Reducing internal lead times in MTO & job-shop production environments: a case study

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Production development and management
This Master’s thesis has been carried out at the School of Engineering in Jönköping within the subject area of Production Development and Management. The thesis is one part of the two-year Master of Science university diploma programme. The authors take full responsibility for the opinions, conclusions and findings presented in this work.

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Abstract

This Master’s thesis has been carried out within the subject area of Production Development and Management and aims to reduce internal lead times in make-to-order (MTO) and job-shop production environments with the use of identified theoretical methods.

The reason this particular production environment was chosen was the flexibility and satisfaction it provides its customers. Today, customers expect customised products, a situation which causes problems for manufacturers as they are unable to produce such products in large amounts. In order to investigate problems with these kinds of environments and the causes for long lead times, we have conducted a literature study where we identified the problems these particular kinds of production environments experience regarding production planning and control which are related to the immense amount of time consumed by changeovers because of high demand variance and high requirements for customisation.

To affirm the theoretical findings, we opted to undertake a case study and chose Talent Plastics Gislaved AB as our case, because this company utilises an MTO and job-shop production environment for its production of highly customised products with high demand variance. In the analysis of our case, we found that the wastes in the organisation were similar to those identified in the theoretical findings. The current planning system and the current state of the manufacturing lead time system were evaluated and a theoretical framework using a combination of lean production, work load control and constant work-in-process theories was suggested. We claim that concentrating on the reduction of setup times can lead the job-shop towards drastically decreased lead times and a much more effective use of time throughout the organisation.

Because the organisation will continue to face problems due to the ever-increasing demand variance and requirements for customisation, there are plenty of opportunities for further research in these kinds of production environments. Emerging theories, such as quick response manufacturing, may also be tested to construct an efficient framework.

Keywords

Job-shop, Make-to-order, internal lead time, changeover time, production planning, planning lead time, manufacturing lead time, work load control, lean production, CONWIP, preventive maintenance.
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Finally, the authors would like to thank each other for sharing knowledge and for venturing into the one and only experience of carrying out a project together.

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Kalyanchakravarti, Jally
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1 Introduction

This chapter explains the background of the research and states the research problems by presenting the research gap, the purpose of the research, the questions framed to support the purpose, the scope, and the delimitations of the thesis.

1.1 Background

This thesis has been carried out to investigate the possibility of reducing internal lead times in MTO and job-shop environments as part of the two-year Master Programme in Production Development and Management.

This master thesis concentrates on MTO and job-shop production environments and aims to look into various production management theories and philosophies while developing a framework by choosing theories that will reduce internal lead times.

Customers today demand a high level of customisation in products, which means producing a wide variety of products in low volumes. Suri (1998) states that customers’ expectations are unpredictable and that the demand for customised products vary from day to day. This situation force manufacturers to become better at predicting customers’ demands and follow them. As a result of the requirements for customised products, the number of products to be manufactured within the same product family is increasing rapidly, which complicates matters in manufacturing environments.

In order to satisfy customers’ requirements, different manufacturing systems have been developed (Peter 2003). Job-shop production is one of the four major manufacturing systems described by Peter (2003) and Kumar et al. (2008) which can deal with high levels of customisation of products. Elaborating on the concept of job-shop production, Browne, Boon and Davies (1981) explicated that a job-shop is a flexible system that maintains the general purpose equipment needed to meet widely varying customer requirements. Muda (2011) examines and explores the effects of incorporating an MTO approach with a job-shop manufacturing system as it is a wide-spread manufacturing or production strategy utilised to deal with high requirements on customisation. Manufacturing organisations that will only start manufacturing products after a customer has placed an order and provide their customers the flexibility and comfort of selecting the type of product, design and even materials are most suitable for the MTO and job-shop approaches (Muda, 2011).
Going beyond customisation, customers also expect the product to be delivered only a short period of time after placing their orders, which Suri (2009) defines as the external lead time, i.e. the lead time as perceived by the customers. According to Wiendahl (1995), this situation creates competition among manufacturers to manufacture and deliver products as fast as possible while emphasizing the importance of minimizing lead times. Hendry et al. (1993) signify the need to win the order in a competition where prices and delivery times are must attributes.

However, if the MTO and job-shop approaches are satisfying the customer’s requirements for customisation, the planning and scheduling of production along with the control of various operations on the shop-floor become increasingly complex (Browne et al., 1981), which tend to increase the total lead time. According to Bennet (2006), job-shops experience high demand variability and a slow flow of materials through the process. Time, quantity and customisation are considered main factors concerning demand variability. In this type of situations, achieving a reduction of lead times may not be as simple as it is for single-line assembling process organisations, which has a high flow of materials throughout the process.

Hopp et al. (1990) states that reduction of lead times is the key element to compete in the manufacturing industry as it helps the organisation deliver products to customers in the shortest possible time. Wedel (1996), who has done research on lead time reduction in the Swedish manufacturing industry, explains that on average, manufacturers have reduced their total lead times about 30 % in the past five years and that they are striving to reduce it even further to obtain optimized production systems. From this, we can conclude that the importance of lead time improvement is great to most manufacturing organisations. Christofer et al. (1979) state that the concept of lead time can have different meanings depending on the activities of the supply chain, as it may also represent each single activity and operation. After considering the importance of lead times, we will now go on to formulate the research problem based on problematic activities within MTO and job-shop production environments.

1.2 Problem formulation

Our topic of interest is job-shop manufacturing systems pursuing MTO as a production strategy. In addition, we intend to explore problems with the manufacturing systems while attempting to find solutions for them. Arisha et al. (2001) mention that planning and scheduling production in job-shops carries a high level of complexity, which results in long planning times. Fernandes et al. (2009) state that demand variance is a major complication in planning and scheduling the production along with the maintenance of inventories.
for raw materials and finished goods. Paulo (2007) describes the stages of production planning and scheduling after receiving the order from the customer as order confirmation, order release and order dispatch.

Paulo (2007) also states that during the confirmation of the order, the manufacturer checks the availability of required resources and negotiates the due date with the customer, which means that the lead time is pre-decided at this stage as every activity required to deliver the order is considered. In this situation, the manufacturer undertakes major replanning, which will cause a delay in delivering the orders. During the next step, i.e. releasing the order to the shop-floor, production scheduling has been considered a major problem because of the complexity of a number of the operations to be performed and high variety of the product-mix (Arisa, 2001). After a job has been released to the shop-floor, problems may occur in selecting a dispatching rule, e.g. FCFS and EDD, as the whole progress of the job will depend on it and the dispatch rule will decide when production is to start (Paulo, 2007).

Examining the bottlenecks of production planning, Fernandes and Carmo-silva (2009) determined that job-shops using an MTO production strategy tend to have long manufacturing times because of very long changeover times caused by high variety in the product-mix. Along with changeover times, it seems waiting times, queuing times and also machine and operator availability tend to increase the actual lead time (Tatsiopoulos and Kingsman, 1983).

Considering the problems identified through the literature review above, the aim if our research is to identify the solutions to these problems with the support of literature. However, because planning time and manufacturing time are considered major components of internal lead times (Wedel, 1996), we delimit our research to identifying theories aiming to reduce internal lead times.

Wedel (1996) explains that lead time comprises the time consumed to perform all the individual activities of manufacturing a product from order to release. As a part of the total lead time, internal lead time comprises the time consumed to carry out planning and manufacturing. Wiendahl (1995) states that an evaluation of current internal lead times helps identify problems related to inventory management and shop-floor management, which will in turn lead towards optimizing the production system and an end to unnecessary investments in inventories and also unconventional use of manufacturing time. Thus, an evaluation of current planning lead times and manufacturing lead times in an organisation appears to be important to our topic of interest. With this in mind, we have designed our purpose and research questions as follows.
1.3 Purpose and research questions

The formulation of the research problem of this thesis is based on problems related to internal lead times, which consist of the sub-groups planning lead times and manufacturing lead times, in job-shop manufacturing systems using the MTO production strategy. Thus, the purpose of our research is,

“To investigate how internal lead times may be reduced in a Make-To-Order and job-shop production environment in order to satisfy the requirement for shorter lead times”

Based on the purpose, the following research questions have been posed to explore the area in focus:

- **RQ 1: Why do MTO and job-shop production environments tend to have long lead times?**

Although we formulated our purpose by identifying the problems of the MTO and job-shop production environments, this question is designed to illustrate these problems more clearly through a comparison between the literature and the case study.

- **RQ 2: How can planning lead times be reduced in MTO and job-shop environments?**

As stated by Arisha et al. (2001), customisation and demand variance will cause long planning lead times in a job-shop production environment using an MTO approach. To answer this question, we will attempt to draw up a proper planning with the purpose to achieve shorter planning lead times. As Wedel (1996) described, planning lead times are one of the major components of internal lead times, why this will work towards fulfilling the purpose of this thesis.

- **RQ 3: How can manufacturing lead times be reduced in MTO and job-shop environments?**

This question is related the purpose because manufacturing lead times are considered part of internal lead times (Wedel, 1996). This question will look at the time consumed for manufacturing products on the shop-floor and account for sub elements of manufacturing such as cycle times, changeover times, waiting times and queuing times.
1.4 Scope and delimitations

Defining the scope by sub-dividing the major components of literature into smaller measurable and manageable components, such as planning lead time and manufacturing lead time, helped us find the most effective data collection techniques to search for solutions for our research questions. Analysing the data collected is more effective with a pre-defined scope, as it brings a constant focus on the research questions.

Figure 1: Scope of research (Modified, Wedel, 1996)

The scope of our research is based on the research questions (as is shown below). Because the first question attempts to identify problems in MTO and job-shop production environments, the scope here revolves around overall characteristics. In order to connect the findings from the first question to the case study, the second and third questions narrow the scope towards what is relevant to the case study, which is where we prefer to find our results. However, there is also a possibility for the scope to be widened towards elements of external lead times such as delivery lead times and waiting times for delivery and so on if it is relevant to the case study. Thus, the figure above explains the overall elements of lead time for MTO and job-shop production environments and relates them to our research questions.

The components presented in the scope of our research will be discussed in the theoretical framework.

