requirements of the product layout and then assign tasks to the stations and balance the workload at the workstations in order to achieve efficiency (Slack & Chambers & Johnston, 2004).

### 2.7.2.1 Process efficiency & line capacity and utilization

Based on forecasts, or other demand records, are manufacturing and capacity plans created in order to set the production targets for the process to meet (Ortiz, 2006). These production targets are adjusted for expected disturbances of the material flow and downtime at the production line (Fogarty & Hoffmann & Stonebraker, 1989). The production targets are linked to the available production time through the Takt time, which is a fraction of the available time divided by the production target. This time is also referred to as the cycle time for the layout, and is showing the pace at which the production line needs to operate in order to meet the production targets (Ortiz, 2006).

\[
Takt\,\text{time} = \frac{\text{Available working time}}{\text{Number to be processed}} = \frac{\text{Effective hours} \times \#\,\text{of shifts}}{\text{Product volume}}
\]

A product layout consists of stages that are loaded with work tasks in order to create a flow. The Takt time is setting the pace by which the final products flow out of the line and are moved from one stage to the next (Srinivasan, 2004). The Takt time and the time required for processing the product, the so called “total work content”, are related to each other through the decision regarding the number of stages at the production line (Ortiz, 2006).
The number of stages is thus, indirectly, related to the production targets (production volume) through the Takt time in the equation above (Ortiz, 2006). The number of stages is also telling the number of operators of the production line and should thus be rounded up to the next largest number since operators cannot be divided (Slack & Chambers & Johnston, 2004).

2.7.2.2 Assembly line balancing

When the Takt time and the number of stages are computed, the next step in the detailed design of an assembly line is to balance the workload in order to achieve an efficient Manufacturing system (Hitomi, 1996).

Bhattacharjee & Sahu (1986) have identified three main purposes with assembly line balancing:

- **Minimize the balancing delay**
- **Minimize the labour force**
- **Minimize the cost of assembly**

The two first points are achieved through balancing the workload of the assembly line, and the third point is the result from the two previous (Bhattacharjee & Sahu, 1986). If the three points above is achieved, the assembly line is operated efficiently, thus not necessary optimal (Becker & Scholl, 2006).

It exist several techniques for balancing the assembly line, ranging from simple heuristics to complex computational algorithms (Boysen & Fliedner & Scholl, 2008). According to Fogarty & Hoffmann & Stonebraker (1989) there are two kinds of situations that implicate the assembly line balancing:

- The Takt time is fixed due to production requirements, and the intention is to minimize the number of workstations.
- The number of workstations is pre-established, and the objective is to minimize the cycle time and create a workload balance.

Despite which of the two types of problems above is present, the line balancing must take into consideration the precedence relations that exist between the assembly tasks that are to be balanced (Olhager, 2000).
Some tasks are related to each other through the assembly relations that must not be broken, otherwise it might arise technical infeasibilities that cause errors (Fogarty & Hoffmann & Stonebraker, 1989).

The simplest way of carrying out a line balancing is to simply start loading the first of the calculated number of workstations with tasks until that station is full or at least not overloaded, according to the required cycle time. Then continue to load the following stations in the same manor until all assembly tasks are dedicated to a station, and the precedence relationships are not broken (Sule, 1994).

![Basic line balancing](image)

As the figure above shows, the stations are being loaded with tasks without exceeding the desired Takt time, or cycle time. It is recommended not to use the actual Takt time as the loading limit, since that would create disturbances on the assembly line (Ortiz, 2006). Instead, a loading level between 85 percent (Ortiz, 2006) and 90 percent (Hitomi, 1996) is suggested as appropriate.

### 2.7.3 Line Balancing in the real world

Faulkner (2006) states that in the practical world, the approaches to the line balancing problem differs slightly, from the academic approaches and the complex approaches lobbied by the “expertise” of line balancing. The author states that in his research in the automotive industry that managers are often faced with problems with a gigantic number of solutions, and to find an optimal solution can be seen as impossible. Faulkner (2006) mentions a few aspects that his research has found relevant to consider when a line balancing is to be carried out.

- **Workstations Have Identities**
This fact implies that you must consider the fact that a number of operations in a workstation create a identity of that particular workstation. That Identity strongly limits the possible environments the station can be placed at, at the shop floor. Some workstations should not be located next to each other due to environmental aspects

- **Unmovable Operations and Zoning Constraints**

Some of the operations that are to be balanced simply must be located to certain areas of the factory. This fact delimits the possibility to optimize the balance. Operations that consume a great deal of space can be difficult to assign to a workstation due to limited space of the station.

- **Need to Equalize Loads**

It is stated that the goal of the line balancing is to minimize the cycle time or the number of workstations. Faulkner (2006) states that the latter, is only valid when designing a new assembly line. The goal of minimizing the cycle time is not feasible either since the cycle time is customer and market driven. Instead it is argued that the goal of line balancing should be seen as equalization of the workload.

- **Multiple Operator Operations**

Faulkner (2006) states that it is beneficial to letting more than one operator work at the machine the entire time. This setting decreases the lead time of that specific task, and also allows the person carrying out the balance to alter the lead time to a desired value. The downside with this setting is that operators in a workstation might have idle time during the cycle, which is inefficiently. It is also very complex planning required in order using this setting. It is stated that making sure that operators are available at the same time can be difficult for larger assembly lines.

### 2.8 Logistic Aspects of Manufacturing Systems

It was once stated that the flow of materials and efficient logistics are the most difficult aspects to achieve great results within. Unplanned and uncoordinated material positions together with complex material flows can create a great deal of disturbances, quality problems and costs to the company (Lumsden, 2006).

#### 2.8.1 Planning logistics

Planning logistics is an essential part of a company’s supply chain strategy, and should thus be in focus when designing the logistics system.
Guedes & Saw & Waller (1995) describes Logistics strategy as designing or redesigning the supply chain in order to meet the demand from customers and the requirements for service as good as possible. In order to be able to do so the logistics strategy must consist of a distribution strategy, manufacturing aspects and a purchase strategy where the purchase strategy gives answers to questions such as which suppliers to use and what would happen if they use this supplier.

The manufacturing aspect deals with sourcing, location of facilities and technology impact. This together with a distribution strategy that describes the policies regarding stock, location of depots, distribution channels and delivery are the strategically issues the company builds its logistics strategy upon Guedes & Saw & Waller (1995).

2.8.2 Long term planning

Long term planning is described as basing the logistics strategy upon the overall business strategy, which describes the path the company needs to take in order to stay competitive and where the company should operate in order to reach its desired customers. Logistics strategy is thus a great part of the overall business strategy because here the company decide how and in which way they are to compete. Aronsson & Ekdahl & Oskarsson (2004) describes two different competitive strategies that have an impact on the forming of logistics and these are the strategy of cost advantages and the strategy of value advantages.

The cost strategy means that the company focuses upon having a lower cost than its competitors and the value strategy focuses upon giving the customer the sense of a greater value of the product. The optimal solution is of course a low cost to a high value and this is what every company should strive for (Aronsson & Ekdahl & Oskarsson 2004).

Once the company has decided which strategy to compete within the real logistics planning can be started. Aronsson & Ekdahl & Oskarsson (2004) explains the logistic planning as consisting of strategic, tactical and operative planning. Focus is the movement of the product and the activities that needs to be performed and in which order. However, what differs between these planning activities is the time frame.

The strategic planning considers planning into the future more than one year away, tactical planning about one to 12 months ahead and the operative on hourly, daily or weekly basis (Aronsson & Ekdahl & Oskarsson 2004).
Ballou (1992) describes the design of the logistics channel as an overall question for planning and divides it into four areas:

- **Delivery service and lead-time decisions** - The type of delivery service that is offered by the company affects the placement of the customer order decoupling point.

- **Location decisions** - Placement of production and distribution, customers and suppliers according to geography. This decides which customers who get their products from a certain facility and which suppliers should deliver to a certain facility. Decisions are also made for the number of production and distribution facilities to use and their size.

- **Warehouse decisions** - Where should warehouses be placed and how are they steered. Where do we put safety stock, the size of the safety stock and the steering of material? Here it is also decided how to refill the warehouses with products.

- **Transport decision** - Which products shall go with which transport? Decisions are made about whether to use boat, air or truck, how large should the shipments be each time? Also decisions are made about how many products that can be transported together and how to form and plan routes for the transportation in an optimal way (Ballou, 1992).
2.8.3 Planning for inventory

Forming of the warehouse is an important logistical factor. Lumsden (2006) explains that in a warehouse there are lots of different articles existing who have different demands on space, average volume, weight and more and that is why a warehouse is seldom formed from one kind of philosophy or technique. Instead it has the shape of different combinations between shelves, storing and palleting. It is therefore important to form the warehouse so that changes can easily be made when an article changes character. Lumsden (2006) highlights the issues to consider when forming the warehouse and these issues are reproduced below.

- **High fill rate** - The warehouse should have the highest fill rate possible. However, it shall not be so high so that the handling of material becomes difficult and so that the transportation increases. The utilization rate of the available volume should also be as high as possible as long as it does not affect the handling as stated above.

- **Minimize transportation** - In order to minimize transportation and reduce unnecessary movement of material, working areas should be adapted to the order in which the inventory is moving inside the warehouse. Inventory with high turnover should be placed so that transportation is short while low turnover rated articles are placed further away.

- **Make it easy to find and reach** - As the headline states articles should be easy to find and reach without being forced to move other articles or pallets that are in the way.

- **Finding the optimal solution** - As stated the planning and forming of the warehouse has a great effect on the material handling and storing of articles. There is a tradeoff between efficiency in storing and the efficiency of handling because as Lumsden (2006) states, effective material handling demands good accessibility of the articles while the storage of the articles needs a high usage of volume. If the inventory turnover increases and there is a more effective way of storing articles the cost of storing decreases. However, this implies that the handling of the material increases since articles are moved and transported more frequently, and thus the cost of the handling increases.
In other words, there has to be a balance between material storage and material handling. Thus, one must consider both maximizing the usage of space as well as being able to easy locate and reach the articles needed (Lumsden, 2006).

Figure 2-10. The cost for storage and handling as a function of the turnover (Lumsden, 2006).

### 2.8.4 Material Handling

Material handling deals with the way the material is handled from delivery to production, and how this affects the cost and delivery service (Aronsson & Ekdahl & Oskarsson 2004).

Aronsson & Ekdahl & Oskarsson (2004) describes the activities in material handling as consisting of

- **Arrival of goods** - Here goods arrive and is reloaded if necessary in order to smoothen the material handling. The goods are registered and enter the company’s system. If there is no time for taking care of these goods directly then a temporary storage location must be available.

- **Inspection at arrival** - Divided into *quality* and *quantity* control. Quality control is the inspection of the goods that they are satisfactory for production.
Depending on the cost of the article, the number of articles in stock might be few or many. With small numbers, this could also imply that probably these are expensive articles and therefore it is necessary to check each and every one. Quantity control is done in order for the system to show the correct number of articles that are in the house. This is important to do otherwise there might be shortages or orders are done too late.

- **Inbound storing** - Material is shipped into a storing place or buffer after arrival and inspection. Inbound storing is described as containing two main systems; *fixed positional system* and *floating placement system*. Fixed position gives each article a special place in the warehouse for picking and buffer. However this demands space. The floating placement system means that the goods are placed in the warehouse according to priority. This ensures that the articles are placed in right order according to frequency (Aronsson & Ekdahl & Oskarsson, 2004). Each pallet can be placed anywhere in the warehouse and therefore the number of available space for pallets can be more efficiently used which in turn means that if efficiency increases less space is needed for the pallets (Lumsden, 2006).

- **Storing** - Here the goods are divided into buffer and picking goods. The placement of the goods for picking is controlled by four parameters.
  - **Frequency of outtakes** - How often is the pick place visited?
  - **Article Volume** - Affects the placement of the article.
  - **Quantity of outtakes** - How many articles are picked after each visit.
  - **Weight of the article** - Affects the placement of the article. Articles with high outtake frequency shall be placed in a way so that they are easily accessible. What needs to be researched is the actual usage of articles and to rank and optimise the frequency of this usage. Next issue is the quantity of the article that is taken out. This deals with the quantity that is taken out each time since if a large quantity is taken out and the article has a large weight this can give rise to queues. The volume and weight of the article also matters when placing the article.

- **Re-storing** - Means moving the goods from the buffer place to the picking place. The pickers notify the buffer operators when a refill is needed.
Theoretical background

This can be done orally or in writing or the computer system signals to the buffer operators when the articles are under a certain level.

- **Picking** - Two methods are described and these are the manually picking method and the machine picking method. Machine picking means that the work is performed by a robot. Manual picking is divided into two alternatives and these are picker to the goods and the goods to the picker. Picker to the goods is done by truck and is divided into low picking; middle high picking and high picking depending on the height the goods is collected from.

- **Marking and delivery** - Goods should be marked and packed in such a way that it avoids being damaged, and to make it easier to handle and identify. The flow of goods from the company should be levelled out during the day in order to have a smaller amount of picked goods waiting for transportation (Aronsson & Ekdahl & Oskarsson, 2004).

### 2.8.5 Flow of material

Depending on the nature of the assembly being performed in the company the flow of material throughout the factory takes different shapes. Lumsden (2006) describes four main directions for material flow.

- **Linear flow** - The linear flow means that material is transported from one end to the other in the factory, from arrival to shipment. This is suitable when there are large volumes but few articles being handled since it demands much transport. In this way there is a clear view of how the goods is moving throughout the factory but the down side is that material must move throughout the whole factory which means long distances and higher costs due to increased lead time.

- **U-shaped flow** - In the U-shaped flow the arrival and shipment takes place at the same location. Goods can be placed according to an ABC division where the goods is classified according to the value of its volume with A having the highest value and should be prioritized. If using this type of flow transport is minimized. This setting is most efficient in flexible environments (Ortiz, 2006).

- **Triangular flow** - Used for functional layouts.
• **Circular flow** – Here is the arrival and shipment combined into one and saves costs since it uses the same gate for both activities (Lumsden, 2006).

![Diagram of different flow patterns](image)

Figure 2-11. Illustration of different flow patterns (Lumsden, 2006).

### 2.8.6 Feeding the assembly system

Lumsden (2006) describes this as a series of factors that plays a great importance in the choice of material feeding system. Since there is a strong bond between the assembly system and the material feeding system there should be a parallel development of these two in order to gain the best possible solution.