Although the research in this thesis has been planned carefully based on our topic of interest, it will still be limited and will even have some deficiencies.
1. The research is carried out for a single manufacturing organisation, Talent plastics Gislaved AB. This organisation may be different to other organisations although the properties of the MTO and job-shop production environments are similar.

2. An investigation of internal lead times implies various activities such as design, working with suppliers, planning and manufacturing. The decision to focus on evaluating two major dominating activities, planning and manufacturing, is based on the problems identified in the organisation.

3. In order to evaluate lead times, the investigation will include very few products among the 2634 products manufactured by the organisation; although evaluating the lead time for each and every of the entire product range would make the study better, it would be too time-consuming.

4. Although the questionnaires used for interviews with staff at Talent Plastics will not be useful in investigating internal lead times in a comprehensive manner, they are intended to provide an understanding of the planning strategies, policies and manufacturing execution system of the organisation.
1.5 Outline

The structure of this thesis is presented below, dividing the content into chapters as follows.

**Introduction**: this chapter presents the background of the research carried out, presents the identified research gap and formulates research problems, purpose of the thesis and research questions designed to fill in the research gap. This chapter also presents information regarding how the research effort was initiated and how it is meant to be concluded.

**Theoretical background**: this chapter presents a framework of various theories along with explanations of major components of the research and theories that have been considered useful to fill in the research gap.

**Methodology**: this chapter provides the research methods which have been considered for carrying out systematic research. It also shows the quality and reliability of the research work.

**Findings and analysis**: this chapter provides the data collected and analyzed for the case study. After the analysis has been carried out and presented, the research questions are answered.

**Discussion and conclusion**: this chapter discusses the research carried out to find the research gap, the data collected and analyzed and also research methodology.

**References**: this chapter presents the list of articles, journals, books and other forms of literature collected using the Harvard referencing system.

**Search terms**: this chapter provides key words from the report helping the reader to identify important terms and words.

**Appendices**: this chapter provides additional information related to the research in this thesis considered to be of interest to the reader.
2 Theoretical Framework

This chapter highlights literature considered to be relevant to the purpose of this thesis. A theoretical framework is presented to provide the reader with a thorough understanding of theoretical components and how they relate to our research.

2.1 Components in the Framework

The theoretical framework is designed specifically to fit the purpose of our research and the problems formulated and attempts to illustrate the connectivity among the various theories considered useful in the task of answering the research questions. There is a vast amount of literature available on optimizing lead times, e.g., lean manufacturing, quick response manufacturing, world class manufacturing, load oriented manufacturing control and theory of constraints and so on. We focused on the theories which we found would best fit to the purpose of this thesis.

As our first research question aims to identify why MTO and job-shop production environments tend to have longer lead times, we choose to present the characteristics of MTO and job-shop production environments while concentrating on the causes for the increased lead times along with the definition, classification and components of lead time.

We will then narrow our scope towards presenting solutions for the problems causing long lead times as the second research question attempts to establish how planning needs to be done in order to increase the efficiency of the production, where we will illustrate the choice of theories which is considered most efficient. However, among the theories, the lean production theory is considered one of the major theories because it helps identify all the major possible wastes in any manufacturing organisation. We have also considered the various theories which are considered to be the pillars of the philosophy of lean production. Among those, we consider the theories on total productive maintenance, total quality maintenance, and value stream mapping to be valuable to our effort of providing a solution for the research question and, in addition, the value stream mapping theory was considered valuable in evaluating lead times.

Aside lean production, the other major theory considered for this thesis is the theory on work load control, which many authors consider to be effective to achieve efficient and optimized production planning and control, particularly in MTO and job-shop production environments. However, along with the theory on work load control planning, we have also considered CONWIP as a shop control mechanism as part of the answer to the research question.
For the third research question, which attempts to identify how manufacturing lead times can be optimized, we have considered the single minute exchange of dies theory developed by Shingo along with other theories such as automation and work standardization. The illustration below presents the way we have ordered the theories as components in providing solutions that will result in a reduction of manufacturing lead times.
The simplified theoretical framework above places the most relevant theories where they may help bring about reductions in lead times. It should be noted that this placement has been performed based on the researchers’ knowledge of the theories.

In summary, we will undertake an investigation of lead time reduction in MTO and job-shop production environments. Below, we present relevant theories and definitions that support our research.

## 2.2 Production approach

The production approach of a manufacturing organisation can be explained as the way it considers various resources, e.g. materials, manpower and machinery, as input that can be transformed into desired, useful output if the controls and policies issued by the management are followed. According to Kumar and Suresh (2008), production approaches can be classified in four major categories based on a comparison between the volume of products and the variety of products:

1. Job-shop production
2. Batch production
3. Mass production
4. Continuous production

All these four categories of approaches aspire to manufacture the right number of products at the right time, using the production strategies preferred by the management. However, the four approaches differ greatly from one another in terms of configurations, advantages and disadvantages.

![Classification of production systems](Kumar and Suresh, 2008)
Of the categories of approaches listed above, this thesis intends to investigate the job-shop production approach. Job-shop production deals with a wide variety of products in low volumes and does so in a distinctive manner called a “high mix low volume” strategy. In general, job-shop production environments consist of machines intended to perform specific operations. Each product has to go through at least one and often a number of manufacturing operations and as each product has its own material flow, the material flows of the production environment vary.

Regarding make-to-order and make-to-stock production strategies, a job-shop always has the characteristics of a make-to-order environment because products are custom-made. In this strategy, the products will be pulled through production without any need to maintain stocks in the warehouse, which would result in the negotiation of inventory costs.

![Figure 4: Flow chart: make-to-order environment](image)

However, manufacturers often maintain safety stocks for their important customers, which cause the job-shop environment to become both a “make-to-order” and a “make-to-stock” environment.

![Figure 5: Job-shop with safety stock production environment](image)

In make-to-stock environments, products are meant to push into the market instead of being pulled by customers. The “make-to-stock” strategy represents
manufacturing of low-customised products in huge volumes, an approach that can be considered the opposite of the job-shop production approach.

A job-shop environment is meant to manufacture highly customised products, a wide variety of products and, although product volumes may vary between companies based on customer requirements, generally low volumes. When the products to be manufactured vary widely, production planning becomes critical and requires huge amounts of time for replanning, which finally results in increased planning lead times and, due to frequent changes in the set-up of the machines, increased manufacturing lead times as well. One of the major advantages of job-shop production is high flexibility in utilization of machinery and manpower, where a break-down of one machine will not prove to be disastrous as the job can be assigned to a similar machine within the department, which results in a reduction of manufacturing lead times.

![Diagram of job-shop production](image)

**Figure 6: Job-shop production (Hurtl and Preusure, 2009)**

**Advantages:**
1. High flexibility in utilization of machines and manpower.
2. Wide variety of products can be manufactured.
3. High utilization of the operator's potential.
4. Supervision can be made very clear and effective.
5. Many opportunities to utilize the employee’s knowledge about the products and production development.

**Disadvantages:**
1. Production planning and scheduling become critical.
2. May require large amounts of time spent on replanning.
3. High frequency of changes in machine set-ups
4. High variance in material flow makes material handling critical.
5. High inventory levels require large amounts of space.
Although there are both advantages and disadvantages to the job-shop production approach, it is a widely recognised approach in the component manufacturing industry, which supplies products to assemblers or manufacturers who in turn deliver products to wholesalers, retailers and consumers. The following section will present definitions and classifications of lead time along with optimization theories.

### 2.3 Lead time

The term lead time is often used differently by authors, which is understandable considering the range of activities the term covers. It is also used to represent the time it takes to perform a single operation. An extensive definition of lead time is to describe it as the time the customer waits until he/she receives the product after placing an order, i.e. the time between the order form is sent until the product is delivered (Christopher et al. 1979). Perry (1990) considers managing lead times in order to achieve customer satisfaction a competitive advantage. Perry’s research on lead time management point to that it often helps to identify possible improvements in the utilization of organisational resources.

According to Wedel (1996), an extensive definition of lead time includes the time taken to perform each and every activity from the moment the order was received from the customer up to the moment the order has been fulfilled. In general, it includes major activities such as planning, manufacturing, assembly and delivery.

![Figure 7: Total lead time](image)

The time consumed by the customer placing the order is his/her own responsibility and cannot be properly measured. Following reception of the order from the customer, planning for production will be affected by e.g. availability of materials, machinery, components and manpower. Thus, in order to satisfy the customer in terms of delivering the order in a short period of time, all activities will be considered to evaluate the anticipated or planned lead time. However, planned lead times often differ from actual lead times due to more or less unforeseen events such as shortages of machines, materials and manpower.
Since the total lead time represents the time until the order has been completed as it is perceived by the customer, planning of lead times based on the customer perspective is given priority. From the customer’s point of view, lead time is divided into value-adding time and non-value adding time, where value-adding time includes the time consumed for manufacturing and delivery. Thus, the time consumed for planning is non-value adding time.

2.3.1 Classification and components of lead time

To manage lead times, they have to be divided into different elements or components (Perry, 1990). A general classification can be presented based on Wedel’s (1996) framework for defining the components of lead time, which starts by dividing total lead times into external and internal lead times and then includes all related activities accordingly.

<table>
<thead>
<tr>
<th>Total lead time</th>
<th>Internal lead time</th>
<th>External lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order handling</td>
<td>Order information transfer</td>
<td></td>
</tr>
<tr>
<td>design</td>
<td>purchasing</td>
<td>planning</td>
</tr>
<tr>
<td>manufacturing</td>
<td>assembly</td>
<td>delivery</td>
</tr>
<tr>
<td>Pre-processing lead time</td>
<td>Processing lead time</td>
<td>Post-processing lead time</td>
</tr>
</tbody>
</table>

Figure 8: Classification of lead time (Modified, Wedel, 1996)

In the lead time classification diagram above it can be seen that external lead time only consists of the time consumed to deliver the finished product to the customer, whereas in reality it also includes the time taken to inspect the product and the waiting time the product spends in the warehouse before it is delivered to the customer. Internal lead time, on the other hand, includes the entire process from receiving the order from the customer until the finished product leaves the manufacturing facility. To provide further understanding of the classification, pre-processing, processing and post-processing lead times are defined as follows:

1. Pre-processing lead time: the time consumed receiving the order from the customer, planning and scheduling the production by inspecting the availability of resources (raw-materials, machinery and manpower) and confirming the order to be released for production. Here, if the required
resources are not available and have to be procured from the supplier, pre-
processing will include supplier lead time also.

2. Processing lead time: this is the time consumed to convert raw materials
into finished products for a particular order quantity.

3. Post-processing lead time: the time consumed for transporting the finished
products to the warehouse, inspection time, the waiting time of the stock
in the warehouse before it is delivered to customers and the time spent
transporting the product from the warehouse to the customer.

![Figure 9: Distribution of lead times](image)

For most manufacturing industries, pre-processing lead times consume the greater
part of total lead times. This is because of the complications in planning and
scheduling the production, according to Kingsman and Tatsiopoulos (1983). By
exploring the components of lead time, it will be easy to identify which is
consuming more time.

Elaborating on the classification of lead times, each classified element will divide
into several components. Here, each identified component requires a particular
amount of time. However, there are factors that affect planned lead times and
cause unpredicted increases to them. The components of lead time are here
presented in the sequential order they take place in manufacturing organisations

- Order processing: involves the time consumed to place the order by the
customer followed by the processing time spent on e.g. investigating the
stock room to check the availability of raw materials.

- Engineering design: time spent designing the product following the
requisition of the customer.

- Production planning and scheduling: this component plays a vital part for
whole components as it involves the time spent planning the production of
the product including availability of every resource needed to manufacture
it and delivering it within the time-limit the customer demands.

- Procurement: following the order, this is the time spent acquiring the raw
materials, machinery and components needed, either from a supplier or in-
house. In case of supplier involvement, this component will also include supplier lead times.

- Order release for production: the time spent confirming the order to be released into production and making a final evaluation of the availability of the required resources normally consumes considerable amounts of time, including planning time.

- Manufacturing: the time it takes to convert the raw materials into the finished product is included in manufacturing lead time. However, it also includes set-up time, which is the time it takes to change between the manufacturing of different products.

- Assembly: the time spent assembling components into finished products.

- Warehousing: the time the finished products spend in a warehouse before they are ready for distribution.

- Distribution: the time spent to transport the product from the warehouse to the customer, which may also be referred to as delivery time. Wedel (1996) states that it also comprises the time spent packing and inspecting the finished products.

Wallace et al. (1990) explored the importance of waiting times for the components described above, regarding anything from waiting for machinery, components and manpower to waiting for a supply of raw materials to arrive. His research on optimizing lead times suggests that investigating waiting times will lead to drastic improvements. However, the performances of all the components discussed above depend on the preferences expressed by the customer in the order, as some of the components may be passed by altogether. Some of the operations may also be outsourced by the manufacturing organisation, which would make it supplier lead time instead.

By evaluating the individual time consumed by each component, we will arrive at the planned total lead time. However, there are always discrepancies between planned lead times and actual lead times because of the factors affecting the latter.

### 2.4 Lean manufacturing

Alukal and Manos (2006) describe lean as a manufacturing philosophy that helps reduce lead times by optimizing the non-value added activities throughout the supply chain. Liker (2006) explained lean manufacturing as one of the most successful production optimization and development philosophies developed by Toyota, because it mainly focuses on reducing wastes in the organisation and helps improve efficiency and profitability. The major wastes identified by Liker (2006) in his research are:
Theoretical Framework

- Over production: manufacturing a higher number of products than required. This will cause excess material handling and affect inventory levels.
- Waiting time: may occur at any stage of the manufacturing process and may involve materials, machines and operators.
- Transportation time: unnecessary movement of materials and operators.
- Over/under processing: manufacturing the products with a lower or higher number of operations or lower or higher quality materials than required will cause either unnecessary investments or poor quality.
- Excess inventory: excess storage of raw materials and finished goods. Stocking materials all over the organisation and works-in-process are also considered to be waste.
- Unnecessary movements: movements by the operators which are not actually required to complete the task.
- Defects: manufacturing products which needs to be remade because they are defective will reduce productivity.
- Underutilizing the knowledge of the employees: failure to encourage ideas the employees have which may result in small improvements.

Optimizing these wastes in order to have an efficient, lean organisation is explained as building blocks by Alukal and Manos (2006) in the illustration below:

![Figure 10: Building blocks of lean (Adopted, Alukal and Manos, 2006)](image)

However, under the umbrella of lean manufacturing, there are many theories. In the following, we will further explain the theories which were considered appropriate for a job-shop production environment using an MTO approach.
2.4.1  Spaghetti diagram

Alukal and Manos (2006) explicated the spaghetti diagram as a most useful tool in order to identify, understand and even train employees in the flow of materials, information and even movements of operators all over the organisation. This diagram will visualize all activities in the organisation where movements occur and later it will help to eliminate all the possibly unnecessary movements in order to optimize production according to lean philosophies. Moreover, it is a very easy tools to use because all it requires is paper and pencil to draw and some team work.

The procedure for drawing the spaghetti diagram is explained by Keller (2005):

- Draw the plant layout or shop-floor plan including all the required activities such as machinery, storage areas and operators.
- Note places where you need to work or where the process begins and connect them to the next stage and so on.
- Work in teams to identify possible modifications to optimize the flows.

2.4.2  Single minute exchange of dies (SMED)

The Single minute exchange of dies theory was developed by Shingo (1985) in the mid-20th century in order to perform quick changeovers between operations, never exceeding a time limit of one minute. The term changeover is the time needed to change tools or machine settings while switching between different types of products. The changeover time is also referred to as set-up time, the time required to set up the machine or assembly line for further operations.

Shingo (1985) states that SMED consists of three major steps that improve the set-up times influencing internal lead times.

- Step 1: separating internal and external set-ups.
- Step 2: converting internal to external set-up.
- Step 3: streamline, examine both set-ups thoroughly for further improvements.

2.4.3  Total Productive Maintenance (TPM)

Total productive maintenance (TPM) is a technique that aims to enhance manufacturing productivity. The method can be summarized as the practical application of data obtained by studying equipment availability, schedule attainment, and product quality. Using these measurements, overall equipment efficiency (OEE) will display the best use of resources (Dwyer, 1999). Moore
Theoretical Framework

(1997) argues that TPM implementation can result in fundamental changes in shop-floor activities with respect to culture, process, and technology. According to Nakajima (1989), among the benefits of the TPM philosophy, one of its major contributions is the innovative approach this technique adopts to optimize equipment effectiveness, eliminate breakdowns, and increase the motivation of operators in daily maintenance activities through autonomous maintenance.

Based on a recent study by Hartman and Charles (2001) on improving equipment performance to the highest level possible and sustaining the achieved situation, it is not possible to settle for a general approach. Alignment of TPM goals and TPM installation should be undertaken to achieve the ambitious goals known as the three zeros:

- Zero unplanned equipment downtime
- Zero equipment-caused defects
- Zero loss of equipment speed

Ahuja and Khamba (2008) state that although various authors have published numerous books and articles with the aim of explaining TPM concepts and the building blocks of TPM, variation is inevitable. However, the pillars of TPM have been presented more or less similarly by various authors, although with different terminologies. The major pillars of TPM can be presented as in the illustration below:

Figure 11: Eight pillars approach for TPM implementation (Adopted, Ahuka et al., 2008)
1. Autonomous maintenance: Autonomous maintenance mainly concentrates on development of operator ownership. This can be developed by performing certain tasks such as cleaning, lubricating, tightening, adjustments, inspections, and readjustments on production equipment.

2. Focused improvement: Focused improvement as systematic identification and elimination of 16 losses by using why?-questions. FMEA analysis achieves system efficiency. Improves overall equipment effectiveness on production systems.

3. Planned maintenance: Planned maintenance can eliminate most of the waste and machine breakdowns. Planning of efficient and effective maintenance such as time-based measurements over the life cycle of the equipment. This can be performed by using PM check sheets and improving MTTR.

4. Quality maintenance: The main aim of quality maintenance is to achieve zero defects by tracking and addressing all the equipment used in the production, through which the root causes of the problems for all machines, operators and materials are identified.

5. Education and training: Training operators to handle different equipment by providing the required technical knowledge and also creating awareness about quality standards and quality controls. Involving operators in different machine works and helping them developing multiple skills. Updating operators on their performance.

6. Safety, health, and environment: Providing safe working environments and creating suitable working conditions at the work place can eliminate injuries and accidents. Providing standard working instructions to the operator.

7. Office TPM: As has been mentioned, TPM involves overall development and improvement of the correlations between different business functions in an organisation. Addressing cost related issues. Maintain the office environment by implementing 5S.

8. Development of management: Development of the management is about learning from the past and implementing these experiences in future products or in new equipment, which will minimize the occurrence of problems. The main objective is to eliminate the learning curve when changing from old to new systems, which is part of maintenance improvement initiatives.

The major activities of TPM comprise identification and elimination of defects categorized into six major losses, namely breakdown losses, set-up and adjustment
losses, idling and minor stoppage losses, reduced speed losses, quality defects and rework losses, and start-up losses (Van Der Wal and Lynn, 2002).

2.4.4 Total Quality Management (TQM)

The evolution of TQM began in the 1980s and mainly focused on customer-driven quality. Feigenbaum (1991) states that TQM mainly has been based on leadership, thorough understanding of quality improvement from various angles, and commitment towards quality by the members of entire organisations with the aim of reducing total quality cost. However, in recent research, Hellsten & Klefsjö (2000) indicate that TQM goes beyond a set of factors, interdependent components, and management through critical factors. Dale and Shaw (1991) describe techniques and tools as inseparable features of TQM which enable supporting and developing the quality improvement process. The chief benefits contributed through implementation of the TQM philosophy in organisations can be summarized as elimination of defects, reduced scrap and rework, reduced level of cost, higher efficiency and productivity, and increased employee morale and empowerment (Walsh, Hughes, Maddox, 2002).