One should not be delimited to different parts of the organisation but instead one must focus on the function of the feeding system and consider all parts that have an effect on the material handling such as the warehouse layout, distance from the assembly line and the steps the operator has to take before being able to assemble the part.

The characteristic of the part to be produced is also one of the most important things to consider and Lumsden (2006) describes these characteristics as *price, size, product structure and risk for damages*.

So what kind of material handling system should be used? Based upon the characteristics described above Lumsden (2006) describe three different types of systems that are used.
They can be used all at the same time and this is sometimes very useful because then they can effectively compensate each other when there is a wide variety of articles.

- **Continuous support** - This is described as situations where material is distributed in suitable units and then are being replaced in the order they are used. All article numbers are available at the workstation in order to be able to produce all variants.

  When producing at a line this variant is very effective as there is usually a small amount of articles needed at the workstation due to the short cycle time. Material is fed to the line directly in the packages they arrived in from the supplier.

- **Serial Outtakes** - Serial outtakes are described as feeding a determined series of objects in the assembly with material. If these objects are assembled in batches then this is a good method to use. However since companies often produce many variants problems have arise regarding the usage of space. Since more variants demands more different kinds of material space has decreased and has thus become a limiting factor.

  The usage of smaller packages is one way to resolve this issue and it is suggested that the packages are being made by the supplier in order to get the delivery straight into the assembly instead of having to repack it in the house.

  Further described is sequencing of articles where different component variants are repacked in order to fit them into the sequential stages of the assembly line. Usage of only the material needed for the variants produced is also an alternative and secures the quality and correct assembly of the product (Lumsden, 2006).

- **Service for each assembled object** - Planning for every object in the assembly system, meaning that each article number is serving several different workstations. Implications for this are that the space for workplaces are filled and becomes critical. More work with material is required and the transportation of material is increased. Shortages may occur more frequently and there is a problem with administration when changing product structure.

Lumsden (2006) describes three ways of material handling to counteract these problems:
• **Material squares** - Usage of material squares means to move material to a common area, which is shared, by several workstations. The delivery from the supplier can be moved to this point where the operators then can gather the material needed. By doing so the area at the workstation can be smaller and there is a smaller frequency of material transports to different addresses.

![Diagram of Material squares](image1)

Figure 2-12. Material feeding using decentralized material squares (Lumsden, 2006).

• **Warehouse kitting** - Material needed for the assembly object is collected and gathered in the warehouse and delivered as a kit to the workstation for each assembly object.

![Diagram of Warehouse kitting](image2)

Figure 2-13. Material feeding using Warehouse kitting  (Lumsden, 2006).

• **Sequenced channels** - Use the same channel for several articles and sequence them so they arrive to the assembly objects in the right order. (Lumsden, 2006).
2.8.7 Inventory

Lumsden (2006) divides the function of inventory in three different areas:

- **Keeping inventory for the process** - This is necessary for keeping the process free from disturbances mainly by the lack of material. This type of inventory keeping divides the components necessary for the production of the product into different inventory keeping areas such as supply for tools and adding material, components for manufacturing, consumption goods, WIP and finished goods.

- **Keeping inventory for function** - Deals with what function the keeping of inventory really has in the company. Here inventory is kept as circulation inventory, safety inventory for reducing the effect of variations and lack of material, process inventory which is determined of the number of articles needed for the process to function. Levelling inventory in order to smooth out the variation in demand and to use low production costs and minimize the exchange times. Marketing inventory used for satisfying the needs when demand is increased temporarily due to new introduction of products or campaigns. Speculation inventory is used when demand and availability is hard to predict. Coordination inventory means that coordination of products using the same tools and processes are made.

- **Keeping inventory for the flow** - Means building the inventory according to the flow and after the layout of the flow. The flow of articles is followed through waiting in front of the process, in the process and during transport. Three areas are discussed in inventory for flow.

1. **Buffer inventory** - Buffer inventory is made in front of the process in order for the process to function. The buffer also helps in disconnecting the operations. According to Hill (2000a) buffer inventory exists because average demand varies around the average and if demand is higher than the average companies must hold buffer inventory in order to not run out of material. If a company wishes to maintain a high service level and reduce the risk of being out of material then buffer inventory must be high.

2. **Process inventory** - Process inventory is the inventory where the architecture of the process needs a certain amount of details in order to function. The size of this stock is depending on complexity of the product.
3. **Transport inventory** - Means that when transporting goods or articles the unit that transports the articles has full capacity during the transport. In other words the articles that are transported are said to be in a transit inventory i.e. they are in inventory as long as the transport goes on (Lumsden, 2006).

### 2.8.8 Throughput time

In logistics, a central concept is the one of throughput time. Throughput time is the time it takes for one product or order to pass through one particular part of the production system (Goldratt & Cox, 1986). The throughput time is defined as the time it takes from one activity is started until it is completed (Aronsson & Ekdahl & Oscarsson, 2004).

A process flow can consist of several throughput times and together they make up the lead time of the production or order process. The question that has to be answered is according to Aronsson & Ekdahl & Oscarsson, (2004) that which one of the several throughput times in the process flow should be used for calculating the systems throughput time.

![Diagram of Throughput Time Issues](image)

Figure 2-14. Throughput time issues to consider (Aronsson & Ekdahl & Oscarsson, 2004).

The figure above is illustrating the issue of determining the systems total throughput time. The importance of that time figure is that it is both needed for the design of the production flow as well as calculating some supply chain key figures (Krajewski & Ritzman, 2002).
The throughput time is calculated:

\[
\text{Throughput time} = \frac{\text{Average inventory level}}{\text{Demand}}
\]

The implication of the calculation above is that holding the demand constant, the average inventory level is dependent of the throughput time. This means that an extensive throughput time of the system will create an extensive inventory pile up in the system. Thus lowering the throughput time will reduce the inventory held and also reduce the space required for the inventory storage (Aronsson & Ekdahl & Oscarsson, 2004).

2.9 Human Factors and Ergonomics in Manufacturing Systems

For manufacturing system design, ergonomic aspects affect by leading the designer to develop a system that considers the fact that humans are expected to work within it. Without considering the human aspects the system might be technologically efficient, but ergonomically inefficient. The total sum of those two aspects will not lead to a total efficient system; instead, it will be a sub-optimized system (Helander, 2006).

2.9.1 Definition Ergonomics

Helander (2006) describes human factors and ergonomics as a term that considers the environmental as well as the organisational constraints surrounding the workplace. It uses the knowledge of the human abilities and its limitations in order to be able to easier design a system, organization, job, machine, tool or a consumer product in order to make it safe efficient and easy to use (Helander, 2006).

Another definition comes from the IEA (2000) stating that Ergonomics is an scientific discipline that deals with understanding of the interactions between humans and other elements in a system and it applies the data, methods into the design so that human well-being is optimized and increasing the overall performance of the system (IEA, 2000).

Hill (2000a) describes three factors considered when discussing ergonomics and these are:

- Workplace factors
These factors deal with the interface between the workplace and the physical attributes of workers. These attributes might for example be the height of equipment against body posture and others that affect the efficiency of the tool. One should design workplaces to avoid a mismatch between man and equipment and try to adapt them to one another.

- **Environmental factors**

Workers need a safe environment to work in that in the long term perspective as well as the short term makes sure that they stay healthy and in good shape. Issues here might be the temperature of the workplace, handling with chemicals, correct lighting and noise levels.

- **Behavioural factors**

There is a need for a workplace design that gives the workers a meaningful set of activities and that they understand and see that they are actually contributing to the whole. By empowering the workers, and motivating them by letting them take part in decisions concerning their own situation and also making them understand what their part is in the big machinery behaviour can be affected in such a way that it increases productivity, efficiency and motivation (Hill, 2000b)

When workplaces are designed there has been a tendency of the designers to consider technical aspects and not the human factors. The result of this is that the work station later has had to be redesigned as problems with the operators have occurred due to bad work posture (Helander, 2006).

Helander (2006) describes this as when focusing on technical aspects of how to design the work situation, aspects on human performance is often forgotten and it is hinted that the greater the technical challenge is there is a greater risk that human factors are forgotten in the assembly system design. Further it is described that poor posture of the body may lead to permanent damage of body tissue. Therefore it is of importance to classify postures in order to be able to draw conclusions so that improvements can be implemented into the design process (Helander, 2006).

**2.9.2 Anthropometrics**

Anthropometrics is defined as a gathering name for the measurement of people and their attributes.
According to Fernandez (1995) there are factors like gender, ethnical belonging, ageing, social class income, clothing and personal equipment that affect the anthropometric result. These measurements are extremely important to take into account when designing the assembly system since people in different parts of the world have different attributes and are quite diversified. Work posture

According to Pheasant (1996), work posture is described as: “the relative orientation of the parts of the body in space. To maintain such an orientation over a period of time, muscles must be used to counteract any external forces acting upon the body (or in some minority of cases internal tensions within the body)”.

The posture when performing a certain task is dependent upon the relationship between the person’s body dimensions and the items used by the person and the dimensions of the items. The interaction between the person and the tools and the frequency of this interaction is what sets the frame for the work posture. The way the interaction is done is also a determining factor.

These interactions can be divided into two areas namely the physical area and the visual area. The physical area involves for example chairs and desks and the visual area involves the location of buttons, labels and displays.

### 2.9.3 Work enrichment

In order to create an efficient assembly system, other aspects than the technical needs to be considered when designing the system. Helander (2006) mentions organization as well as human/ergonomic aspects as equally important to the design process.

Neumann et al. (2006) describes that certain production system design elements may affect the system’s performance, productivity as well as human aspects, in a positive way. Some elements are mentioned as important to regard when designing the production system (Neumann et al., 2006):

- **Cycle time**
- **Parallel to serial flow**
- **Kitting to line picking**

A lower cycle time means that the operator has easier to learn the task and can become very efficient when carrying out that specific task.
Contrary, the work content will be repetitive and thus lead to lower operator work satisfaction that might lead to declining quality and operator health (Helander, 2006; Neumann et al., 2006). It is a choice between order picking and kitting that can be done in the system design. Parallel flow leads to increased job control and better resistance towards disturbances. This leads to increased psychological rest for the operators and reduces the stress-level, which in turn increases the job satisfaction and performance positive.

Serial flow increases the possibility for the employees to change the work organisation which improves the job satisfaction and creativity among the operators (Helander, 2006; Neumann et al., 2006). Kitting is efficient, but might lead to the fact that more heavy lifts has to be done. Line picking may also lead to the fact that operators need to walk a longer distance in order to fetch material for the operation (Helander, 2006; Neumann et al., 2006).

Neumann el al. (2006) also states that it is important to set targets for the ergonomically performance of the production system, and evaluate these from time to time. Despite the fact that certain element settings affect positive, most of them also brings some sort of disadvantage with them.

### 2.10 Quality in Manufacturing Systems

A manufacturing system is supposed to transform inputs to outputs through a transformation process. In today’s competitive environment, quality is no longer an order-winner; it is rather an order-qualifier (Hill, 2000b). The view on quality in general has changed from something that is achieved by inspection and control of finished goods, to something that is achieved by a superior transformation process (Sandkuhl & Johansson, 2000).

#### 2.10.1 Integrating quality

In today’s global competition more and more companies have realised that in order to stay alive they have to take quality very serious and integrate it into the core businesses of the company. Perhaps the most known approach is Totally Quality Management and is defined as “to constantly strive to fulfil, and hopefully exceed the customer’s needs and expectations with a minimal use of resources through a continuous work with improvements where everyone is engaged and where focus lies on the organisations processes” (Bergman & Klefsjö, 2002).
According to Jablonski (1992) there are three factors necessary for successfully implementing TQM into the organization. These are:

- **Participative management**

  Participative management means involvement of all the members in the organization in managerial decisions. This means that management acts and sets policies and decisions based upon the input of those who are affected by those decisions. By doing so management can get a better and more realistic view of the operations actually going on at the floor and also it empowers and motivates the people on the floor giving them the feeling of that they themselves form their own work situation.

- **Continuous process improvement**

  Continuous process improvements are described as small improvements performed continuously which in turn give large gains over a long-term period. The idea is to sacrifice short term goals and objectives for long term investments. This makes it easier to gain confidence and adapt to the benefits of TQM.

- **Utilization of teams**

  Described as teamwork, which is necessary for TQM. The involvement of cross functional teams enables knowledge sharing and a wider understanding of opportunities and problems and also gives the people a clearer view of their role in the organisation (Jablonski, 1992).

Bergman & Klefsjö (2002) have identified five factors that are essential for TQM:

- **Customer focus**

- **Work with processes**

- **Continuous improvements**

- **Creating conditions for participation**

- **Decisions based on facts**

  *Customer focus* is described as actively investigating what the customers expect of the product and what their demands are in order to give them the product they want to the right quality and price.
This may seem easy but is in fact very tricky as there is no universal way to investigate the needs of the customers since these needs are so varied.

**Working with processes** - Involves the transformation of raw material and information to the output of a product or service that fits the customer needs. This is supported by the organisation consisting of different kinds of people interacting with each other and with different kinds of aids.

**Continuous improvements** - Is the strive for never being satisfied with what you got but instead keep on working in a systematic way in order to fulfil the specifications and quality targets set by the customers. This involves not only the product but also the processes within the company. Costs are high for lack of quality so there is much to gain when working continuously with increasing quality. A successful continuous improvement work usually results in better quality with fewer resources used. The circle of improvements (PDCA cycle) often stands as a symbol for how to work with this (Bergman & Klefsjö, 2002).

- **Plan**

Plan the work; find the root cause of problems by using facts. Gather these facts and use statistics to reveal the sources of errors and variation.

- **Do**

Appoint a workgroup that makes sure that the countermeasures decided in the planning phase are implemented.

- **Check**

Check if the countermeasures had any effect upon the result. Use tools like the seven improvement tools. If the countermeasures are successful then the work should be focused upon maintaining this new higher level.

- **Act**

Learn from the improvements and adapt to the new higher level and embrace it. If unsuccessful then start the PDCA circle over again. When satisfied with the new level start over with the next problem and work continuously in this manner.
Creating conditions for participation is simply described as working in a way that makes it easier for every co-worker to be a part of and also to actively take part in the decisions regarding the improvement work.

To make it happen it is important that communication, training and responsibilities are clear for all the people. Klefsjö & Bergman (2002) gives two ideas of how to work with this and these are to create smaller groups responsible of creating and implementation of different improvements and to solve these issues.

The other idea is described as the utilization of knowledge among the co workers by the use of suggestion rewards. By doing so the co workers see that their knowledge and ideas are appreciated and also spurs them to come up with suggestions.