A survey undertaken by Sharma and Kodali (2008) found that although the various frameworks in the TQM philosophy display some common elements and factors, other factors differ considerably. However, based on Wiley (2011), the major pillars of TQM are:

1. Management Commitment (Leadership)
2. Customer Focus
3. Continuous Improvement
4. Employee Empowerment/Employee Involvement
5. Use of Quality Tools
6. Design Quality Management
7. Process Management
8. Managing Supplier Quality

2.4.5 Just-in-time (JIT)

The just-in-time manufacturing strategy was initially explicated and developed by Taiichi Ohno (Ohno, 1988) under the roof of the “Toyota production system” philosophy. Although JIT was initially intended to reduce all forms of wastes in organisations, the major concerns were to maintain the lowest possible level of inventories and maintain the highest possible rate of productivity with the highest possible level of quality. Kumar and Panneerselvam (2007) explore JIT as a system to achieve the goals of the “zero” concept, i.e. maintaining zero inventories, zero
breakdowns, and zero defects and so on. Mason (1999) states that JIT helps control the works-in-process more accurately than a push system does, which presents JIT as an accurate approach for a pull system.

Kumar and Panneerselvam (2007) explored if JIT would work more effectively if combined with other production strategies such as KANBAN, CONWIP, etc. and also described the compatibility of JIT with various other production systems and strategies as is shown below.

![Figure 12: Classification of JIT in literature (Adopted, Kumar et al., 2007)](image)

We find that JIT is compatible with the purpose of this thesis, i.e. to investigate the possibilities to reduce lead times in job-shop production environments using an MTO production approach. Therefore, we will go on to present the theories that can be combined with JIT in order to find solutions to the problems posed in the case we study. The illustration above is meant to provide understanding regarding the possibilities of extending and combining theories with JIT.

In their work, Huq and Huq (1994) hold to that JIT should not be implemented in job-shop production environments using an MTO production approach because of it is a highly unusual production method. As in this case, the routings of jobs may differ from one other and there is also the possibility of high variance in process times. Muda (2011) states that the intentions of researchers such as Handfield and Pannesi (1995) to implement JIT in job-shop production environments often face problems regarding the MTO approach and the requirements for customisation. However, Muda (2011) also mentions that part of the JIT philosophy could help reduce the inventories and queues and also improve the workers’ knowledge about how quality maintenance helps avoid rework.
Muda (2011) also states that authors such as Lingayat et al. (1995) and Huq and Huq (1996, 1998) suggest looking over work load control theories as job-shops ought to be able to both meet delivery dates and satisfy customisation requirements. However, with regard to the supply of tools during changeovers and the stock of semi-finished products between operations, use of JIT can be considered as it helps reduce extensive work-in-process inventories.

Thus, to control the work-in-process inventories in job-shops using an MTO approach, Muda (2011) suggests that CONWIP is more effective than KANBAN. Following that suggestion, we focused on the CONWIP system which will be described below.

### 2.5 Constant work in process (CONWIP)

CONWIP is a production control system suitable for job-shop production environments used to control the work-in-process inventories and was first described by Spearman, Woodruff and Hopp (1990). Along with its beneficial approach towards controlling work-in-process inventories, it also comprises the following advantages as explained by Spearman et al. (1990):

- Reduces throughput time, i.e. the time required for a product to be manufactured by going through all the required manufacturing operations.
- Reduces inventory levels.
- Provides flexibility for material flows on the shop-floor.
- Visualizes production effectively.

Based on the advantages listed above, it is clear that CONWIP aims to optimize lead times by making improvements to the operations on the shop-floor.

Marek, Elkins and Smith (2001) explain that the CONWIP system uses a set of cards in order to control work-in-process inventories. When an order is received, the raw material will receive a card confirming the entry and the same card will then be used to confirm movement of the material on the shop-floor until manufacturing of the product is finished, at which time the card will be released, thus allowing new material to enter the system.
2.6 Work load control (WLC)

Land and Gaalman (1994) are considered the first researchers to explore the concept of work load control (WLC) with the aim of optimizing the queues accumulating before work stations on the shop-floor. They suggest that by optimizing queue lengths, it is possible to optimize waiting times and, in effect, manufacturing lead times. Stevenson et al. (2011) further supports our choice of WLC when he states that WLC is one the most effective production planning and control concept available and one of the few that suits MTO organisations. Land and Gaalman (2009) illustrates that WLC is both suitable and compatible with
small scale job-shops facing high demand variance along with high customisation. However, planning for WLC is categorised under planning lead time, why WLC can be said to optimize overall lead times. Following Land and Gaalman’s (1994) theory, Hendry et al. (1998) discussed three levels where it is possible to control queues:

- Priority dispatching level: the day-to-day shop-floor control level,
- Job release level: the short term production planning level,
- Job entry level: the medium term production planning level.

Considering MTO production organisations, the job entry and job release levels were depicted as important by Hendry et al. (1998). At the job entry level, customers’ orders are received and processed and the possible delivery dates are confirmed with the customer. At the job release level, considerations regarding the sequence in which orders will be released and jobs assigned to machines inform decisions made in order to pursue the start of production.

Hendry et al. (1998) explicate that WLC maintains a “pool” for the jobs yet to be released, while considering the effects of releasing them on the pre-planned queues in terms of the risk of exceeding time and/or storage space. Thus, it reflects a reduction of work-in-process inventories. In order to control work-in-process inventories, WLC considers the pool and also the current shop-floor inventories at the job entry stage. However, Stevenson (2006) illustrates through his research that problems may occur regarding uplift of orders and sequence dependent set-up times. The reason for the problems is explained by the lack of a detailed strategic guide. However, Stevenson (2011) also states that the vast majority of researchers who have achieved the lowest possible inventories along with reduced lead times have done so using WLC.

In order to implement the WLC strategy successfully, Stevenson (2011) proposes a framework consisting of three major stages:
Pre-implementation is a first stage during which the compatibility between theory and organisation is assessed using the criteria stated in Henrich et al. (2004). Then, considering the implementation process as a second stage, Stevenson (2011) explains that this stage is mainly meant to fill the gaps between theory and organisation while it may require a reduction of set-up times and may even be atomised considering information flows. Afterwards, post-implementation is a final stage which is meant to monitor, sustain and improve the concept and requires considerations regarding works-in-process, throughput times and ease of use.

Thus, at the first stage, where Stevenson (2011) suggested following the assessment criteria designed by Henrich et al. (2004), the framework is constructed by considering relevant characteristics together with inbound orders versus shop-floor capacity. The characteristics are:

- Arrival date (a)
- Due date (b)
- Technological requirements
  - Operations (c)
  - Routing (d)

However, the characteristics may vary between organisations, particularly for SMEs. Possible variability indicators are listed in the figure below:
Theoretical Framework

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Indicator</th>
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| a) order arrival dates | (a₁) arrival intensity  
(a₂) inter-arrival time variability |
| b) due date requirements | (b₁) due date tightness  
(b₂) variability of due date allowances |
| c) operations | (c₁) processing time lumpiness  
(c₂) processing time variability  
(c₃) set-up/processing time ratio |
| d) routing | (d₁) routing sequence variability  
(d₂) routing length  
(d₃) routing length variability  
(d₄) routing flexibility  
(d₅) level of convergence |

Figure 15: Characteristics and indicators (Adopted, Henrich et al., 2004)

Afterwards, a matrix were drawn up which considers the functional relationship between elements of WLC and characteristics of the company where the researcher is to identify criteria. The relationships were explained as follows:

- Control point at release: here, the main control point is considered to be the decision made at the release of the order which is considered to be quite common for a typical job-shop. However, long routings and low sequence variety are considered to be conflicts affecting the release of orders.
- Aggregate measures: here, workloads are meant to be considered as aggregate values of each individual process time, while supporting the relation between workloads and throughput times. The best fit here tends to be organisations with high arrival intensities and relatively short processing times.
- Resource buffering: depends on due date allowances for queuing, closer buffer waiting times, and conflicts created by the tighter schedule, why avoid queues requires flexibility regarding capacity.
- Shop-floor buffering: resource buffering also conflicts with tight due dates. However, differences in the allowances of due dates may be corrected by longer and shorter pool waiting times.
- Central load balancing: reduces queue lengths effectively and considers variations in arrivals, routing lengths and sequences, and processing times. However, conflicts arise regarding the requirements of set-up time reduction. However, it is considered to be the best fit for an average MTO organisation.
The figure above illustrates the relationship between the characteristics of the organisation and the characteristics of WLC in order for the researcher to be able to identify them easily.
3 Methodology

This chapter explores the research method used in the thesis along with the data collection techniques that have been considered in order to obtain the proper results. Hence, the chapter is divided into three subsections: research process, research design and research quality.

3.1 Research process

The research methods are the strategies or philosophies that guide the researcher through his/her research work and provide a set of pre-defined rules and structured processes which are applied in order to attain the purpose (Ghauri and Gronhaug, 2005). In order to carry out a systematic investigation, the thesis work has followed a process based on Williamson’s (2002) work as is illustrated below:

![Diagram of research process]

Figure 17: Project plan (Modified from Williamson, 2002)
Considering what would be required to achieve optimal solutions for our research questions, the purpose of the research work was formulated: “To investigate how internal lead time may be reduced in a Make-To-Order and job-shop production environment in order to satisfy the requirement for shorter lead times”

In order to fulfil the purpose of our research, we designed a theoretical framework along with an elaborate presentation of the major components in the framework. The components dissertated were:

- Production approach: presenting the explanation of job-shop layout manufacturing organisations considering the advantages/disadvantages and suitable production strategies for this approach, such as MTO and MTS.
- Lead time: presenting a clear definition of the lead time concept along with classifications, components and factors affecting it.

The theories presented above gave us a thorough understanding of the purpose, which in turn made it easier to understand the case. Following the desired research approach to satisfy the purpose of this thesis, we chose a sample organisation. In the next section, the approach and research design is selected and discussed as outlined by Williamson (2002).

## 3.2 Research design

### 3.2.1 Approach

To promote further approachability of research works, Williamson (2002) presents two approaches. The first is the positivistic approach that explores the deductive reasoning style, which is further explained as moving the arguments or having research start from generalized principles and then narrowing them down to particular instances. The second approach is the interpretivistic one, exploring the inductive reasoning style, which is further explained as starting research in particular instances and broadening it towards general principles.

As our research work aims to investigate how internal lead times can be reduced in a job-shop production environment, there was a need for us to experience what internal lead times means and what a job-shop is. Afterwards, we were able to search for literature on optimization of internal lead times, such as lean manufacturing and quick response manufacturing. Subsequently, we developed a framework created of theories which were deemed to be feasible for a case study employing the interpretivistic approach discussed above (Williamson, 2002).
Interpretivism is explained as a paradigm which emphasizes qualitative research and the two most common research designs of this paradigm are the “case study” and “historical research” according to Gorman and Clayton (1997). Constructivism is explained as a key element of this paradigm by Sutton (1993), because the interpretivist approach deals with various realistic concepts which are derived individually. In this approach, the researcher refers to literature in order to understand the topic and then plans and develops theories to collect and interpret data (Renker, 1993). Furthermore, Williamson (2002) explains research designs in this approach as iterative because they provide the researcher with flexibility to adjust theories, data collection procedures, and even research questions throughout the research period in order to obtain higher research quality (shown in the figure below).

![Framework for qualitative research](image)

Figure 18: Framework for qualitative research (Adopted from Williamson, 2002)

Following the interpretivistic approach, our strategy and design towards attaining the purpose of this thesis is described below, together with a time plan.

### 3.2.2 Strategy and Design

As was concluded in the discussion above, our research work will use the interpretivistic approach and as Sutton (1993) explained, “case studies” and “historical research” are the two most suitable research designs for this approach. In order to strengthen the qualitative research method, the case study research design is selected as the most appropriate for the research in this thesis (Patton, 1990).
As has been mentioned above, the research questions are:

- **RQ 1:** Why do MTO and job-shop production environments tend to have long lead times?
- **RQ 2:** How can planning lead times be reduced in MTO and job-shop environments?
- **RQ 3:** How can manufacturing lead times be reduced in MTO and job-shop production environments?

We first set out to find a manufacturing organisation with a job-shop layout that also uses the MTO production strategy that would correspond well with our purpose and research questions. Secondly, we correlated the theoretical framework presented above with the demands and requirements of the organisation. Afterwards we collected the data, which comprised an evaluation of the current production approach of the organisation including a plant layout, material flows, demand variance, product varieties and current lead times.

We assessed that the possibility of achieving the purpose of this thesis, i.e. to reduce internal lead times, would increase if we broadened the range of theories used with various production management philosophies and data collection procedures. Cavaye (1996) explains that a case study is the best approach to develop and test theories while providing the researcher with flexibility. Yin (1994) states that the case study is: “An empirical enquiry that investigating the contemporary phenomenon with in its real life context especially when the boundaries between phenomenon and context are not clearly evident.”

A case study allows us to use multiple methods for data collection, interviews, questionnaires, observations and even analyses of documents, and also for interpreting the data. In this case we were given an opportunity to use both qualitative and quantitative data, although Orlikowski and Baroudi (1991) state that case studies are most commonly used for qualitative data collection.

The research questions posed indicate the nature of the questions “HOW” and “WHAT” mentioned by Yin (1994), who discusses the close nature of case study research questions along with other questions such as “WHO”, “WHERE” and “WHY”. Yin (1994) also states that case studies can comprise single or multiple cases. Because our research work has been undertaken for one particular organisation, we have chosen to pursue the single case study approach.

Considering the single case study approach, Miles and Huberman (1984) explores the qualification requirements when selecting the organisation to study, as it should provide the researcher with all the necessary types of data and
characteristics. Based on this, Talent Plastics Gislaved AB was chosen as it has a job-shop layout and uses an MTO production strategy.

As a part of our strategic research design, a systematic time plan was drawn up and followed (below).

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<th>ID</th>
<th>Task Name</th>
<th>February</th>
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Figure 19: Time plan

### 3.2.3 Data collection

Prior to commencing data collection procedures, we undertook a thorough literature review and planned our use of data collection techniques carefully, selecting techniques by considering which would best answer the research questions (Williamson, 2002). In order to proceed from this point, we were required to form an understanding of the difference between primary data and secondary data resources.

Primary data is data collected by the researchers in order to fulfil the purpose of the research work at hand such as observations, measurements and interviews. Secondary data signifies the literature referred to in order to analyse the primary data and interpret the results, forming an understanding of the purpose and a generating theoretical framework (Williamson, 2002).

**Questionnaires and Interviews:** in order to obtain answers for the research questions stated above, we designed questionnaires in order to conduct semi-structured interviews with the following people:
• The managing director: here, the interview was performed to understand the overall execution and management systems of the organisation along with its various policies (Appendix 1). The duration of interview was 1 hour 30 minutes.

• The production manager and the planning manager: this interview was conducted to understand the current production and planning systems of the organisation (Appendix 2) and lasted for 1 hour 30 minutes.

• The quality manager and the maintenance manager: here, the intension was to understand the quality policies, the quality system and maintenance issues and policies of the organisation (Appendix 2). The duration of this interview was 1 hour 30 minutes.

• The changeover personnel and the operators: this interview was conducted to understand the difficulties encountered on the shop-floor regarding ergonomics and work standardization (Appendix 3) and lasted for two hours.

Although the interviews followed the list of questions, the participants were provided the flexibility to add ideas and discuss more when they felt there was a need to, which holds to the guidelines in the theories of semi-structured interviews as explained by Williamson (2002).

**Observations:** in order to understand the production approach of the organisation regarding organisational layout, the location of machines, the location of inventories, and material flows, visual observations have been carried out along with video recordings of the required areas. Kellehear (1993) states that each and every detail is considered while conducting and analysing observations. We observed the plant layout for two days and documented it in order to for us to be able to provide the organisation with improvements in material flows and feedback regarding improprieties in the allocation of inventories.

**Measurements:** in our research work, measurements of lead times have been conducted in order to substantiate current lead times using time as a physical quantity. Recordings have been used to measure the time consumed for changeovers between operations and cycle times have been measured either for a single product or a batch of products. The physical distance between the various entities of the organisation have been measured in order to explore the material flows (Kothari, 2004).

**Literature review:** the initial stages of the literature review are carried out in three different stages:
Firstly, in order to understand the topic of interest and develop the purpose with the support of research questions.

Secondly, to explore the components of the theories considered relevant to fulfil the purpose and to develop a theoretical framework.

Thirdly, to draw up the research methodology and data collection procedures.

After these initial stages, literature is referred in order to analyse the data collected and used to support and maintain the validity and reliability of the interpretations of data. Williamson (2002) and Yin (1994) argue that the theoretical framework should be designed by referring to literature and that this can be carried out using various sources such as books, journals, articles and even web resources.

3.2.4 Data analysis

Williamson (2002) explains that although qualitative data analysis does not have particular rules to be followed, the researcher should be knowledgeable about the amount of data to collect and how it can be interpreted.

Data analysis is carried out to create a proper structure for the collected raw data (Rice-Lively, 1997). The data collected through interviews are transcribed in order to be available for re-check and also to be categorised; here, transcribing can refer to taking notes while listening to recordings (Williamson, 2002). The uses for numerical data vary based on the requirements of the research purpose. The measurements of changeover times and cycle times have been analysed using SMED, VSM and other theories.

However, there is a risk non-valuable data will be obtained through the data collection techniques referred to. To exclude non-valuable data from the analysis, we first categorised the data and then compared it to the theoretical framework designed by referring to literature. In order to present the best outcomes in relation to the research purpose, Williamson (2002) suggests that researchers play with different academic ideologies. For the interpretation of our research, we discussed it in groups and also let the employees of the manufacturing organisation discuss it in groups, which also created an opportunity for us to hear some of their ideas.
3.3 Research quality

3.3.1 Validity

Yin (2008) explains the validity of research by dividing it into two: internal validity and external validity. Internal validity is further explained as the quality of the research work carried out. The quality of our research work is illustrated through the methods we have chosen and the research approach, research design and the data collection techniques we have utilised. External validity is explained as the level of generalization of the findings; in our research work, we have used previous research from the initial stages of finding the topic of interest and followed by creating the research problem, designing the purpose and the research questions. After this, we presented a theoretical framework connecting the purpose and the research questions by referring to relevant literature.

Thus, the research method we have chosen and the theoretical framework we designed to provide our research with some extent of validity. The data collection techniques we have used, such as interviews, observations and measurements, present further validation.

3.3.2 Reliability

Williamson (2002) explained reliability as achieving the same results or findings when repeating a study or an experiment. As our research work is based on a case study conducted on a particular manufacturing organisation, Talent plastics Gislaved AB, the reliability of our research may come into question. Unless future research is performed under similar circumstances, the results will undoubtedly be different from those presented in this thesis.

However, for the research we have conducted, the findings of some of the data collection procedures will present similarities and correlations, e.g. between interviews and measurements. For the interviews, we used the simple questions accounted for in a separate appendix, which increase reliability. However, regarding the observations of changeover times, there is a risk the results cannot be repeated as it is not possible to measure the same changeover a second time. Still, if there was a possibility to measure the same changeover during another session, that changeover may not be able to repeat the same problems identified during the previous one. Our conclusions were made considering the possibility of making an overall reduction of internal lead times. Thus, considering that the theories have been found to be appropriate to affect a reduction of internal lead times, the results presented would be the same if the study was repeated; however, if the choice of theories is changed, the findings and results will vary.
4 Case description

Following the case study methodology discussed above, we have chosen the manufacturing organisation Talent plastics Gislaved AB as our case.

Talent Plastics Gislaved AB is a manufacturer of various customised plastic products that uses plastic granules as a raw material. Injection moulding is considered to be the main manufacturing operations of the organisation and, according to customers’ requirements, extruding and assembling operations are also performed.

Figure 21: Logo, raw material and a product sample of Talent Plastics Gislaved AB
The executive committee of the organisation consists of six members, who also sit on the major managerial positions of the organisation. This managerial committee is responsible for creating demand, organizing the staff, material and machinery, production planning, and planning for effective time management to attain the shortest possible lead times and see to it the organisation has access to the required number of operators. The organisation is in no lack of staff, neither overall, nor for any of the required staff categories.