Talha (2004) states that small and new companies often have limited resources when it comes to finance, resources and personnel and that they, when exposed to great variation in customer demand and behaviour find it hard to meet these variances.
Therefore, is the need for someone in a leading position to step up and take the role of quality manager important. Furthermore, six steps developed by Talha (2004) are presented for the successful implementation and practising of TQM in new and small companies:

1. The Quality work and the customer focus must be at the centre of every workers perception.

2. Also the focus for every employee must be to continuously improve quality.

3. All activities within the company must have both workers and suppliers involved.

4. No extra cost should be involved in making quality and customer satisfaction a priority.

5. There might be a need for larger and more significant changes in order to improve quality and customer satisfaction.

6. The small improvements are those that give the company advantages towards its competitors and distinguish its quality and customer satisfaction from others (Talha, 2004).

2.10.2 Built in quality

Built in quality is described as the interaction between the human operator and the equipment in order to stop the process when there is a problem. Liker (2004) describes this as necessary as manufacturing today often has very low levels of inventory and no buffers and therefore it is of high importance that things has to be made right at the first time. Furthermore, when a problem occurs this should be highlighted by the use of flags or lights together with an alarm in order to show that a problem has occurred and that help are needed (Liker, 2004).


3 Methodology

This chapter is highlighting the methodology that was used for this thesis. This chapter includes the strategy the problem has been approached with, and the way the problems have been dealt with.

3.1 Framework for system development

When developing a manufacturing system, a structured methodology and a plan is a key factor for achieving a satisfying result (Bellgran & Säfsten, 2008). A framework for development of manufacturing systems is presented in Bellgran and Säfsten (2008). The framework is emphasizing the need for a structured approach to the development project, since the development of manufacturing systems are quite complex. The framework is based on both empirical, as well as theoretical investigations.

![Framework for developing a manufacturing system (Bellgran & Säfsten, 2008).](image)

The planning part of this framework is considering the pre-decisions and the organizational aspects of the development work. The task is to plan for the development project and by so make sure quality and control of the project. The design and evaluation part is including the development of the process layout of the manufacturing system. Before that, choices regarding processes and technology are done and implemented into conceptual layouts.
These are then being evaluated based on specific criteria’s of concern. Later on is the solution implemented in the reality and the production gets ramped-up (Bellgran & Säfsten, 2008).

The methodology from this framework was used at the early start of the thesis project. The structured way of working and planning level in figure 3-1 above were guiding for the entire project, and kept the project in line with the set targets. Since a structured way of working was requested, a plan for the development project was created and is presented in the next section.

Influences from the Design and Evaluate level in figure 3-1 were absorbed. This was guiding when the method of separating the conceptual and the detailed design in this project was formed. The implementation level in figure 3-1 was not considered due to the fact that the thesis project was delimited to only developing a system, not realizing it.

3.2 Scientific approach

A Master thesis is to a certain degree a research project and may include both doing academic research and applying already known science in what is referred to as applied research (Saunders & Lewis & Thornhill, 2000). Further on, the result of any research project benefits from a well arranged project plan. This plan should include the goal of the project, which is the factor that the plan should be designed according to fulfilling it. The plan should also include the methodology that is supposed to lead the project to the goal (Saunders & Lewis & Thornhill, 2000).

Since the goal of this thesis is to develop an entirely new assembly system, the project plan must be designed in order to facilitate this situation. Due to the complexity of the subject, it was required to break down the problem into smaller entities, which was done in a project plan shown below.
The plan starts with a literature review, which was supposed to guide the design process and give the necessary academic basis. The next step was to analyze how the design process was affected by its surrounding environment.

From Muther (1973) and Slack & Lewis & Johnston (2004) some implicating factors was identified as limiting factors to the design process. Therefore it was found relevant to investigate how they affect the design process.

The assembly system design was broken down into 2 smaller design processes: assembly line and logistic system design, as can be seen in figure 3-2 above. When the concepts of these 2 were developed they were combined and an assembly system design was generated. The assembly system design was a compromise between the two combined concepts in order to find the best solution possible.

The last step was to evaluate the assembly system design and reflect upon its weaknesses and strengths.

3.3 Literature review

A literature review is essential when carrying out a thesis work. It is supposed to be a framework that guides the student with her thesis work and enables her to work in a systematic and academic way. A literature review was done at an early stage of the project.
Methodology

The study provided some necessary inputs to the later assembly system development. The focus of this study was set on finding practical guidelines, therefore is the previous chapter, the theoretical background, mainly presenting those literature findings that provided most practical use, rather than for an academic purpose.

This thesis is in the field of Production Systems, which in the literature is similar to the more frequently used Production and Operations Management. The literature that is included in the theoretical background chapter is thus based on that research area, together with logistics and production development. The literature used was mainly books, but also some articles were found relevant and therefore used. The literature review was essential for the outcome of the thesis and provided the necessary inputs for the assembly system design process.

3.4 Interviews and empirical observations

In order to find design inputs and the delimiting factors of the design process, it was necessary to seek the information were it was located. The following 2 paragraphs describe the way the information was gathered.

3.4.1 Meetings and cooperation with Aercrete Industries

Much of the information needed for the development of the assembly system was empirical, and was to be found from the employees working at Aercrete Industries. During the project, there were some briefings and discussions, which provided the necessary data that was requested.

The management at Aercrete Industries provided comments about the project and together with the supervisor at Jönköping School of Engineering, tried to steer the project towards a successful end. Since the project was faced with the fact that hardly any documentation or data was to be found stored, a close collaboration with the company was soon realized to be crucial for the outcome of the project.

3.4.2 Data collection

As described in the previous section, much of the data collected was empirical. Since the product was entirely new and there was no existing assembly system, the empirical data was mainly based on experience and qualified guesses by the management at Aercrete Industries. One type of data gathered was time estimations for the assembly of the product.
This data was mainly based on estimations and previous assembly of demo products. Another data collected was assembly information, which is crucial for determining the assembly order. This data is based on experience and logical thinking of assembly efficiency. Data regarding the facility was both measured and gathered through interviews. Much of this data are requests from the management at Aercrete Industries, and thus limiting the scope of design possibilities. Most of the data gathered is presented in attachments 2-5 and in chapter 4 as preconditions.

### 3.5 Design process

As previously described, the design process was broken down into smaller entities in order to simplify the task. The design process was split up into an initial preconditions analysis and how those preconditions affect the design process. Then the conceptual designs of the assembly line and logistic system were developed. Later on the detailed design of the assembly system was created by combining the conceptual design together. The combining task was complicated by the fact that some factors forced rework and rethinking regarding the finalization of the system design. The methodology used for the combining task was a discussion between the authors and the management at Aercrete Industries.

#### 3.5.1 Assembly technology

The factors that affect the assembly process itself were investigated in order to gain an understanding of what data was needed and what design steps to use it for. The assembly technology was especially relevant for the detailed design of the assembly system, when the assembly work was supposed to be distributed out in the system.

#### 3.5.2 Systematic Layout Planning

The systematic Layout Planning framework was used as a methodology to understand how to design the physical layout of a manufacturing system. It was also useful for gaining insight in what aspects to consider when making the layout. Besides, the method displayed the necessary inputs that are required to gain knowledge about in an assembly line development project. The framework was not followed as strict as it is recommended and that is due to the fact that some factors were unknown as well as the applicability was considered limited on this specific situation.
3.5.3 Lean production approach

Lean Production is a philosophy that should be guiding the design process. Its strong focus on limiting the waste in every detail was constantly at mind during the design process and affected the decisions made during the thesis project. Similar to the Systematic Layout Planning framework was the Lean Production approach not followed strict since it is often taught as an improvement tool instead of an development tool. However, as described previous, the Lean philosophy was followed in the way the design process and surrounding factors enabled it.

3.5.4 Technology aids

In order to increase the visibility and help designing the assembly system, some technical aids where used during the thesis. Besides the standard office package, this following software’s where used:

AutoCAD

At an initial stage of the thesis work, the AutoCAD software was used to illustrate the facility’s dimensions and constraints. Printings from this program were also used for the block design of the assembly system.

Solidworks

Further on in the thesis work, when the detail of design increased, Solidworks was used to make a graphical representation of the results of the design. It was also used for making some of the attachment in this report. The Cad documents were also part of the presentation of the results to the project givers.

3.6 Validity & Reliability

When carrying out research, it is important to reflect upon it and question it, in order to increase the quality of the result (Williamson, 2002). In research the term validity is used to investigate whether the scientific work is valid. Golafshani (2003) states that high validity brings truth to the scientific work, and gives strength to the given conclusions and recommendations.

It exist 2 types of validity: internal and external. The internal validity is used to determine whether the research process carried out is about the intended context. The external validity is used to determine if the research results are possible to apply in other situations, or in other words is general for any situation given (Jacobsen, 2002).
If the internal validity is low, the results might be infeasible due to the fact that they are based on an incorrect basis. Another term for judging the quality of scientific work is reliability. Reliability is used to determine if the results are of good quality or if there are any factors affecting the results negative (Williamsson, 2002). The trustworthy of the results are strongly depending on the reliability of the results. Golafshani (2003) states that it is important to plan for validity and reliability at an early stage in a scientific project. Besides, value and criticize the outcome of the own scientific work is necessary for a serious researcher.

The factors in this project that that were identified as possible sources of error affecting the reliability are:

- Low accuracy of the time measurements, making time estimations necessary.
- Little knowledge of the assembly process of the machine, making practical experience of others important.
- Little documentation regarding the machine, making estimations necessary.

The internal validity of this project was considered to be relatively high since the subject is rather focused. Since the subject is rather focused, the external validity will be low due to the fact that the result will be strongly situation adapted, or in other words fairly dedicated to the specific parameters affecting in this situation.
4 Analysis of the preconditions

This chapter is supposed to highlight the preconditions that exist to the design of the assembly system. The preconditions are analyzed and described in detail of how they affect the design of the assembly system. The preconditions are investigated both by analysis of the product and by empirical information.

4.1 Strategic implications on the assembly system

Strategy is considered to be an important starting point for the design of an assembly system. The chosen strategy is supposed to guide the design and in the end create success for the business. The strategic decisions mentioned in this section are formulated in corporation with the management of Aercrete Industries and are in line with their intentions for their overhead goal; Growing a business and start-up production.

4.1.1 The strategically decisions

The role of strategic decisions is stated as the logical starting position for the design of an assembly system. The strategic decisions are thus influencing the design, through putting boundary conditions and pre-requisites to the design process. The decisions are also limiting the possible solutions.

1. As described in the introduction chapter (section 1.1), one of the strategic decisions that were set previous to the start of this thesis was the volume flexibility constraint of the assembly system. The system was decided to be able to handle volume flexibility between twenty and eighty machines per year. Another volume decision was that the assembly system should, preferably, handle the flexibility without increasing the number of shifts of the staffing. Or in other words, the use of a single day-shift was preferred from the management.

2. The management of the company had decided that short delivery-times in combination with short throughput-times where order winning elements.

3. It was also stated from management that the assembly system should be designed in such a manner, that the facility was to be used rational. The meaning of this was that the assembly process should not consume more space than was necessary, thus leaving space for other activities then the assembly of the machine.
4. Another strategic decision that implicates the design of the assembly system was that the process of foam production was to be situated in the same facility as the assembly process. And later on, the position of the foam production process was decided to be situated as shown in Attachment 1, due to nearness to necessary water supply and deposes.

5. In the facility, there was located a movable shed. Due to some constraints regarding the transportability of this shed, the management decided that the shed should preferably not be relocated, and therefore the position of this shed was an implication on the design of the assembly system. It was also decided that the shed should preferably be used for the assembly of the electric cabinet.

6. Due to uncertainties at the market, the management had decided that keeping as little inventory and work-in-process as possible as a key element for success. Some components where on the other hand important to keep in inventory due to uncertainties of some supplier’s performance. And some components were considered as low-value products and could preferably be held as inventory in-house. The location of the inventory area was preferably at section C and close to the walls of the facility at section B.

7. Another implicating decision was that the testing of the machine was to be located in a separate area (see attachment 1; Section A), due to practical reasons.

4.1.2 The implications on the assembly system

1. The volume flexibility strategy has some implications on the assembly system. First, the assembly system needs to be able handle different levels of Takt times and thus needs to be able to shift between these smoothly. This requires that no workstation cannot be modified to be able to handle the lowest or highest Takt time.

Secondly, the system will be staffed differently, depending on the current production volume. This requires that the system is designed in order to facilitate flexibility
2. The short lead-time/throughput-time decision has the implication that the system should be designed in order to facilitate a rapid flow of material and components to the machine, which in turns needs to be assembled without interruptions and waiting times. Thus, the system should be designed in order to enhance flow.

3. The strategic decision to minimize the space used for the assembly system affects the design in some ways. First, the amount of space used for every workstation has to be carefully evaluated in order to achieve a realistic block layout. Second, the space not used for the assembly system is planned to be used for other activities and that implicates that the assembly system should not be spread out over the facility.

4. The decision to locate the foam production process at the same area as the assembly system has the implication that the possible flow of materials decreases and thus reduces the possible solutions of designs. The foam production process also requires space for storage and finished goods, and this reduces the amount of free space at section B to use for the assembly system. Besides, the foam production process consumes space for operating and may be a disturbing factor to the assembly process.

5. As can be seen on attachment 1, the location of the shed is inconvenient due to the limiting effects of material flow. Since the shed is located in the centre of section B, the possibility of position a straight assembly line through the centre of the section B decreases. Instead, an assembly line must be moved away from the centre out to one of the walls of the facility.

6. The decision of keeping some components in inventory and with the preferred location next to the walls, implicates, that some storage of material could be situated on pallet racks, or similar, next to the wall of the building. Some larger components could be stored in a different location than the assembly system.

7. The location of the testing area in a separate section of the building has the implication that the machine has to be moved from the assembly system into the testing area.
4.1.3 Logistics strategy and implications.

The role of logistics is the other large area of importance when forming an assembly system as there is a need for material and information to quickly and easy be able to arrive at the right location at the right time in order to stay within production schedule and to prevent delays as well as a too early production start. Since the logistics system is what keeps the assembly running it is essential that the strategy is based upon the preconditions of the assembly system with regards to plant layout, complexity of the product to be assembled, and the attributes of the articles. In this section the findings from the preconditions are mentioned and serve as a starting point for the forming of the logistics system.

1. The cost of the finished product implicates that an Assembly to order strategy is suitable and this was also confirmed by the management stating that since the product is new and about to be released in production the cost is too great to keep it in store and therefore should be assembled according to customer orders. This implies as stated before that the company keeps those articles in store that are low value and where supplier performance is unreliable. Another issue to consider is the keeping of spare parts for future service of already delivered machines.

2. The facility holds three gates where loading and unloading can take place (see attachment 1). Out of these three, the terminal is suitable for loading of the finished product as it easily can be rolled out by its own into the container in which it is freighted. The implication for this is that the product when finished needs to be transported from one end of the facility to the other, from the testing area to the loading dock since testing of the machine is to be located in a separate area due to practical reasons (see attachment 1). Management also stated that this was most likely to be the primary dock used for loading and unloading but if necessary, the other docks could also be used.

3. The use of an overhead crane is also an issue to consider. Since the overhead crane is to be used in order to move heavy objects in the assembly system it is vital that these heavy objects are concentrated in that part of the system where the overhead crane can reach.
4. The placement of material in the facility is important to consider. According to the management, there was a wish of storing the fewer and larger articles at the side of the assembly system where racks are placed following the assembly system (see attachment 1). For the large volume, frequently used articles the desire was to place these close to the assembly station in a trolley or similar storage wagon so that they could be easily accessible and to avoid frequent transports.

5. At the hose assembly, the idea was to place a hose rack or wheel where the different kinds of hoses were to be stored in large rolls onto the wall or ground in order to easily be able to roll them out and cut the right length and number of hoses needed for the assembly operation.

### 4.1.4 The strategy framework investigation and implications

In section 2.1, a framework for linking the manufacturing/operations strategy to the corporate strategy was presented. Since the need for strategic decisions to guide the assembly system design, an investigation of the different elements of that framework was done. The results from the investigation are presented below in figure 4-1.

<table>
<thead>
<tr>
<th>Corporate objectives</th>
<th>Marketing strategy</th>
<th>Order winners</th>
<th>Process choice</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production start-up</td>
<td>One product initially Innovation Standardization Integrated system, machine and foam Initially no variant flexibility</td>
<td>Price Delivery speed Service Technical support and training Quality The systems performance</td>
<td>Foam production process located at same area as assembly system Flexible capacity, 20-80 machines Short lead time</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 4-1. Result from investigation of strategies (framework based on Hill, 2000a).

As can be seen in figure 4-1 above, the overall corporate strategies is to start-up a production of machines and to make the company grow and generate profit. The identified order winners implicates that the system has to generate a high level of quality to a low cost, while being able to handle short delivery times. The process choice factors and their implications are further described in the previous section of this chapter. Due to the fact that there is no current production or operation at the company, there were no infrastructure strategies that could be stated at the moment for this project.
4.2 Facility constraints affecting the manufacturing system

The facility that is supposed to hold the assembly system is presented in attachment 1. The facility dimensions were measured in the beginning of the thesis project, in order to be able to design the layout. As can be seen in attachment 1, the facility is divided into two major sections and a third smaller entity. The sections are separated through walls with gates. The facility is equipped with a logistic terminal that is designed for enhancing loading and unloading goods from a truck. Therefore, is the logic in and outflow of materials from that terminal. Section A is a mechanical shop and therefore suitable for some kind of mechanical work.

Section C has been used for storage of goods previously, and is therefore suitable for materials storage and inventory holding. Section B is the largest area in the facility and is the most modified section for production. Due to the fact that section B is 37,5 meters long, an assembly line must be shorter than that length. The length of an assembly line must also be reduced due to the fact that space for material handling must be facilitated. Section B is connected to section A and C through two gates (see attachment 1) and these are 3,5 meters wide and are able to handle transportation with forklift. Section A has a large gate (4,9 meters wide) and can thus handle inflows of large materials or goods.

4.3 The product’s effects on the assembly system

As described in the methodology chapter, the product was analyzed regarding how it affects the design of the assembly system.

4.3.1 The parameters

In attachment 5 the results from this investigation is presented. The analysis incorporated some parameters of the product and its components that were found relevant for the design process. The parameters that were found relevant are:

- *The assembly time.*

  Used for designing the layout and calculate the necessary staffing of the assembly system.

- *Assembly precedence order*
Analysis of the preconditions

Used for designing the assembly system and decide where to locate the workstations. Also required for determine the assembly procedure and balancing assembly lines.

- **Special assembly requirements**

Used for describing what special requirements that the components require, in order to be efficiently assembled.

- **Part space**

When designing the layout it is required to know how much space every component consumes in order to decide where the assembly should take place. The part space is also important for deciding the storage and transportation of the components.

- **Assembly space required for the parts**

The conceptual design of the assembly system layout requires that the workstations are created as blocks. These blocks should be in the same size as in reality, thus demanding an estimation of the assembly space every assembly station will consume. The block space is then used for making a preliminary sketch of the assembly system.

- **Tool requirements**

The tool requirements are used for deciding if there are any logical positions of the workstations due to nearness to the existing facility environment. Also used for deciding what kind of work place to use for the different assembly operations. Can also be used for determine if it is required to install some extra helping devices for the assembly system.

### 4.3.2 Results of the assembly time investigation

For the assembly times, it exist two different types; one that measures the time it takes to assemble the different components to the machine, the so called final assembly time. The second variant is the pre-assembly time which is the time it takes to assemble the components previous to when they are assembled to the machine, a so called sub-assembly. In attachment 2 the results from the early investigation of the assembly times are presented. Note that some times are divided in to two person assembly, meaning that it is necessary for two persons to participate during some time for that activity. Also note that the chassi part does not have a final assembly time since all other components are assembled on the chassi. The water hose, air hose and electric assembly are smashed into a single time since it is an accumulated value.
The component assembly time in attachment 2 is including the final assembly times presented in the same attachment. It also includes several other assembly and finishing activities that are not specified due to the fact that it is an entirely new product and there is little knowledge about how it specifically will be assembled. This time also includes a safety marginal for disturbances in the material flow.

4.3.3 Result from the precedence order investigation

The assembly operation precedence of the machine is presented in attachment 4 and some basic constraints are also noted in attachment 5. The precedence order investigation is carried out in cooperation with experienced engineers at the company, and based on previous assembly of prototypes of the machine.

The assembly operation precedence is not completely fixed, contrary; the precedence order is possible to alter slightly depending on some factors. Since defining the assembly operation precedence is a difficult task, the process was divided into two steps. The assembly operations were first clustered into groups depending on both the similarities between the different operations and the group’s logical assembly precedence. The assembly tasks within the groups are thus able to be altered in their order to achieve an efficient assembly of the machine.

The first logical step in the assembly process is to start assemble the chassi. This is due to the fact that all other components are to be assembled on it. Besides, subsequent to the assembly of the chassi it is possible to move the sub-assembly since the chassi is equipped with wheels. The chassi sub-assembly is at this stage to be moved into some kind of assembly line for final assembly.

The first parts to assemble on the line are some of the heavier ones since they require free work space on the chassi. Therefore is the first precedence group consisting of the diesel engine and the hose pump, both carrying a weight about 600-700 kg. The fact that they both are heavy requires that some kind of lifting tool is used when assembling them to the chassi. This implicates that they should be in a near precedence order.

The next step is to assemble the pumps to the chassi, which is followed by the hopers. Due to the weight of the hopers, it is logically to assemble it after the diesel engine and the hose pump since they balance the weight load to the chassi, thus bringing stability to the machine. Followed by hopers are the tanks, air intake and the foam process part.
Next, the light ramp and electric cabinet is assembled. The final component to be assembled is the cover, which can be assembled previous to the hose assembly until the final testing. The hose assemblies are the second last assembly operations of the machine. The last operation is the assembly of the electric wiring and system. The process of putting the machine together is finalized with the testing operation which is supposed to make the machine ready for being sold.

The flexibility in the precedence order lies within the precedence groups, rather than between them. The right column in attachment 4 is showing the suggested precedence order for the assembly of the machine. The result is concluded to be a feasible solution for the process of assembling the machine, not necessary the optimal though.

### 4.3.4 Result from the part space investigation

The result from the part space investigation is presented in attachment 5, and is showing the space every component consumes. What is to be noted is that the chassi sub-assembly can be adjusted so that the part space is reduced by half a meter.

### 4.3.5 Result from the assembly space investigation

In attachment 5 the results from the investigation is presented. The assembly space is the space the sub-assemblies operations consume. The assembly space includes the area that the assembler needs for the operation. It also includes the space the material to the sub-components requires. The hopers require extra space in one direction when being assembled. This is due to the fact that the screws, that it consists of, are long and needs to be mounted in the hopers with their fully length from outside.

### 4.3.6 Result from the tool requirements investigation

All of the components require some kind of tools for the sub-assembly of them. Some of them require power tools and other similar tools. These are not affecting the design of the layout; though need to be considered when designing the workstations in detail.

The result from this investigation that requires some attention is the fact that some of the components require the assistance from an overhead crane. This fact is implicating the design of the assembly line layout since there are constraints regarding the possibility to locate the crane to certain areas in the facility. For the detailed result of the investigation of tool requirements, see attachment 5.
4.3.7 Summarize of the input parameters to the conceptual design process

To be able to start developing the conceptual design there needs to be a final decision about what kind of parameters the system should be based on. The input parameters in Muther’s (1973) framework for developing layouts are previously investigated in this chapter and can be summarized:

- **Product (P)** - The features of the product is presented in attachment 5 and further described in the previous sections of this chapter.

- **Quantity (Q)** – 20 to 80 machines per year

- **Routing (R)**-The product will be assembled according to the precedence order in attachment 4.

- **Supporting service (S)**-The product will require materials handling, by fork truck is recommended. There need to be storage space allocated to the assembly system.

- **Time (T)** - The product will be assembled in accordance with the times presented in attachment 2. The product is to be assembled in such a way that the lead times are kept low.
5 Conceptual design of the assembly line

In this section, the process of the conceptual assembly system design is presented. The process has been carried out in cooperation with the technical staff at Aercrete Industries in order to achieve a feasible design that is relevant for the company.

The cooperation has been described previously in the methodology chapter. This section can be seen as a slightly modified version of phase 2: general overall layout in Muther’s (1973) approach to the layout creation process. The results from the investigation in chapter 4 together with the delimits of this thesis, was analyzed and was to be the starting point for the conceptual design of the assembly system.

5.1 The starting position

When analyzing the results from the investigation of the preconditions, the main conclusion is that the choice of manufacturing process is a decision including trade-offs. The machine has a relatively low volume and is thus not traditionally suited for some kind of mass production approach.

On the other hand, the machine is the only product that is to be processed in the assembly system, thus makes the project and jobbing processes not completely feasible. This is the volume-variety decision that Fogarty & Hoffman & Stonebraker (1989) claims exist in every design process. The most suitable process type for this case is a mixture between batch process and mass processes, which equals low variety and relatively low volume.

In figure 2-5 there is a framework for linking the chosen process type to a basic layout type. According to this framework the feasible layout types for the assembly of the Aercrete machine (in line with the previous chosen process type) is process, cell and product layout. The cell layout is according to the framework, the layout type that is responding best to the volume-variety trade-off for the Aercrete machine.

But the cell layout was found infeasible due to the fact that there is no product variety and designing a layout that can handle variety must be seen as a waste of capital since the system will have over-capacity. The same conclusion was found about the process layout type and leaves only the product layout type left as an option. After an evaluation of this alternative it was found that the product layout is a feasible solution for the Aercrete machine, even though it is mainly used and recommended for higher volumes.
The implications of a product layout are that the assembly system will be inflexible to handle variety, though it is possible to handle volume variety. The volume variety has traditionally been met by rearranging the assembly line and altering the number of workstations in combination with staffing (Slack & Chambers & Johnston, 2004).

The most commonly used type of a product layout is the assembly line. The assembly line has been used with great success ever since Henry Ford invented it in the early twentieth century (Sandkull & Johansson, 2000). The advantages with the assembly line is that it creates little work-in-progress inventory and smooth flow which minimizes the queuing (Hill, 2000b). Little’s law says that the inventory in the assembly system is proportional to the lead time in the system, thus meaning that less inventory equals a lower lead time (Srinivasan, 2004). This is one of the previous identified crucial order winners of the Aercrete system.

5.2 The assembly line

To be able to design a conceptual assembly layout, there are some inputs that need to be gathered. From the theoretical background in chapter 3, it was found necessary to determine the Takt time of the system and the number of workstations required. Also the assembly tasks and their precedence relations were noted as important input to the design process. The conceptual assembly line should then be able to be designed.

5.2.1 Takt time and number of workstations

The assembly work of the product that is to be assembled is carried out in different stages, so called workstations. The number of these workstations that are to be used must be decided. In paragraph 2.7.2.1 it is indicated that the number of workstations are depending on the Takt time of the assembly system. The Takt time is depending on the desired production volume of the assembly system.

Since the desired production volume in this case is flexible the system needs to handle two extremes (twenty and eighty machines) and the capacity between. For the ease of sake, it was decided that the system’s volume flexibility should be limited to twenty, forty and eighty machines on a single shift. If a volume is required between these three values, then there has to be changes in the working hours or staffing.

The Takt time is also dependent on the available working hours per year. As can be seen in attachment 6, the available working time per year and person is approximately sixteen hundred hours. This figure is based on an estimation of the actual hours an operator is at her station and performing value-adding work.
With this available working time the Takt times for the three desired production volumes are eighty hours (twenty products/year), forty hours (forty products/year) and twenty hours (eighty products/year). See attachment 6 for the calculation of the Takt times. With these Takt times calculated, it is possible to calculate the number of workstations/operators. In attachment 6 these calculations can be seen, the total assembly time figure (two hundred seventy point five hours) used is a summary of the pre and final assembly times for the completion of the machine.

The result of the calculations in attachment 6 shows that the required number of workstations/operators for the different Takt times are four (eighty hours Takt time), seven (forty hours Takt time), fourteen (twenty hours Takt time). From this point on these three settings will be referred to as:

- Setting A: Four workstations/operators, eighty hours Takt time, twenty machines per year
- Setting B: Seven workstations/operators, forty hours Takt time, forty machines per year
- Setting C: Fourteen workstations/operators, twenty hours Takt time, eighty machines per year

These figures are applicable in a perfect environment and should thus only be used for the design of the system. The staffing can and should be altered in the detailed design and when operating of the assembly system.

Figure 5-1. Schematic illustration of early conceptual assembly system design (eighty hours takt time).