The managing director of the organisation bears the overall responsibility for major operations and the departments of the organisation while also taking the stress of obtaining orders and maintaining communication with customers. The responsibilities of the planning manager comes in after the customer has placed an order and include activities such as confirming the order by checking the availability of staff, machines and materials. The confirmed order then passes to the production manager, who takes a decision on when to start production, which machines are involved and the maximum time production is allowed to take. The maintenance manager takes care of any problems with machinery, which points to a lack of preventive maintenance measures.

The organisation is a supplier of components to the end-product assembling and manufacturing industries. In the interview with the managing director we learned that the time for manufacturing and delivering the products is highly influenced and often decided by the customer. Thus, in order to meet and satisfy customer demands, the management strives to deliver the right number of products at the right time while facing harsh competition from competitors globally.
In considering the flow of materials and the layout of the manufacturing organisation we refer to Wedel (1996), who explains that the layout of the organisation plays a key part among the factors affecting lead times. The organisation is physically divided into an administrative building, the shop-floor and a warehouse. The shop-floor is further divided into the following sections:

- Hall 1: small machines (low tonnage; injection moulding)
- Hall 2: large machines (high tonnage; injection moulding)
- Assembling hall
- Tool repair/engineering hall
- Raw material drying room

The warehouse is divided into four different parts:

- Raw material storage
- Finished good storage
- Mould tool storage
- Scrap storage

The layout plan of the organisation was designed after observing the sections listed above and the physical distribution of them can be found in Appendix 4.

Regarding the sequence of operations and the flow of materials over the shop-floor, the only two required stops of a product are the two major process steps: raw material drying and injection moulding. Any further steps of the process, such as assembling and even hand work, are carried out following the various requirements of customisation. However, the flow of material is still critical to some extent because the raw material needs to be transported from the warehouse to the drying room and the moulds need to travel from the tool warehouse to the machine and then, the finished products have to travel to the finished goods storage section of the warehouse. From the observations and interviews we found that the problem here is ineffective space utilization, which creates obstacles for material flows and causes increases in waiting times, which also leads to increased lead times.
Furthermore, our interviews with the managing director, the production planner and the production manager revealed that the management concentrate on reducing unnecessary investments on possible major wastes in the plant and attaining the goal of delivering the right number of products at the right time. Thus, we chose to concentrate on the term “unnecessary investments on wastes” used by the management, which belongs with the philosophy of lean production. This situation led us to look into the lean philosophy, adopting this ideology regarding possible wastes in manufacturing industries in order for us to compare with the current situation at the plant. According to Liker (2006), it is possible to identify eight major types of wastes occurring in any manufacturing organisation through the lean manufacturing philosophy.

Discussing wastes in our interviews with the management lead them to identify the major problems the organisation faces as:

- Excess inventory: excess storage of raw materials and finished goods, stocking the materials all over the organisation and work-in-process considered to be waste.
- Waiting times: may occur at any stage of the manufacturing process regarding materials, machines and operators.

Thus, both the wastes identified resulted in increased lead times. Moreover, as the company has the layout of a job-shop and use a make-to-order production approach, it also maintains the “safety stocks” needed for frequently ordered products and products in high demand.
Figure 24: Excess material stored on shop-floor

As shown in the picture above, unnecessarily high levels of inventories are maintained, also on the shop-floor.

Regarding the waiting times, we found through the interviews with the changeover staff and the production manager that a lot of the waiting time connected to receiving the raw material while performing changeovers. As changeovers occur frequently, this situation tends to create long changeover times. However, the waiting times are explained by the production manager as a failure to adequately plan the production.

When an order has been received from the customer, the confirmation of the order depends on the master production scheduling software, which has been in use with the organisation for a long time, and there is no manual planning. This situation, i.e. depending heavily on the software, leads the management to do a large amount of replanning while stopping the production, which in turn causes vast increases in lead times.

In discussions during the interviews with the management, we learned that the organisation produces 2634 different products, all of them manufactured using a make-to-order production approach, and that safety stocks are maintained for 65 of the products. The demand variance is very high for all products throughout the year, which makes production planning and scheduling critical as there are numerous changeovers.
Having identified problems with the internal lead times of the organisation and following Wiendahl's (1995) statement about the necessity to evaluate lead times, we chose two products in order to evaluate lead times based on the priority rule. These two products represented something of icons to the organisation as they are manufactured to supply two large and prestigious corporations, Volvo and Electrolux. Regardless of the importance of these products to the self-image of the organisation, we chose one product that is manufactured in the small machines and another manufactured in the large machines. In the following chapter, we present the evaluated lead times and the activities associated with them while also analysing them using the theories discussed in the theoretical background.
5 Results and analysis

This chapter presents the findings and analysis of our research work. Firstly, we present the findings related to the case study in relation to the purpose of this thesis and the research questions posed. We then go on to present an analysis of the findings supported by references to the literature.

5.1 Job-shop & MTO production

Complying with the first research question, i.e. to identify why MTO and job-shop production environments tend to have long lead times, we present the findings and relate them to the literature discussed in the theoretical background.

MTO and job-shop production environments are known to have a high variance in demand along with high levels of customisation for their products, why achieving the most efficient production possible is a complex process because of the need of the organisation to fulfil the requirements of the customer. Taking into account the capability and capacity of the planning and manufacturing of the organisation as well as demand variability, time, quantity and customisation are considered the main factors behind the long lead times of MTO and job-shop production environments (Fernandes et al., 2009). Arisha, Young and El Baradie (2001) mention that planning and scheduling the production in job-shop production environments are highly complex procedures that result in long planning times due to the high demand variance. According to Bennet (2006), job-shops are afflicted with high demand variability and the flow of materials through the manufacturing process is slow. Fortifying the bottleneck of planning, Fernandes and Carmo-silva (2009) determine that job-shops using an MTO production strategy tend to have long manufacturing times because of the immense amounts of time consumed by changeovers and they also stated that batch size reduction may be complex in this kind of production environment as, in general, batch sizes will be low because of the customised products. Shingo (1985) mentions the importance of reducing changeover times and illustrates that doing so is the most effective way to achieve reductions in total lead times. Browne (1981) explained that MTO and job-shop production environments often require replanning because of failures in the initial planning caused by the stress of frequent changeovers, slow flow of materials and high demand variance.

In this type of production environment, reduction of lead times may not be as simple as in single-line assembling process organisations, where the flow of materials through the process is high and constant (Handfield, 1995). The flow-chart below illustrates the sequence of causes and effects resulting in a tendency for MTO and job-shop environments to have long lead times.
Results and analysis

Figure 25: Theoretical findings of MTO & job-shop (Modified, Fernandes et al., 2009)

In spite of the problems with MTO and job-shop production environments, Bennet (2006) and Kumar and Suresh (2008) argue that among other approaches, this type of production environment can be considered to be the most effective in terms of achieving high customer satisfaction.

However, considering the classification of lead times according to Wedel (1996), planning lead time and manufacturing lead time together make up internal lead time, which in turn is a part of total lead time. Hence, we considered the evaluation of internal lead times to be our major task, a position that further was strengthened by the last two research questions. The following sections will explain how we connected the theoretically identified problems to the case.

5.2 Production planning & control

After achieving clarity as to what the organisation manufactures and what problems it has been facing in relation to our first research question, this chapter will explain the current planning and control systems of the organisation along with an analysis conducted with the help of literature.

The following figure describes the current system for planning and control used by the organisation. However, this planning is actually done entirely by the master production scheduling software (MPS).
Since our purpose is to investigate the possibility of reducing internal lead times, our task will in fact start only after the order has been received in the figure above. In handling the confirmation of the order, the planning manager uses the MPS to decide when the product can be manufactured at the plant and communicates his decision to the customer through the order confirmation form shown below.
After the order has been confirmed, an order release form is created with the support of the MPS which states the machines needed for the process, a list of materials required, the date production will commence, batch size, the calculated cycle times and set-up times.

![Figure 27: Order confirmation form, Talent Plastics Gislaved AB](image1)

![Figure 28: Order release form, Talent Plastics Gislaved AB](image2)
Studying the order release form, it can be observed that the time required to manufacture the product is four days (beginning on 14\textsuperscript{th} of June 2012 and ending on 18\textsuperscript{th} of June 2012) which is based mainly on set-up times and cycle times. However, the management is not able to consider the occurrence of difficulties such as waiting times.

After the order has been released to the shop-floor, the release form is placed in a planning board located near the work floor, from which the operators fetch the document and follow the instructions. The planning board is divided to provide separate slots for each machine. The order release forms are placed in the slots marked with the number of the machine. However, the number of orders placed in the slots by the managers is considerably larger than the capacity of the machine: if a machine has a manufacturing capacity of e.g. two orders per day, there are always more than two orders in the slot of the machine on the planning board.

Our observations of the planning board indicates that some orders have been waiting for a long time because of new orders being released and placed in the slots of the board (following the direction of the MPS) without considering the line of waiting orders and the complex situation these waiting times create, which in turn affects overall lead times.

![Planning board, Talent Plastics Gislaved AB](image)
When large numbers of orders are placed on the board, it provides the operators with the flexibility to choose the orders they feel comfortable with, which causes confusion among the operators as they are left to make decisions on which orders to manufacture. Here, we observed a lack of control over the sequencing of orders at the managerial level.

Along with the problem described above, the MPS system of the organisation does not provide the required flexibility when orders are delayed. It does not in any way inform or display information on the delay: it simply releases new orders, leaving the managers to handle the complexities of replanning.

Considering all these activities, the total time spent on production planning and control is between five and thirty minutes. However, it can be observed that more time is wasted on replanning because of the problems described above. The principles of lean production and WLC state that replanning is a considerable waste, why a strengthening of the MPS system would be advisable according to the theories.

However, as is seen in the illustration of the production planning and control systems of the organisation, problems still existed. At this stage we combined the theories of WLC, CONWIP and lean production in order to answer our second research question and went about identifying the most efficient planning system.

5.2.1 Application of WLC

Land and Gaalman (2009) illustrate that WLC is one of the very few production planning and control concepts which will increase efficiency in job-shop and MTO production environments.

Henrich et al. (2004) argue for deployment of the WLC concept, and Stevenson (2011) suggests that the current state of planning and control of the organisation should be assessed before deployment of WLC. Our assessment is that all production planning follows the arrival date of the order, which is to say that whenever an order arrives, the planning stages discussed above are carried out and the order is placed on the planning board, which is the cause behind the high work load of the organisation.