The figure above shows the schematic illustration of an assembly system with eighty hours Takt time and with four workstations/operators. The same schematic can be applied to the other two Takt times presented previously, though with a different number of workstations.
The great difference in the number of workstations is a complicating factor for the conceptual design of the assembly system. Increasing the number of workstations with ten between eighty and twenty hours Takt time is thus requiring an increase in the workspace with approximately two point five times. This implication has to be solved in a convenient and efficient way.

5.3 Layout proposal number 1

The first attempt to create an assembly system layout had a so called “trial and error” approach. The idea was to start from a basic academic approach and adapt that one into a feasible solution for the specific situation.

At this early stage of the design process a decision to focus on one single parameter setting was taken in order to simplify the work. The setting to use was decided to be setting A, due to the fact that it is the initial precondition of the assembly system design.

5.3.1 Background

The underlying idea behind layout proposal number one was to design an assembly line layout with four workstations, eighty hours Takt time and use the basic line balancing methodology presented in paragraph 2.7.2.2.

The assembly tasks (see attachment 2) were dedicated to a workstation, starting from workstation one. The workstations where filled with tasks until their work content reached the Takt time. The result can be seen in figure 5-2 below. The precedence order for the assembly of the machine (attachment 4) was slightly altered. This was due to the fact that it is preferred to have the longest workstation times in the earliest parts of the assembly line.

As can be seen in the figure, workstation three and four has a great deal of slack time, meaning that there will be waste in the system. The calculated efficiency, or utilization, of this system was computed to be eighty five percent (see attachment 6). This means that fifteen percent of the total labour time is waste. It also indicates that there will be imbalance in the system, and hence probably lead to disturbances in the production flow in the future.
The calculated efficiency rates in attachment 6 also include the rates for Setting B and C, though this concept proposal was not elaborated to include these settings. This is due to the fact that this concept was not found as a feasible solution for setting A, but it was found relevant to include these calculations to see whether it is possible to achieve a high efficiency for different settings in general, which was confirmed.

The throughput time for this proposal is the time from when the chassi sub-assembly is stated to being assembled until the machine is tested. Since the takt time is eighty hours and there are four workstations, the throughput time is $80 \text{ hours} \times 4 \text{ workstations} = 240 \text{ hours}$.

### 5.3.2 Findings and advancement from conceptual layout design 1

The major conclusion from conceptual layout proposal one was that the lead time, or throughput time, of the assembly line is too long compared to the stated goal of one hundred hours. The throughput time of the proposal above is two hundred and forty hours, which is far over the target.
The concluded reason for this is that the sub-assembly times and the final assembly times are not separated from each other in this proposal. This fact makes it necessary to determine the critical line, which is the assembly path that generates the shortest possible throughput time. The task is to separate every assembly task that is not necessary to be performed while the chassis part is at the workstation. This separation is supposed to generate an assembly process that makes the machine flow through the assembly line and not being withheld while sub-assemblies are made. The reason for why the sub-assemblies are causing withholding of the machine is that the sub-assembly times are greater than the final assembly times. In other words, it takes longer time to assemble the components than assemble them to the machine. Therefore is it logical to letting the sub-assemblies of the components flow towards the final assembly line and being assembled to the machine in sequence.

In attachment 2 the assembly times are divided into two different kinds; Pre and final assembly. The Final-assembly times are part of what was previously defined as the critical line. A summarize of the final-assembly times shows that the critical assembly path is one hundred eight hours, in other words eight hours longer then the suggested goal of one hundred. This fact implicates that some of the assembly operations must be carried out in parallel with two persons in order to save time on the critical path. Therefore are the air, water and electric hose assembly split into a two person assembly, thus reducing the critical path time to ninety six hours which is below the one hundred that was requested.

![Diagram](image)

Figure 5-3. Illustration of findings from conceptual layout number 1

The throughput time calculated and presented above, is for a non-paced assembly line. A paced assembly line should thus keep the throughput time decided by the Takt time that has been calculated.
5.4 Conceptual line layout proposal number 2: The final assembly line

The objective of layout proposal number two was to find a creative solution that facilitated the requested throughput time while still to fulfill the other requests of efficiency. As described in paragraph 2.8.8 the throughput time can be defined and measured different depending on from where one chooses to start and end measuring. For this assembly line the throughput time was chosen to be defined as from where the chassi is starting to become a part of the final assembly process. The end is when the machine is tested and ready for shipment.

The question at this stage was how to manage meeting the desired Takt time and throughput time, while separating sub and final-assembly tasks. It was decided that it might be feasible to load the individual operators with work instead of the workstations. The implication from this decision was that it was found relevant to separate the illustrative workstations, from figure 5-1, on the final-assembly line and the workstations used for sub-assemblies. This would lead to the fact that the final-assembly process could be one workstation with three, or more, others serving it with components and sub-assemblies instead of four sequential (see figure 5-4 below). This approach would also make it possible to pace the line in order to make it running according the Takt time and thus be efficient.

Figure 5-4. Illustrative figure describing concept proposal 2.
This kind of manufacturing approach is a so called “assemble-to-order” strategy, as described in paragraph 2.6.2. This strategy makes it possible to run a rapid final assembly with a short throughput time. This approach also facilitates a decoupled manufacturing process, meaning that the pace of the final assembly line and the subassembly processes can be different. That could be valuable, and makes it possible to build up buffers in the system. Those buffers can be useful in the attempt of avoiding disturbances on the final assembly line. Such disturbances can be due to uneven inflow of material from suppliers or problems in the process of the sub-assemblies. Besides, the assemble to order strategy also makes it possible to keep the level of finished goods low, which in turns keeps the amount of capital invested in the system down. This is due to the fact that it is less costly to keep components than finished goods in inventory.

The conclusion from the previous reasoning was that this approach was found as a possible way of getting around the problem of maintaining the critical line floating without interruptions.

For this to be feasible, the final-assembly station’s critical line must keep a lower cycle time than the Takt time of eighty hours and be paced according to it. From paragraph 5.3.2 the throughput time was calculated to be 96 hours, which is the critical line of the final assembly. As described previously, a paced assembly line’s workstations operates at a fixed Takt time. The Takt time is 80 hours and there are 4 workstations within the final assembly line, which means that every workstation can not be loaded with more than 20 hours work (20 hours workstation cycle time). Since some of the tasks that are to be carried out at the final assembly line are longer than 20 hours they must be split up into 2 person assembly, even further than has previously been done. Besides, the need for breaking down the hose and electric assembly times was found at this stage, in order to balance the final assembly line.

In attachment 2, the hose assemblies and the electric assembly are mixed up into one common time estimation. The possibility of breaking down these tasks into smaller entities was investigated. The result of this investigation was that it was possible to, somewhat, appreciate the individual times for these tasks. The result of this investigation can be found in attachment 3, and shows the new individual assembly times for the water and air hose assembly, when separated from the electric assembly.
The new times in attachment 3 facilitates a, somewhat, better balance of the final assembly line, though there still exist tasks with too long assembly time. The component assembly time is 40 hours totally, but it is possible to split it up into 2 person’s task, which makes the throughput time 20 hours. The hydraulic hose assembly task takes 16 hours to carry out, thus below the cycle time of 20 hours for the workstations at the final assembly line. Since water hose assembly is fairly similar to the one of hydraulic hose, it is possible to combine them into the same workstation, which sums up 20 hours. The testing task takes 20 hours, which makes it logically to use as one workstation since it operates at the cycle time. Sequential before the testing task, is the electric and air hose assembly situated. As can be seen in attachment 3, the electric assembly takes 24 hours if it is carried out by one person. If the task is divided by two persons to a certain degree, it is possible to decrease the throughput time to 16 hours. Together with the air hose’s assembly time of 4 hours, it makes up 20 hours, which is the maximum cycle time for every workstation at the final assembly line. A summarize of the above described balancing reveals that it is possible to operate the final assembly line at a 80 hours throughput time, with four individual workstations operating with 20 hours cycle time. This is illustrated in figure 5-5 below.

Figure 5-5. Illustration of concept behind conceptual layout proposal number 2.
Since the final assembly line will be used for 3 different Takt times, the volume flexibility will be achieved through the way the line is staffed. At a slower pace (Setting A, 80 hours Takt time) the line will only have one machine in one of the workstations, per cycle. In other words, when one machine is tested another one is started to be assembled at the beginning of the line. When the pace of the line is higher (Setting C, 20 hours Takt time) the line will have one machine in every workstation continuously. This means that every 20th hour a new machine is started to be assembled.

For the staffing point discussed above, the implications are that during the low operating pace the line will have flexible staffing. This means that the operators that will carry out the tasks at the final assembly line will not be stationed at the workstation the entire time. The operators are thus forced to move from one station to either another station or a sub-assembly task, during their work cycle. When the line is operating at the highest pace (20 hours Takt time) it is necessary that at least one operator is stationed at every workstation at the final assembly line. For the component and electric/air hose assembly stations it needs to be 2 persons stationed, in order to carry out the task accordingly to the Takt time.

The fact that for the Setting A with only one machine at the final assembly line, it might be questionable whether it is necessary to move the machine from the start at the component assembly station through 3 more stations before it is completed. For this setting, it might be feasible to apply the fixed-position layout approach presented in section 2.5. Since only 1 machine is being assembled at the same time, 3 workstations are constantly free and unused.

This could be seen as a waste from a Lean Production perspective (see section 2.3). But due to the fact that the system is also supposed to handle setting B and C, it is necessary to build the system in a way that enables a smooth change between the different settings. For setting C, it will always be one machine in every workstation, thus make the fixed-position approach be infeasible or/and inefficient. Basically, the over-capacity for setting A enables the volume flexibility that is desired. Therefore must the machine be moved even for setting A.

In paragraph 2.7.2.2 it is stated that the cycle time for a workstation should preferably not be 100 percent of the Takt time, which would lead to imbalances and disturbances of the assembly line. This is a fact that was considered and reflected about, and the conclusion was that it is not relevant to include it into the design of the final assembly line.
One reason is that the assembly task times used are appreciated values and not measured times. Another reason is the fact that learning curves exist and will affect the assembly times (see paragraph 2.7.1). The learning curve effect might lower the assembly time and make the cycle times end up at 85-90 percent of the Takt time, which is recommended. A third reason is that even if the two reasons described above will appear or not, the line will have to be re-balanced anyhow after being in operation for some time.

After the final assembly line concept was designed, it was evaluated whether it was suitable for becoming a fixed design, and taken to the design phase. In cooperation with the management at Aercrete Industries the concept was evaluated from several perspectives as: Flexibility, cost, quality conformance and its feasibility in practice. The conclusion was that the final assembly system was a possible and satisfying solution, and should thus be the base for the next steps in the design process. The implication from this decision is that from now, every design will include the principle of the final assembly line concept presented in figure 5-5. The concept is applicable and will be used for all 3 of the different Takt time settings that the system is supposed to handle.

5.5 Line layout proposal number 3: The sub-assembly system

After the development of the final assembly line concept, which handles the critical line tasks, the next step was to develop the design concept to include the sub-assemblies as well. As previous mentioned in section 5.4, it was found relevant to load the individual operators with workload. Since the workstations at the final assembly line concept is loaded with tasks, and not the other way around, most of the operators must alter between working at the final assembly line and the sub-assembly system, at least for Setting A. This will lead to a more complicated, at this stage, design process of the assembly system. When the system is operating, it will also lead to a more complicated planning process of the system.

The sub-assembly system is not an assembly line as the final assembly line is. Instead it will be a number of stations where the components are to be assembled, and since they are not part of an assembly line it is not necessary to have a perfect balance the workload. Though, the operators should be assigned assembly tasks according to meet the required Takt time. Due to practical reasons it is not possible to include time for breaks and other non/overhead productive occasions. Therefore it is necessary to leave some slack time for the operators and thus creating a time buffer in case of need.
The sub-assembly system is not directly depending on the final assembly line and can be operating even if the final assembly line is shut down due to some reason. Contrary, the final assembly system will be dependent of the sub-assembly system in order to get components for the component assembly task. This implicates that the workload in the sub-assembly system should not be designed so that there is a risk for overload. This overload might lead to disturbances and delays, which will lead to component shortages at the final assembly line and force it to stop.

![Sub-assembly and Final Assembly System Diagram](image)

Figure 5-6. Illustrative figure describing the concept of the assembly system, setting A.

As described above, the operators should be assigned work tasks and this assignment was to be carried out with the delimit that the final assembly line’s critical line must not be delayed. Except for this, there was only one other delimiting factor for the assignment; namely the fact that it was preferred from the management that most of the electrical tasks was to be carried out by the same operator (mainly affecting Setting A). This was due to the fact that the electrical work is slightly more complicated and requires some knowledge from the operator regarding electricity and electrical components. Therefore is an operator with electricity/electrical competence desired, and that operator should thus be carrying out most of the tasks related to electricity. As can be seen in figure 5-6 regarding the final assembly line, the assembly of the components to the machine is carried out in the first workstation. This implicates that if the components are to be sub-assembled in the same cycle, as they are final-assembled to the machine, requires that they are done so in less than 20 hours.
This also requires that all of the components are sub-assembled in less than 20 hours. This was found impossible with respect to the critical line and throughput time limit. Instead of supplying the current final assembly cycle with components, the sub-assembly system is supposed to build up the next cycle’s component stock. A benefit from this is that if there are some problems with the supply of components from the suppliers, the final assembly line can be operating for a while without being affected (mainly setting A).

5.5.1 Setting A assembly task assignment concept

The assignment of assembly tasks to operators was initiated, and for setting A the final result is presented in attachment 7. Before this result, some other similar concepts were developed. These concepts were neglected due to the fact that they did not fulfill the performance levels that were requested. It was early discovered that the final assembly line’s structure strongly affected the possibility of assigning tasks. The line must be staffed with operators when the machine is in a workstation being final assembled. Therefore must the operators be assigned sub-assembly tasks between the times they are stationed at the line (mainly affecting setting A). So the initial action was to assign the final-assembly tasks, and they can be seen in attachment 7 as the ones with bold and italic font.

Later on the sub-assembly tasks were assigned to the operators (4 for setting A) and the methodology was a simple trial-and-error approach. The only condition to consider was the fact that the electronic work was preferably done by the same operator, as stated previously. This operator was assigned all the electronic work, but also to assist with the hopers and cover sub-assembly when needed. The air hose and the 4 hours of extra electrical assembly were, logically, assigned to another operator due to the throughput time limit. The idle time some of the operators seem to have in attachment 7, are time that can, and should be used for other overhead activities. Operator 4 has 14 hours of idle time scheduled, but that time might be required for preparing for the electric final assembly.

5.5.2 Setting B assembly task assignment concept

The assignment of task to the setting B concept was more complicated to carry out, due to the fact that there is a natural imbalance in this setting. The final assembly tasks (grouped to 4 stations) need to be carried out in a certain sequence in order to avoid the imbalance of the final assembly tasks.
Conceptual design of the assembly line

Station 1 need to be staffed at the same time as station 3 is staffed. Station 2 and 4 needs to be staffed at the same time as well, and not at the same time as the 2 previous stations. This is due to the fact that there are two machines on the final assembly line at the same time, which together with the 40 hours Takt time makes it necessary to carry out 2 final assembly station’s tasks in the same cycle, in order to meet the Takt time. This implicates that station 2 and 4’s tasks needs to be carried out in the last 20 hours of the 40 hour cycle.

An issue that that can be seen in attachment 7 is that if any Takt time lower than 40 hours is used makes it necessary to use more than 1 person for the assembly of the foam process. The foam process is the operation with the longest lead time, and thus the pace limiting factor for this setting.

5.5.3 Setting C assembly task assignment concept

The setting C concept turned out to be an efficient task assignment. This is due to the fact that most tasks are possible to configure in order to keep a cycle time near 20 hours. All the 4 workstations at the final assembly line will be staffed all the time and some sub assembly tasks needs to be carried out in parallel in order to meet the requested cycle time.

This task assignment concept is carried out accordingly to meet the highest pace of the assembly system. If any higher pace is desired it will be imbalances and lower efficiency. Besides, the final assembly line concept would not be able to handle the increased pace without increasing the available working hours, for example with an extra shift or double capacity (parallel final assembly line).

5.5.4 Alternative task assignment concepts

The previous 3 presented task assignment concepts are feasible solutions to the task assignment problem. Though feasible, they are most likely not the optimal solution, which leaves potential for future improvements and re-balancing when the assembly line is in operation.

The setting with most improvement potential is setting A, which has the most complicated balance of assembly tasks. If the learning curve effect will be significant or the assembly times were overestimated, there is a potential in even reduce the number of workstations/operators required for assembling the machine.
5.5.5 Human factors and Ergonomic aspects

The ergonomic or operator satisfaction aspects are difficult to perceive during the assembly system design process. Therefore is estimation necessary in order to identify possible downsides with the design.

The long cycle times of some of the assembly tasks make it difficult for the operators, in the beginning, to learn the task. The long cycle times makes it more interesting and challenging for the operators, which serve as a positive aspect of the work content. The long cycle times makes it necessary to control the work before it is finished, in order to detect defects. This leads to the fact that the operators must be motivated to carry out these activities, and quality instructions must be written.

The assembly line concept has more and more started to be seen as something negative, from the job satisfaction point of view. This is a known fact with assembly lines: they are effective from a production point of view but boring from an operator’s view. This is something that has to be dealt with when the operators are at place and the workplace is being designed in detail, which is not included in this thesis.
6 Conceptual design of the logistic system

This chapter gives an insight in the activities taking place in the designated assembly system. It serves as an overview of how the logistics is to function in the assembly system. This chapter can be seen more as an overhead design of the logistic system and creates the basis for the detailed layout presented in chapter 7.

6.1 Loading/Unloading

Based upon the preconditions and theory it could be stated that the primary gate also known as the terminal (see attachment 8) was to be used for loading of the complete machine and unloading of material since this is the most suitable area for this. The implication here though is that the product when finished at the testing area has to be moved throughout the plant to the loading dock. This is however no problem as there is enough space to move the product at the side of the line and is calculated within the balancing of the operators.

When articles arrive to the facility there is enough time available for operators due to their slack to receive the articles and to do a preliminary quality and quantity control where they at this stage quickly check if there are any visual defects on the articles and if they are at the right quantity. This is of course impossible for the high volume articles as it is time consuming to check each and every one. Instead this would be prioritized for the low volume articles at this stage. High volume articles are instead controlled directly at the assembly station when being used and then the final testing to ensure that the machine is working properly.

6.2 The overhead crane

For the overhead crane it was argued that it was to be positioned in such a way that it could be used rationally and have the most utilization possible. (see attachment 8) The main preconditions of course are those that there are heavy products that needs to be lifted and cannot be managed by hand. In the assembly line the overhead crane moves these articles from storing to subassembly and then from subassembly to the critical line where they are assembled onto the chassi. These articles that were of particular concern were the engine, hoppers, hose pump as these carry the most weight and volume. Another implication for the use of the overhead crane is that the critical line assembly has to be divided into two stations where at the first the hose pump and engine are assembled and at the second the hoppers are assembled.
This is done in order to balance the workload for the operators but also to make sure that the overhead crane is more balanced and that it does not disturb any other assembly function. The main concern with the overhead crane is how to use it rationally in order to prevent it from standing still and being busy and here the sequencing adds in. What sets the sequence for this crane is the precedence order, the actual usage of the crane at the workstation and the distance it has to travel. These are the parameters needed for the effective usage of the crane. Dividing it into the product that needs the crane we have:

**Hose pump**

The hose pump has two movements, which are from the inventory to the subassembly and from the subassembly to the critical line assembly. The hose pump has no further aid from the overhead crane and would not cause any major problems. Furthermore the Hose pump has little subassembly operations and material for the subassembly does not need much space.

**Chassi**

The chassi also has the need for the overhead crane when assembling the wheels and axles, which demands access to both sides of the chassi. As stated before the management is considering a fixture for this assembly, which would free the overhead crane from being, tied up at this station. The material needed for the assembly demands some space and is best placed at ground level close to the station.

**Engine**

Is moved from the storage to the subassembly station and then from the subassembly station to assembly station 1 on the critical line. The engine is the article that has the shortest subassembly time and does not create any problem for the overhead crane as it does not use the crane more than the few minutes it takes it to travel to and from the different stations mentioned.

**Hopers**

The hopers is the article that demands most time and aid of the overhead crane since some moments in the assembly has to be done on the bottom side of the hopers. This calls for the usage of the crane those hours this is to be done. A consideration is made whether to use a fixture instead where the hopers are easily adjusted and turned around which would free the overhead crane.
The hopers consist of some heavy objects such as screws and hydraulic engines which demands some space for inventory. For the screws some help of the overhead crane could also be needed to get them into place inside the hoper.

6.3 Inventory storage

In the preconditions it was stated that there was a wish for placing the high volume low cost articles such as bolts and screws directly at the assembly station and the low volume, expensive and heavy articles such as the engine and hose pump in racks at the side of the assembly line. Since these are quite heavy and expensive articles they should be placed at the floor level in order to minimize the risk of damages from dropping them from high above and to make it easier for transporting them quickly to the assembly station with the use of the overhead crane.

The high volume articles are also stored within these racks and with the use of a trolley the operator can smoothly head to the rack and refill the trolley when empty or at a low level. The articles should be stored following the line, which means that the inventory storage is based upon the precedence order of the assembly starting with the chassi and ending with the assembly of the hood. This idea follows the theoretical statement by Lumsden (2006) stating that transportation and unnecessary movement of material is minimized when adapting the working areas to the order in which inventory moves inside the warehouse. By placing high turnover rated articles close to the assembly and low turnover articles further away this is seen to.

6.4 Material flow

The flow of material is important to consider as material must reach the assembly in time and at the right quantity. The theory states that there must be considerations taken to the distance between the assembly line and inventory, the actual layout of the warehouse and operator steps taken before being able to assemble the part. Secondly the characteristics of the product must be taken into consideration such as the prize, and size together with the product structure and damage risks. This together with the preconditions stated forms the basis for the material flow and gives some alternatives for how to form the flow of material and how the assembly system should be fed with material. To start with, it is suggested that the assembly line moves throughout the factory in a linear shaped flow where material moves from one end to the other from the arrival to the testing of the finished product. Although this is said to increase the lead-time of the assembly and lead to higher costs it is believed at this stage that it is more important to get a good and clear view of how the material is moving inside the factory in order to secure the future flow.
At this low initial volume of 80 hours/piece and considering the length of the assembly system this would not cause any problems with not coping to feed the whole system with material. However if problems are encountered with this and lead time would significantly increase then the issue of the line layout could be discussed and what would most likely be considered is switching into a U-shaped line where transports are decreased. For lower Takt times and the need for decreased lead times of course this should be considered.

Material is moved by truck in marked pallets. To make it easier for the truckdriver and to save time the storage place or warehouse which at this stage is placed directly at the factory should be marked out with a specific place for a specific article. Again this place depends on the size of the article, the outtake frequency and the closeness to the assembly station.

6.5 Feeding the assembly line

For the assembly line a mixed approach of kitting and centralized material squares could be considered. The constraints presented regarding the overhead crane in combination with the characteristics of the articles and thirdly the precedence order of the assembly are the determining factors for the feeding of the assembly line. For the overhead crane it was argued that it was to be positioned in the beginning of the assembly line (see attachment 9: Station 1) as there are constraints in the facility such as pillars and constructional constraints that gave few alternatives for the placement of the crane.

The precedence order of the assembly also stated the area as the most suitable for lifting the heavy articles used in the beginning of the process. This in turn, affected the placement of the heavy assembly objects as it was necessary to do the subassembly of the objects within the reach of the overhead crane. These, together with the given assembly times are two large inputs for the forming of the assembly system. The affected objects where the chassi, engine, hopers and hose pump as these are the parts that carry the most weight, volume and value. The subassembly of these objects therefore had to be considered from two aspects namely the precedence order they were to be assembled in and also within reach of the overhead crane.

6.5.1 Suggestions

The preconditions and the suggested outline stated above gives incentives for a suggestion of how to handle the logistics function of the assembly line.
One must bear in mind though that these are only suggestions based upon estimated information which is not certain. Therefore the suggestion is made in a more overhead and less detailed approach since there are no direct measurable variables that could be used.

**Unloading/loading**

As it was stated before, articles arrive at the loading terminal (attachment 8). From here, they are received and an inspection is made of the large articles with few volumes in order to secure that there are no damages that can be determined visually. After the initial inspection, articles are sorted into articles that are common for many assembly objects and into articles that are specific for each assembly object. This is also the point where articles are registered and entered into the inventory system. For the large assembly objects such as the engine, hose pump, hopers, and chassi these are registered and taken directly to a storage point close to the assembly station (see attachment 8).

Since the assembly of the electric cabinets and the foam process are to be assembled inside the movable shed it is important to separate the articles for the assembly as soon as possible, preferably already at the receiving. The designated operators for the foam process and electric cabinet could do this in order to get it right as they are the “experts”.

**Placement/storing**

After dividing and marking out the articles they are taken to the decided storage point (see attachment 8), which for the object specific articles should be situated close to the assembly station. The common articles used by many operations (nuts, bolts or hoses etc.) should be placed as central as possible in order to have such a short distance as possible when refilling.

For the refilling, a binge containing boxes for each article is suitable to use. In order to quickly see what article the boxes contain it is preferred that the boxes are in different colours and size in order to quickly identify its content. In addition it is easier to determine which article that should be in each box which saves time at refilling and picking.
The hose rack used for hoses, which is a frequently used article, should be given its own station close to the hose assembly station. It should preferably be situated at the side of the movable shed, where it is mounted onto or close to the wall (see attachment 8). Here are also cutting tools and welding tools placed as there were some small demands for welding.

**Transports**

For the critical line the chassi, hopers, engine and hose pump are moved by the overhead crane from subassemblies into position. For the critical line to move forward it is suggested to use a truck with a trailer coupling to hook up to the chassi and move it forward to its different assembly stations and to the testing area. As stated before, the finished machine then is moved throughout the plant to the terminal where it awaits its departure.

The area in which it is transported is shown on attachment 8 and this area is also designated for the transport of material to the inventory racks. This transport area is wide enough for transportation of the finished machine as well as the loading and unloading of inventory.

**Spare Part Inventory**

It is of course so that when a number of machines have reached the market there will be an increased need of spare parts. Two ways of spare part keeping could be considered here.
1. **Keep spare parts at suppliers**

Keeping spare parts at the supplier means there will be no area designated for spare parts within the factory and thus more area is free. Secondly, it is essential that responses from suppliers are fast and accurate which demands a tighter bond between the company and its suppliers. This could also benefit the company as a whole if tighter bonds are created with the suppliers since lead times not only for spare parts but also for the ordinary material decreases if the supplier can respond quicker to the demand. These are the tradeoffs to consider when keeping spare parts at the supplier.

2. **Keep spare parts in house**

Keeping spare parts in house gives the advantage of quicker response to the demand from customers. The problem is that the spare parts must compete with the material for the assembly about the space available. At first this would be no problem but as sales increases so does the material procurement and the spare parts keeping. If spare parts are kept in house a designated area must be formed where they are to be held and this means that more space is needed. The placement of such parts must be kept separate from the material intended for the assembly system.

6.6 **Ergonomic factors**

For the assembly system some of the ergonomically factors must be lifted. Often this is more looked into when forming a detailed complete layout of the assembly station i.e. forming the workplace. The idea here is to lift some of the questions raised from theory and apply them onto the low volume articles.

6.6.1 **Examining the factors**

Based upon the theory there is a suggestion that the workplace factors in the assembly system should be considered. As mentioned before there have been considerations on placing articles such as the chassi and hopers in fixtures to make the subassembly easier. The suggestion is that the design is done based upon the anthropometrics of the operators and to ensure that awkward and uncomfortable positions are avoided.

The ergonomic factors that are described in the theory are workplace factors, environmental factors and behavioral factors and these are briefly described when applied to the assembly system.
Workplace factors

These factors deal as mentioned before with the interface between the workplace and the physical attributes of the operator. Since the system is in the making and workplaces are yet to be formed, there can be no investigation or result from these factors until they are formed and in operation. At that point there should be a thorough investigation of the factors, what attributes the operator has in order to secure that the tools, fixtures, and other equipment matches the operator.

Environmental factors

These factors can be described at some aspects such as temperature and lightning. After a walkthrough in the facility, it could be agreed that temperature and lightning are both sufficient for the operators. The facility holds a good lighting and also hatches at the roof letting daylight in and preventing bad eye sight. The temperature is comfortable and suits the assembly operation. However, this is stated from the author’s point of view and should of course be brought up to the surface if problems occur. These are the factors that can be determined by looking at the facility as it is now. For other factors to be determined the assembly system must be up and running.