However, as the organization is provided flexibility by its customers, lead times are longer than actually required. Thus, order releases could instead be done based on due dates, which means following the pre-calculated lead time and start the production just-in-time, i.e. exactly when it needs to start, and thereby avoid the high inventory levels for finished products. Along with releasing jobs to the shop-floor based on due dates, variations in processing times of operations and set-up times need to be evaluated and taken into consideration when planning the production.
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However, by comparing the classification of WLC elements in Henrich et al. (2004), i.e. order arrival dates, due date requirements, operations and job routing, with the characteristics of the organisation, we arrived at the conclusion that central load balancing could be explored. This concept states that the management need to consider the possibility of reducing set-up times, avoiding waiting times, reducing cycle times and also maintaining as low inventories as possible.

After achieving the requirements of central load balancing, the management is suggested to perform extensive follow-ups on the production in order to sustain these improvements.

However, WLC alone is not capable of eliminating all the wastes in the organisation. Thus, instead of helping to develop the planning, we will consider implementing lean production philosophy as is explained below.

5.2.2 Espousing lean production

Lean production as described by Liker (2006) explores the concept of eliminating possible wastes in the organisation. Among the major wastes identified in lean production, waiting times and excess inventories are two wastes from which the organisation currently suffers. Alukal and Manos (2006) explain the building blocks of lean production, which may provide a solution to eliminating the two types of wastes of the organisation. Among the theories, JIT and TPM are considered to be the most efficient to resolve the problems.

Regarding the JIT philosophy, Ohno (1988) explores if it is possible to maintain the lowest levels of inventories at all levels of the organisation without losing the desired level of quality. Mason’s (1999) research concludes that JIT controls the works-in-process more accurately than any other theory available.

In order to implement the JIT approach, Kumar and Pannerselvam (2007) state that the management need to plan the supply of material, staff and machinery moment by moment. In order to achieve this, planning needs to be properly done when calculating lead times. This will provide accurate timing regarding the requirement for raw materials, why implementing this approach can eliminate waiting times entirely.

Ahuja and Khamba (2008) explored TPM as a theory to help maintain an efficient organisation. The theory consists of eight main pillars: autonomous maintenance, focused improvement, planned maintenance, quality maintenance, education and training, office maintenance, safety, health and environmental maintenance. Each of these pillars is meant to help the organisation develop. Although each of these pillars would be helpful in the case we study in this thesis, focused maintenance would be the most efficient of the pillars as planning to avoid rework and machine breakdowns will reduce lead times.
Although JIT and TPM along with WLC would help reduce lead times in certain ways, Muda (2011) finds that implementing and utilizing the principles of JIT along with CONWIP is very effective, in particular for MTO environments. Thus, we will go on to further explore the concept of CONWIP as a shop-floor control mechanism.

5.2.3 Shop-floor control

Muda (2011) states (as do Kumar and Pannerselvam, 2007) that for MTO and job-shop production environments, CONWIP works best as a shop-floor control mechanism along with the principles of JIT. Spearman et al. (1990) illustrated that CONWIP provides effective control of the work-in-process inventories and even reduces throughput times.

To implement CONWIP, a number of cards are needed and we have presented the formula for calculation of that number suggested by Marek et al. (2001) in the theoretical background. After calculating the number of cards required to maintain the system, it follows that when one card confirms the order release to the shop-floor, it also confirms the release of all the required components and raw materials.

However, in our case the organisation releases the orders to the shop-floor using the order release form, which are placed in a slot in the planning board and from where the operators fetch them in order to perform the required operations and also pick up the required materials. Here, we need not calculate the number of cards required, as the existing system itself resembles the CONWIP system. However, we need to make a suggestion to the management to use the release form for each batch separately as it will avoid the piling of raw materials near the machines.

Thus, the combination of lean production, WLC and CONWIP would perfect the planning carried out in the job-shop and MTO production environment and the time spent on replanning could easily be avoided, which would also help reduce total lead times. In the following, we will discuss the findings from the analysis of manufacturing lead times.
5.3 Manufacturing lead time

To fulfil the purpose of evaluating and optimizing internal lead times, we have chosen two different products (as has been described above) and calculated the manufacturing lead times for them both in order to identify the major problems.

According to the classification of lead time components suggested by Wedel (1996), manufacturing lead time consists of two major components: set-up time, which is the time consumed changing over from the one product type to another, and cycle time, which is the time consumed performing the required manufacturing operations. Here, we present the evaluation of set-up times for the two products:

5.3.1 Quick changeover

Shingo (1985) invented and explored the concept of quick changeover, called SMED. We have used an AVIX software designed by Solme AB, Gothenburg, Sweden to perform the procedures of SMED.

Of the two products we were to evaluate, the changeover time of one of the products was much longer and also connected to more problems than the other. We chose to evaluate only the more problematic product as doing so would provide us with better insight into the occurrence of problems with product variance.

The following figure shows the results obtained through the AVIX software. All the operations needed to complete the changeover were performed internally, which means the machine was completely stopped. The total time consumed for set-ups was 404.26 minutes, why this set-up can be considered to be an extremely time-consuming one.

Changeover times figure 30 provides the details on the list of operations performed during changeover before improvements were made. As a first stage, the SMED procedure suggested by Shingo (1985) was implemented, which meant checking which operations would be possible to perform externally, i.e. without stopping the machine, and then deciding whether those operations need to be performed before or after the changeover. As a second stage, the possibility of performing internal operations in parallel was explored. All in all, we managed to improve the previous 404.26 minutes to a mere 79.73 minutes using the AVIX software as shown below:
Changeover Instruction

Area/Department: shop floor
Operator: operator 1
Line: Hall 1
Date for changeover: 
Machine: injection moulding
Variant: 
External task
Internal task
Type not defined

Figure 30: Changeover time before improvement

| Time for preparation: | 0.00 min | Tools used |
| Time for internal changeover: | 404.26 min |
| Time for reordering: | 0.00 min |

Documents:
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Figure 31: Changeover time after improvement
Here, we even utilized one more operator as the organisation had already seven operators performing the changeovers and as each day a maximum of three changeovers would occur, we used this advantage to achieve the shortest possible set-up time through performing the operations in parallel.

The lion’s share of the changeover time was spent waiting for the raw materials, which could have been resolved before starting the changeover following the planning methodology we suggested above.

In the same manner, we altered as many operations as possible to be performed externally and performed in parallel to one another. Using the AVIX software, we developed a clear changeover instruction form.

After identifying the possibility of making huge improvements to set-up times, we moved on to consider the other major component that makes up manufacturing lead time, i.e. cycle time. Following Wedel’s (1996) advice, we looked into the possibility of reducing cycle times by decreasing batch sizes, but as the products of this particular MTO and job-shop production environment are highly customised, normal product volumes are already small. Moreover, the cycle time for this product was calculated to be 40 seconds and the batch of products to be manufactured consisted of a mere 300 units.

Thus, after the improvement, the total time for manufacturing the product, i.e. the manufacturing lead time, was:

\[
\text{Set-up time (79.94 min) + (cycle time * batch size) (40 sec * 300) = 279.94 min}
\]

After the reduction of changeover time was completed, we analysed the flow of material using a spaghetti diagram as is described below.

**5.3.2 Material flow analysis**

In order to study the material flows of the organisation, we used a spaghetti diagram as explained and described by Alukal and Manos (2006). A spaghetti diagram visualizes all activities in the organisation and helps avoid unnecessary movements.
Results and analysis

Figure 32: Spaghetti diagram, Talent Plastics Gislaved AB
Results and analysis

After identifying the material flows of the organisation following the procedure steps described by Keller (2005), we concluded that although they were quite simple and efficient, there were problems with inventories stacking up on the shop-floor that we have already discussed in the case description above.

Thus, improvements would include removing obstacles from material movement areas, which would make operations on the shop-floor much more efficient. Another improvement regarding work floor management will be discussed in connection with the theory on work standardisation.

5.3.3 Work standardisation

Stevenson (2009) states that the reason why the importance of design of work systems is misjudged by organisations lies in that they depend on people’s efforts to accomplish their goals, which is a major part of the management of operations. Employees work for different reasons, most of which relate to the quality of their work life. In turn, quality of work life depends on working conditions such as temperature, humidity, ventilation, noise and vibrations, work time and breaks, safety, and also compensation, which plays a vital role. Quality of work life should maintain a certain standard, which will help employees work.

Stevenson (2009) also describes the concept of job design, which involves working methods and specific content. Job design specifies why, when and who will be responsible for the job. The design objectives are safety and quality of work life.

Stevenson’s (2009) design of the work place involves ergonomics (human factors), contributions and evaluation of the tasks, jobs, products, and an environment compatible with human needs. Ergonomics adds to the design of the work place, which improves overall system performance and increases productivity.

Martinich (1997) states about work standards that once a job has been designed, the organisation needs to know how much work it can receive from the team of employees. Work standardisation will specify task completion time and time spent to perform the task. This is evaluated using standard time, which is the average time spent by a trained worker including machine breakdowns and other unavoidable delays. Standard time data and work standards can be used for employee evaluation and compensation, personnel and production scheduling, calculation of product costs, pricing and process design, and capacity planning.
6 Discussion and conclusions

In this chapter we discuss our findings, both the theoretical findings and the case findings, which reflect the quality of our research work. We discuss the research method chosen to conduct our research.

6.1 Discussion of results

Here, we explain and discuss both our theoretical findings and findings in connection with the case study while comparing these findings to the three research questions we have posed.

- **RQ 1: Why do MTO and job-shop production environments tend to have long lead times?**

With the help of the literature and through analysis of the characteristics of MTO and job-shop production environments, we identified the major problems of this specific kind of environment to be caused by high demand variance and high customisation requirements. These problems were found to be critical to production planning and scheduling, which caused long planning lead times. Another major problem was the immense amounts of time spent on changeovers, which caused long manufacturing lead times.