Behavioral factors

From the behavioral factors, no conclusion or result can be made since there are no operators present as it looks today. However the recommendation is to give the operators meaningful tasks and to design the assembly station from the operator’s perspective. Involve the operators in the assembly and let them make decisions regarding their own area of operations in order to satisfy them to the greatest extent possible.

Recommendations

Some recommendations are stated above for the ergonomic aspect of the assembly system. The suggestion is to look at the aspects outlined in the theory chapter and base the workplace layout with this in consideration.
Detailed design of the assembly system

In this chapter, the final detailed design of the assembly is presented. This chapter can be seen as equivalent to phase 3: Detailed Layout Plans, in Muther’s (1973) framework for process layout design.

The level of detail of this chapter has been chosen to be limited to the assembly line, the logistic system, material handling and the flow of material (see the “delimits” section for further information). The detailed design of the assembly system is supposed to be a feasible solution with respect to both the assembly line aspects as well as the logistic system aspects. The detailed design may be seen as a “best of breed” solution to the design process.

In this chapter the position of the assembly line in the facility will be decided and presented. The decided physical position of the inventory and store room in the assembly system will be presented as well. The anticipated inflow of material to the inventory store room and the in and outflow to the assembly system will be presented, together with the outflow of finished goods, and how the goods dispatch is to be organized.

7.1 The physical shape and position of the assembly line

According to Srinivasan (2004) there exist 2 types of assembly line shapes; straight and U-shaped lines. As described in paragraph 2.8.5, the U-shaped assembly lines work more efficiently in a flexible environment, which is the environment this project is dealing with. The U-shaped lines are considered to be the best solution according to the Lean Production philosophy, and it is stated that they provide a short lead time and the possibility of multi-tasking among the operators (Ortiz, 2006).

The U-shaped assembly line type was found as a possible theoretical solution for the assembly system. The problem that was, in practice, limiting the possible use of this assembly line type was that there were some physical constraints affected by the facility and the preconditions analyzed in chapter 4.

Besides, the fact that one of the stations (testing station) was supposed to be situated in another section of the building and the location of the movable shed was considered to be a major influence why the U-shaped line was eventually considered to be an unfeasible solution. More specified, the U-shaped line was found to consume too much space regard to the available space on the shop floor.
The only rational option left to apply about the shape of the line, was the straight (more or less) assembly line shape, commonly used in manufacturing systems (Ortiz, 2006). With this option, the problem of where to position the stations relative to the facility constraints was the main topic.

The available area at the shop floor can be seen in attachment 1 as the rectangular area indicated in the picture, with the movable shed and foam production process located in it. The fork-truck aisles surrounding the assembly area are consuming a great deal of space and limit the available area for the assembly line. As can be seen in that picture, there are also some pallet racks located in the rectangular area, which even further limits the possibilities for locating the assembly line.

The major limiting factor for a straight assembly line is the total length of the line. In other words, the total amount of workstations and the space required for these cannot be longer than the space available at the shop floor. With the space requirement information in attachment 5 and the available measurements of the available assembly space at the shop floor, it was concluded that a maximum of 4 stations, with 1 machine in each, is possible to allocate without exceed the available space and space requirements. This is valid with a material flow along with the long side of the rectangle.

The question still remaining is where on the short side direction of the shop floor to place the opposite direction of the assembly line. Since the movable shed and foam production process are delimiting the possible area to half of the total space of the shop floor, only half of the space is available which means that the position simply has to avoid being too close to some other physical element.

The assembly line was decided to be located as can be seen in figure 7-1 below. The flow of material is indicated with an arrow in the red rectangle marked “1”. The rectangle marked “1” is basically showing the area the assembly line can be placed within. The width of the rectangle is around 9 meters and the space required for the machine is around 4,5 meters, which leaves some marginal for altering the exact position when the assembly system is being constructed.

The guideline is that it should be approximately 2 meters, or more, between the movable shed and an eventual machine in a workstation. This is due to the fact that it should be possible to walk beside the machine while some assembly work is carried out in a workstation.
Figure 7-1. Figure describing the position of the final-assembly line and free area for process activities in section B.

The other two rectangles in figure 7-1 is showing two locations on the shop floor were there exist some free space for sub-assembly stations or logistic activities. Some sub-assembly workstation must be located within the rectangle marked “1”, in order to fit all the necessary workstations in Section B of the facility.

7.2 The physical position of the sub-assembly stations

When the assembly line (final assembly line) is positioned at the shop floor, the logical sequential action is to place the sub-assembly stations there as well. Due to the nature of a thesis report, it is difficult to present tasks that were carried out in deep collaboration without creating confuse for the reader. It should be stated that this section was not an action carried out in isolation from the logistic aspects that were, previously, claimed to be equally influencing as the other aspects. Instead the reader of this report should see the clear split of the actions as a way to make the report easier to read. It should be noted that some assumptions in this section will consider conclusions that are mentioned and further explained in the next section. When positioning the workstations on the shop floor it is important to think about the aspects that need to be considered, and those requirements that need to be met.
It is therefore necessary to remind those prerequisites that were specified in chapter 4 as well as the results from section 5.4 - 5.5 and chapter 6 regarding the design of the final-assembly line, the sub-assembly system and the logistic system. The space available for the sub-assembly stations can be seen in figure 7-1 as the two rectangles marked 2 and 3.

Besides, it is also possible to position sub-assembly stations in rectangle 1’s area, as long as it not interferes with the final-assembly line’s workstations. It should be noted that the definition of workstation differs between the sub-assembly system and the final-assembly line. The workstations that are mentioned for the sub-assembly system are more of a “workplace” format, than a traditional assembly line workstation.

The workstation type in the final-assembly line context has tasked tied to the station that will be carried out in a particular sequence. In the sub-assembly context, operators are tied to certain “assembly places” (workstations) during the assembly cycle and these workstations are slightly independent of the position of them, as long as the performance targets are met and constraints not violated.

The sub-assembly tasks that are going to be placed on the shop floor as workstations can be seen in attachment 3 as “pre-assys”, together with the rest of the assembly tasks. In order to make it more straightforward, a simplified list is presented below in figure 7-2. The sub-assembly tasks that requires a similar assembly workstation was clustered into groups. The similarity definition steams from the tool requirement analysis and the assembly space requirements, both in attachment 5.

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<table>
<thead>
<tr>
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<tbody>
<tr>
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<td>Chassi</td>
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<td>Diesel engine</td>
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<tr>
<td></td>
<td>Hose pump</td>
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<td>3</td>
<td>Hopers</td>
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<td>Light ramp</td>
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<td>Cover</td>
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<td>Water pump</td>
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<td>Aercell pump</td>
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<td>Air intake</td>
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<td>6</td>
<td>Foam process</td>
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<td></td>
<td>Electric cabinet</td>
</tr>
</tbody>
</table>

Figure 7-2. Clustering of similar assembly tasks for workstation creation.
As can be seen in the figure above, the foam process and electric cabinet are clustered together. As previously stated in chapter 4, the reason is that it was preferred from the management at Aercrete Industries that both assembly tasks are carried out in the movable shed. Group number 5 in the figure above contains the pumps, tanks and air intake. The reason why they are grouped together is the fact that they require a similar assembly workstation approach, and the most suitable is some sort of workbench. Group number 4, the light ramp and cover requires a similar assembly approach, but the size difference might make it necessary to split them.

The hopers are such a demanding and comprehensive task, that it best be a station of its own, preferable located as close as possible to the workstation where it is supposed to be assembled to the machine. The diesel engine and the hose pump are similar in the kind of sub-assembly workstation they require. They should both preferably be sub-assembled close to the final-assembly line workstation.

The sub-assembly workstation should be a height adjustable workbench to the size of the components, and with access to the overhead crane due to the weight. The chassi sub-assembly is a workstation of its own since there are no similar assembly tasks to group it with. The chassi should be assembled close to workstation number 1 at the final assembly line, since the chassi is the first component of the machine assembly.

With this in mind, the position of the sub-assembly workstation was carried out with concern of the preconditions and logistic aspects, and the result can be seen in figure 7-3 below. The result is a suggestion and the actual workplace design is not considered, due to the limitations of this thesis. Since there exist some available space, the final position of some of the sub-assembly stations can be altered in order to achieve an efficient practical solution.

As can be seen in the figure below, there are 4 machines placed in a row on the shop floor. These machines symbolize the final-assembly line’s workstations that were developed in section 5.5 previously.
In the figure above, the cover sub-assembly (number 9) is carried out on a fixture. This approach seemed most appropriate, and the position of this station can thus be altered if the fixture is movable.

Station 2 and 3 are as previous stated, height adjustable workbenches close to the final-assembly line. Stations 4, 5 and 6 are workbenches that have the parts for the sub-assembly in vicinity in order to facilitate an efficient assembly process.

**7.3 Detailed layout of the logistics system**

In this section, the outline of the logistical system supporting the assembly system is described in detail. Based upon the conceptual described system in chapter 6 and the preconditions stated this outline serves as the final result of the logistics system and the intentions are to use this in practice.
7.3.1  Receiving/control

As shown in attachment 8 this is where receiving of material takes place. Inspection of the small volume articles are made at this point. Separation of articles for different assembly stations is made. Common articles are moved on to the centralized storage place (see attachment 8).

7.3.2  Material handling

Attachment 8 shows the marked out sub-assembly stations relative to the critical line. As outlined before the specific articles should be placed close to the subassembly stations in order to quickly be able to receive new material. The picture shows the placement and inventory keeping of the articles.

Overhead crane

The overhead crane is placed according to attachment 8 where it will cover the heavy weight articles and those needing the overhead crane for assembly. The question here is if one sleigh is enough or if there is a need for two sleighs in order for the operations to move on without being limited by a blockage of the overhead crane. This should not be the case though as the overhead crane has small movement times when moving articles and if fixtures are used at stations this would not be an issue.

Chassi components

The chassi sub-assembly components are placed as shown in attachment 8 into the inventory racks. From there they are then collected when needed and moved to the workstation for the assembly. Common components are gathered with a trolley from the common components inventory.

Engine components

The engine components are placed close to the sub-assembly station within reach for the overhead crane. The attached picture shows the place for placing the engine before subassembly. Preferable would be to place the engine close to the wall on the left hand side (see attachment 8)

Hose Pump

Hose pump is placed at floor level close to the assembly station (See attachment 8).
Articles for the subassembly are preferably placed at floor level in the racks close to the assembly area and from there are refilled into the binge wagon.

**Water pump and Aercell pump**

These are small articles and have some small assembly operations. These are preferably placed directly in the racks in kits already picked at the reception so they are to be easily gathered when needed at the workstation.

**Hoper components**

This is a space-demanding article and due to this constraint it would be suitable to store hopers waiting for assembly in the unused area. To smoothly transport them to the subassembly station it is suggested that the racks shown on the attachment just behind the chassi and hopers are removed so that it is easy to enter the sub-assembly with a truck and place the hoper at the station. For the articles to be assembled at the hoper station it is suitable to place them at floor level close to the station according to their precedence order.

**Common components**

The common articles are placed centrally (See attachment 8) In order to facilitate good and effective picking these pallets should be placed at a good height and comfortable body level. The attachment shows the proposed area where these are held as inventory and also the proposed placement of the binge wagons for the different assembly stations.

**Tank components**

Tanks are placed within the racks, close to the assembly station. Since they need small amounts of material for the sub-assembly, it is recommended that this material is kitted for each tank in order to smoothly assemble it.

**Air intake components**

Articles for subassembly are placed close to the assembly station within the inventory racks as shown on the attachment 8. Components are gathered at the inventory rack and are brought to the subassembly station and from there to the critical line assembly.
**Electric cabinet and foam process**

These are assembled inside the movable shed. Material is moved from receiving to the shed where they are divided into Foam articles and electric cabinet articles. It is highly recommended for the foam process as well as for the electric cabinet that these should be arriving in kits already from the supplier in order to get rid of unnecessary material handling and to secure that all articles are assembled.

**Cover**

The cover is being assembled with the aid of a fixture. This is a large article where components are hard to store within the inventory racks. Electrical components could be stored here together with the components for the electrical ramp but the frame used for holding the hood together with the hood can preferably be stored close to the hose rack.

**Hose Rack**

As it was stated before, there was a wish for a rack or roll that would contain the different hoses and which were to be easily rolled out to the correct length and cut. A possible area is outlined in the attachment 8, where the hose rack is placed close to the left downside corner of the facility close to the hose assembly.

**7.3.3 Safety stock**

It has been stated that the company are to have one extra component of everything in safety stock in order to secure the continuous assembly operation. As of today, there would be no problem with space for this at the rate of 20 machines a year. However this issue must be considered when increasing the Takt time as it will demand more components in store. The suggestion is to monitor the development of material handling and if a major increase is visible take advantage of the unused space and in some areas re-plan the inventory function.

What needs to be thought about is where to place the safety stock and how far from the assembly station in order to have a 100 % service rate. In addition, it is important that this safety stock is calculated within the inventory turnover so that it does not sit as an inventory inside the building that is never used and eventually has to be thrown away as scrap. Therefore, the suggestion is to plan for safety stock, find a suitable area to store it and use it.
7.4 Summary of the final assembly system design

The final design of the assembly system can be seen in figure 7-3 and attachments 8-9, and consists of the detailed design of the assembly line, sub-assembly system and logistics system. The final design is a combination of these 3 conceptual designs, and together they are supposed to make up the system that will, hopefully, be implemented at Aercrete Industries.

When the final design of the assembly system was carried out, the major implication between the suggested final assembly line, sub-assembly system and logistic system when they were compared was that station the component assembly station on the final assembly line required modification. This was due to the fact that the overhead crane was needed to serve several stations and it is more convenient if the largest sub-assembly components are not transported a longer distance than needed.

Therefore is it beneficial to spread the component assembly workstation on a larger area, and to make this organized, creating 2 stations out of 1 makes it more rational from an assembly line perspective. The cycle time of these 2 stations is thus half the previous (20 hours) which equals 10 hours. This could be conceived as that the machine is moved within the same workstation, illustrative. The respective tasks that are to be carried out in those two stations have to be evaluated when the assembly system is ramped-up in reality.
8 Conclusions and discussion

In this chapter, the round up of the thesis is presented as conclusions, discussions and recommendations. The aim is that this chapter will clear any confuses the reader might have.

Production through assembly of components (or sub-assemblies) is a part of the mass production approach to manufacturing that Henry Ford introduced in the beginning of the twentieth century. It is supported by the ideas of Adam Smith, that society benefits from specialization and that every person should specialize in the work task most suited for her. Taylor also considered specialization as the most efficient solution to achieve high productivity. The assembly system designed in this thesis capitalizes the concepts of mass production, though with a large touch of flexibility and agility.

To use an assembly line for the assembly of the Aercrete 625 machine, can be argued to be a “too specialized” assembly system design, due to the fact that the entire system will be dedicated to a relatively low-volume product. The dedication will on the other hand enable a flexible volume capacity, which creates a possibility to respond quickly to customer changes. Besides, it makes it possible to have a short throughput time, which in turn leads to a short lead time from customer order to delivery.

The short throughput time also decreases the amount of inventory that will be kept in storage. This leads to less capital tied up in the system, which increases the profitability of the operations and makes it possible to invest or use the capital elsewhere.

Summarize of the assembly system’s attributes:

1. Responsiveness
2. Flexibility
3. Capital efficient

The three attributes above are only possible to achieve through the short throughput time that has been the guiding light for the design process.

The attribute of the assembly system that makes it possible to achieve a short throughput time is the final assembly line concept. This concept makes it possible to obtain the same throughput time independent of which of the three Takt time settings that are currently used.
Since it is estimated that the preconditions that the design process is built on will change, the final assembly line concept might be inefficient or unsuitable for the new situation. The author’s beliefs are that the final assembly line concept will continue to be an efficient and feasible solution, but adjustments might need to be done. An increased production volume will be possible if the number of workstation on the assembly line is increased.

It should be remembered that the number of workstations on the final assembly line was initially calculated to be 4, but due to logistic aspects increased to five (1 spitted into 2 smaller). The two smaller stations operating with 10 hours Takt time will thus facilitate a Takt up to 160 machines a year as long as the other stations lead times are reduced. In the methodology chapter a plan for the thesis project was presented. The plan was supposed to guide the authors during the project, and make sure that a systematic approach to the problem was maintained.

The conclusion at the end stage of the project that the thesis plan was followed, somewhat, strict over the project and the result from this approach is concluded to be satisfying. The plan provided the necessary guiding that was needed when the different parts was carried out.

In the methodology chapter, 3 possible sources of error that might be affecting the reliability were identified:

- Low accuracy of the time measurements, making time estimations necessary.
- Little knowledge of the assembly process of the machine, making practical experience of others important.
- Little documentation regarding the machine, making estimations necessary.

When looking back with the result on-hand, it can be concluded that these factors were indeed affecting the result, and the level of reliability due to this has been discussed at several places in this thesis. But with respect to the data given, the authors have also concluded that the result presented in this thesis is of good quality, with respect to the data that served as inputs to the design process.

The usability of this thesis for Aercrete Industries can be argued, but it is the author’s firm view that the result is applicable and can serve as a good starting point for the company’s further efforts in starting-up production of the Aercrete 625 machine. The results presented in this thesis can also serve as a guide for how to design a assembly system, if Aercrete Industries chooses to develop a assembly system of their own.
8.1 Recommendations

The general recommendation of this thesis is the result of the assembly system design, with the assembly line, sub-assembly and logistic system as cornerstones. The assembly system solution can guide as a goal for the future state when the development of the new assembly system at Aercrete Industries starts. From the author’s point of view, the design process should start with the suggested solution and when further refined, the workplace design process should be initiated.

The tools and workbenches that are mentioned in this thesis is part of that process, among other issues as ergonomic aspects and how to assembly the components efficiently. These issues have not been dealt with in any deep in this thesis, but are nevertheless really important for the future assembly system. If the solution in this thesis can be said to be the guide, the detailed design of the workplaces can be said to be the implementation. It is generally recommended that a plan for the future development and ramp-up of the assembly system is created in order to achieve a good result.

8.2 Reflections and criticism of the thesis

At the very start of assembly system design project, the project seemed to be overwhelming and almost too complicated. Over time, the project has successively become more and more graspable for the authors, which is an indication that you “learn by doing”. The early problems in the project, basically, rose from the lack of time measurements and information and understanding about the assembly process of the machine.

Later on, when these problems came clear, the problem turned into the area of design matters, which eventually was solved with aid from theoretical frameworks and reasoning. Towards the end of the thesis, the problem became the issue of how to effectively present the work that had been carried out over almost half-a-year, with the beginning in March 2009 and end in early September the same year.

The final result, as can be found in chapter 7, is a holistic suggestion for the future assembly system at Aercrete Industries. The strength of this suggestion is that it manages to combine both logistic and assembly aspects into a feasible solution. Besides, the suggestion can serve as a target for the construction and ramp-up of the future assembly system. Another strength is that the suggestion is based on academic knowledge, which together with practical limitations, most likely will make the solution useful than a pure academic or a pure intuition based solution.
The major weakness with the suggested solution is that some the inputs to the design process are more, or less, coming from speculative estimations. Another weakness is that the assembly system might be inefficient due to the fact that it is supposed to be able to handle a significant variation of production volumes.

Another weakness with the result of this thesis can be argued to be that only one solution of the assembly system design is presented. The reason for the choice of this approach was that the uncertainty was too great, and it would have been difficult to value different solutions based on their expected performance.

The frameworks for both production system design/development and philosophies for efficient production were used when making the assembly system design. The extent to which they were used came out to be less than initially expected. One reason for this is inexperience from the authors’ part, combined with complexity of the task. Another reason is that the frameworks are rather generalized and complicated to apply.

Hill’s (2000a) framework for linking corporate to manufacturing strategy provided useful input to the design process by revealing the goals the system needed to satisfy. The SLP framework by Muther (1973) was useful when identifying possible inputs and their influence on the design process. The framework was assumed from the author’s side to be more useful, but the framework came out to be more guiding than leading the design process. The Lean Production philosophy presented in chapter 2 was assumed to be more applicable to the design process than it actually was. The reason can be the fact that Lean Production is more applicable for improvements of existing systems than it is for creating a new one. It should be stated that this argument is not supported by the findings in the literature.

8.3 Visions and concerns for the future

The vision for the future is that the assembly system is being constructed, ramped-up and eventually put into full production pace. In order to achieve a successful implementation of the assembly system it is important that the line is being re-balanced when it is possible to measure the real assembly times in the production environment. The issue of more specific/accurate assembly times is a crucial point and should be of highest priority when the assembly system is put in operation.

The efficiency of the suggested solution, presented in this thesis, is uncertain with respect to the large number of uncertain factors. The calculated figures ranging between 85-95% presented in attachment 6, might be questionable.
Most likely will the efficiency in the early stages of operation be rather low, and after a while be improved, but probably not near the calculated figures. Beside the previously mentioned time accuracy issue, supplier delivery precision, internal problems and system design infeasibility might interfere and create efficiency declines.

In the future, if the capacity requirements of the system are expanded to more than 80 machines a year, the assumptions that lie behind the design in this thesis change. It might be necessary to expand the assembly line to the area in section C, which means that the wall separating section B and C must be removed. When more machines are assembled, more sub-assemblies must be carried out as well. This might lead to the fact that some sub-assembly stations must be moved away from their suggested position in this thesis. Besides, the inventory holding strategy and logistic system might be infeasible to support an increased number of machines produced.

The ramp-up of the future assembly system might be complicated with the assembly system solution presented in this thesis. The reason is that the solution is considering an initial volume of 20 machines a year, but is optimal with 80 machines a year. When the ramp-up starts the solution presented in this thesis might be inefficient and complicate rather than facilitate the ramp-up, due to the low volume expected initially.

### 8.4 Future research opportunities

This thesis has been carried out in an environment that can be described as uncertain and creative. There has not been any actual research questions investigated in this thesis. The thesis is a compromise between academic and practical issues, and the research has been minimized in order to achieve greater practical result. However, a few future research opportunities have nevertheless been identified over the project process.

First of all, it might be interesting to investigate how development projects of “green field” assembly systems are carried out and how to manage the uncertainty. Second, how to plan the future efficiency has been an issue the authors have reflected about. How to plan the performance can thus be seen as a research opportunity since the authors found this difficult to predict due to external and internal factors.
9 Glossary

**Aercell** – A special foam kind that is mixed with concrete in the machine in order to create the foam concrete mixture that is special for the Aercrete system.

**Assembly system** – A system that incorporates all the necessary activities that is necessary for transforming inputs to output in the transformation process.

**Final-assembly line** – An assembly line that incorporates the last assembly of previous sub-assembled components.

**Flexibility** – The ability to deal with changed and uncertain conditions. Flexibility in assembly systems is normally achieved by either over-capacity or a flexible design of the system.

**Logistic system** – Incorporates the aspects of the movement and storage of material, internal as well as external

**Sub-assembly system** – Is a system that takes care of the preparing assembly work that is not carried out on the final-assembly line

**Takt time** – The pace that the production system needs to follow, in order to meet the requested demand from the market. Practically it is the time that can be spent on a piece before a new product needs to be started.

**Tied-up capital** – The capital that is invested in work-in-progress, components and finished goods. Is to a great extent affecting the profitability of a corporation.
10 References


I I Search words

A
Aercrete........................................1, 3, 4, 7, 8, 9, 10, 58, 59, 62, 72, 73, 82, 99, 104, 105, 106, 107, 110
Assembly line..................................2, 5, 8, 11, 12, 13, 30, 31, 33, 34, 35, 42, 43, 57, 59, 64, 67, 69, 70, 72, 
73, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 89, 90, 95, 96, 97, 98, 99, 100, 
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Q
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Sub-assembly system
Systematic Layout Planning
Takt time
Throughput time
Tied-up capital
Toyota Production System
Workstation
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Attachment 1. Plant Layout
Attachment 2. Assembly times (1st version)
Attachment 3. Assembly times (2nd version)
Attachment 4. Assembly precedence order
Attachment 5. Analysis of components for assembly
Attachment 6. Calculations
Attachment 7. Conceptual layout proposal 3
Attachment 8. Detail design of the logistics system
Attachment 9. Detail design of the assembly system (final assembly line)
Attachment 1: Plant layout

1. Movable shed
2. Foam production process
3. Gate to section A
4. Gate to section B
5. Gate to section C
## Attachment 2: Assembly times (1\textsuperscript{st} version)

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## Attachment 3: Assembly times (2nd version)

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<th>Final assy.</th>
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<td>15 (8)</td>
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Attachment 4: Assembly precedence order

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<th>Suggested precedence order</th>
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<td>Hose pump</td>
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<td>Water pump</td>
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<tr>
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<td>Water tank</td>
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<tr>
<td></td>
<td>Diesel tank</td>
<td>8</td>
</tr>
<tr>
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<td>Aercell tank</td>
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<td>5</td>
<td>Air intake</td>
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<td>Foam process</td>
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<tr>
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<td>Electric assembly</td>
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<tr>
<td>10</td>
<td>Testing</td>
<td>19</td>
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</tbody>
</table>
Attachment 5: Analysis of components for assembly
Name: Water pump
Pre-assembly time: 1.5 h
Assembly time: 0.5 h
Precedence: To be assembled after hose pump
Special requirements: Assembled on work-bench, 1 person assembly
Part space: 200 x 200 x 700 mm
Assembly space req.: 1 x 1 m
Tool requirements: Hand tools

AERCRETE

Water pump drawing
Aercrte 625
Attachments
Attachment 6: Calculations

Formulas:

\[ T = \text{Takt time} = \frac{\text{Available working time (per year)}}{\text{number to be processed (per year)}} \]

\[ N = \text{Number of stages/operators} = \frac{\text{Total assembly time}}{T \text{akt time}} \]

\[ D = \text{Total delay time (idle time every cycle)} = N \times T - t_{\text{sum}} \]

\[ E = \text{Line efficiency} = 1 - \frac{\text{Total delay time}}{N \times T} = \text{Utilization of labour force} \]

Input data:

\text{Available working time per year and person} = 7 \times 5 \text{ days} \times 46 \text{ weeks} \approx 1600 \text{ h}

\text{Number of products to be processed (per year)}: a = 20, b = 40, c = 80

\[ t_{\text{sum}} = \text{Total assembly time} = 270.5 \text{ h} \]

Calculation of Takt times:

\[ T\text{akt time}_a = \frac{\text{Available working time}}{\text{number to be processed}} = \frac{1600}{20} = 80 \text{ h} \]

\[ T\text{akt time}_b = \frac{\text{Available working time}}{\text{number to be processed}} = \frac{1600}{40} = 40 \text{ h} \]

\[ T\text{akt time}_c = \frac{\text{Available working time}}{\text{number to be processed}} = \frac{1600}{80} = 20 \text{ h} \]

Calculation of number of stages/operators:

\[ \text{Number of stages/operators}_a = \frac{\text{Total assembly time}}{T\text{akt time}_a} = \frac{270.5}{80} = 3.38 \approx 4 \]

\[ \text{Number of stages/operators}_b = \frac{\text{Total assembly time}}{T\text{akt time}_b} = \frac{270.5}{40} = 6.76 \approx 7 \]
Number of stages/operators \( c \) = \( \frac{\text{Total assembly time}}{\text{Takt time}_c} \) = \( \frac{270.5}{20} \) = 13.5 \( \approx \) 14

Calculation of line efficiency:

Total delay time \( a \): \( D_a = N_a \times T_a - t_{sum} = 4 \times 80 - 270.5 = 49.5 \text{h} \)

Total delay time \( b \): \( D_b = N_b \times T_b - t_{sum} = 7 \times 40 - 270.5 = 9.5 \text{h} \)

Total delay time \( c \): \( D_c = N_c \times T_c - t_{sum} = 14 \times 20 - 270.5 = 9.5 \text{h} \)

Line efficiency \( a \) = 1 - \( \frac{\text{Total delay time}_a}{N_a \times T_a} \) = \( \frac{49.5}{4 \times 80} \) = 0.645 \( \approx \) 85%

Line efficiency \( b \) = 1 - \( \frac{\text{Total delay time}_b}{N_b \times T_b} \) = \( \frac{9.5}{7 \times 40} \) = 0.966 \( \approx \) 97%

Line efficiency \( c \) = 1 - \( \frac{\text{Total delay time}_c}{N_c \times T_c} \) = \( \frac{9.5}{14 \times 20} \) = 0.966 \( \approx \) 97%
Attachment 7: Conceptual layout proposal 3
Attachment 8: Detail design of the logistics system
Attachment 9: Detail design of the assembly system (final assembly line)

1. Station 1: Component assembly 1(2)
2. Station 2: Component assembly 2(2)
3. Station 3: Hydraulic and water hose assembly
4. Station 4: Electric and air hose assembly
5. Station 5: Testing