Further study on the possible causes for the large amount of time spent on production planning and control helped us identify that because of the high demand variance and the high customisation requirements, the management had problems dispatching the materials and tools required for changeovers, which in turn lead to long waiting times and extensive replanning. Considering the immense changeover times, which are caused by specific engineering requirements and low volume production, extensive changes may be required to reduce changeover/set-up times, as it may be difficult for the management to plan for parallel set-ups every time.

- **RQ 2: How can planning lead times be reduced in MTO and job-shop environments?**

To answer this question we chose to perform a case study. The problems identified through theoretical means concerned production planning and control, which become much more difficult because of the various other wastes described in lean production.
To achieve the most efficient production planning system for the MTO and job-shop production environment in the case study, we have chosen the three most elegant theories by going through the literature: lean production together with WLC and CONWIP. The philosophy of lean production consists of various sub-theories functioning as building blocks, among which we have chosen TPM and JIT for the case study while also considering TQM to some extent. Lean production helped us identify the various wastes occurring in the organisation. After this, TPM principles helped us improve the overall productivity of the organisation and TQM assisted in maintaining and sustaining the quality of the organisation. JIT principles were used to reduce unnecessarily high inventory levels.

While lean production helps eliminate wastes and improve the quality and productivity of the organisation, WLC assists in planning and scheduling the production in the most efficient manner. WLC suggests an evaluation of set-up times along with a clarification of when to release the orders to the shop-floor, which leads to the elimination of long lead times. Considering that the organisation already uses a less effective version of the CONWIP shop-floor control mechanism, we suggest that the organisation makes an effort to follow it more in-depth because utilizing CONWIP together with JIT will, according to the literature, provide the flexibility needed to facilitate an efficient release of raw materials to the shop-floor.

Following these three theories, planning lead times can be maintained at the proper level and reduce the amount of time spent on replanning.

- **RQ 3: How can manufacturing lead times be reduced in MTO and job-shop production environments?**

This question was designed based on the fact that MTO & job-shop production environments often face problems with very long changeover times. Thus, we tried to identify the causes for the long changeover times through an analysis of the current state of set-up times of the organisation.

We then chose a product to evaluate changeover times with the help of AVIX software, which is considered to be the most efficient software available. Following the principles of SMED, the AVIX software assisted in finding the best solutions to reduce set-up times. However, most of the problems in set-up times were in fact caused by problems related to production planning.
After evaluating set-up times as parts of manufacturing lead times, we looked to reduce cycle times. However, as in most job-shops, product volumes are very low and as cycle times were already low, we did not pursue the matter further. We did, however, find that standardising the work environment will increase productivity.

### 6.2 Discussion of method

In this section, we will try to explain why we chose to perform a case study, we will discuss the motives behind our actions, discuss the strengths and weaknesses of the chosen method, data collection and analysis, and, finally, whether or not we met the requirements on validity and reliability.

The purpose of this thesis was, “to investigate how internal lead times may be reduced in a Make-To-Order and job-shop production environment in order to satisfy the requirement for shorter lead times”. In order to fulfil our purpose in the complex area of research we work in, we needed to consider many different factors affecting lead times as well as numerous possibilities to reduce lead times and the internal relationships of these possibilities. We found that a case study is a proven method that is capable of handling complex situations in real time situations and allow them to be analysed with precision.

Our research effort included determining and defining research questions that were correlated with and based on a literature review, selecting the case and data gathering and analysis techniques, collecting data in different fields, evaluating and analysing the data, and presenting it in a report. As for data collection, we gathered information through many different methods (questionnaires and interviews, observations, measurements, and literature reviews), which is acceptable in the perspective of our chosen research method as this helped us to study different concepts and their relationships.

As we performed different forms of analyses for different forms of data, e.g. using the AVIX software for changeover times, this provided us with a better presentation of the analysed data and more precise results. The case study provided us with a broad perspective of our challenging research topic. The advantage of performing a case study in our research was that it provided comprehensive understanding of the research objective and allowed a huge amount of data to be analysed and presented in a brief and clear way in the report. A case study provides the researcher with the privilege to learn a lot from the specific case and it also provides a scope for further research.
The case study provided us with in-depth information and also a scope to utilise new technology and skills. However, it will not yield generalized results on the chosen subject and insufficient information may lead to faulty results. The validity of our research is justified by our choice of method and approach, and also by the design and data collection techniques, which were appropriate in light of the character of the research endeavour. We analysed huge amounts of raw data in different ways, such as data from questionnaires and interviews. The results reached using the AVIX software provided answers to one the research questions. Using AVIX we reduced set-up times with more than 40%, which had a huge impact on overall lead times.
6.3 Conclusions

As we conclude our research work of identifying the possibilities of reducing internal lead times in MTO and job-shop production environments, we find that, after thorough reading of the literature, the problems with long lead times in MTO and job-shop production environments are related to production planning and also to very long changeover times; issues dealt with by the second and third research questions. Our choice of methodology fell on the case study and various data collection procedures such as interviews, observations and literature review.

In order to provide the organisation with the advantages of reduced lead times, we chose two different products to evaluate their current internal lead times. However, we have presented only the results of one product in this thesis, as it was found that the problems with this product overshadowed that of the other.

Regarding production planning, we found that the organization relies heavily on its MPS system and that no manual planning is carried out at all, which leads to piling of orders and a huge amount of time spent on replanning, why we presented a framework comprising lean production, WLC and CONWIP, which are considered to be the most efficient systems for job-shop production environments. Using this framework, orders are to be released to the shop-floor based on due dates and before releasing the order, the management needs to consider and plan for set-up times as well. This will see reductions in manufacturing lead times and also a strengthening of the planning of the organisation.

The outcome of this research work can be summarized as a combination of theories used to reduce lead times and create an effective organisation in which all possible wastes are eliminated and appropriate planning applied in order to deliver the right number of products at the right time to the customer.

Although we present this theoretical framework as the most effective, future research can be carried out on new theories, e.g. the application of quick response manufacturing, and as we feel that the complexity of our case study may have been lower than what is typical for job-shop production environments, we suggest that other case studies are carried out on more typical job-shops in order to further ascertain the value of the framework consisting of lean, WLC and CONWIP.

It is often stated by researchers that when an organisation has achieved the shortest possible lead times, it will have to fight economic issues. If so, this may also become a point of departure from where to continue our research.
7 References


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8 Appendices

Here, we attached the supporting evidences for the data collected in our thesis which the readers might want to refer.

8.1 Appendix 1:

Interview questionnaire
Date: May 28, 2012

The interview intended to be a method for understanding the organization structure, policies and how it is operated in order to achieve the customer satisfaction. The data will be used in our master thesis conducted at dept. of. Industrial engineering and management at Jonkoping university and will not be used for any other purpose.

Interviewers: Kalyanchakravarti, Jally., Vamsikrishna, Todeti.
Interviewee: Managing director, Talentplastics Gislaved AB

Questionnaire:
1. Can you explain about the organization?
   a. Which type of services you provide to your customers
      i. Total number of customers
      ii. Lead customers
   b. Which type of products you manufacture
   c. Co-operation policies with other companies
      i. Total number of companies
   d. Total number of employees
   e. Quality policiees
   f. Safety policies
   g. Certifications
   h. Honours
      i. Vision & mission of the organization
   j. Plant area
   k. Key personalities in the organization
   l. Future goals
2. As an MD which responsibilities you pursue in order to run the organization?
3. Can you explain the executive committee of the organization along with responsibilities of each person?
4. Can you brief the various functional groups of the organization along with number of persons allocated and there responsibilities?
5. Can you give the details regarding involvement of you as an MD in various functional groups?
6. In which functional group of the organization you bear more responsibilities? Can you explain briefly?

Supplier:
1. Are you responsible for co-ordinating with the suppliers?
2. Which type of communicative systems do you use to co-ordinate with suppliers?
3. How do you evaluate the quality of suppliers?
4. How many suppliers do you have in total? (Raw material/ components/ tools/ machines)
5. How many of them are acting as leading suppliers?
6. Do you categorize the suppliers?

Customers:
1. Who is responsible for co-ordinating with the customers?
2. Which type of communication systems you use to co-ordinate with your customers?
3. Does your customer also use similar communicative systems like you?
4. Do you categorize the customers? (if yes)
   a. On which criteria you categorize
   b. Does importance level varies between the categorized groups

Auditing:
1. How many types of audits do you perform in organization?
2. How often do you perform the audits?

Support:
1. Does the employees ideas/knowledge encouraged
2. How do you appreciate the success of the employee’s ideas?
3. Do you train your employees for supporting organizations continuous improvement?
4. How often do you contact/meet with your employees?
5. Who will report the problems in organization to you?

Demand/forecast:
1. Do you evaluate the demand variance in order to forecast for future?
2. How the demand does vary in general, considering a period of one year?
3. Do you document the demand if so, how? (does it categorized based on customer or time period)
4. Do you forecast orders/demand? If so, which type of forecasting methods you are using?
Appendices

Production type:
1. Do you make products following the customer order? Or, do you make the products and push them into the market?
2. Do you maintain any finished good stocks? If so, at average how much time do you hold it?
3. Do you hold any safety stocks? If so, which type of system do you use to measure the safety stocks and who are responsible?
4. Do you run the production throughout year 24/7? If not, which period of time you won’t run production and why?
5. Do you manufacture the products in batches/continuous/job/mass?

Investments/Pricing:
1. Which type of system you use to decide the pricing of the products?
2. What is the average investment/profit ratio per year?

Shop floor (if it is related to you):
1. How many machines do you have in house?
2. How do you categorize them?
3. How many manufacturing operations you perform in the organization?

Management software/visualization:
1. Which type of software’s do you use in organization? Which functions of the organizations are performed by those software’s?
2. Do your suppliers/customers use the similar software’s? If not, are you aware of their systems and the compatibility with yours?
3. Do you use any system (software/board/symbols) to visualize the current situations (production rate, volume of products to be manufactured, pitfalls) on shop floor?

Continuous improvement:
1. Which type of actions do you take to pursue the continuous improvement? Explain them briefly?
2. Does the management aware of the current trendy philosophies of production development (Lean manufacturing, world class manufacturing, Quick response manufacturing)?
3. Do consider and document the problems faced in the organization in order to take the preventive measures for future? If yes, can you explain some of the situations?
4. Do you have any strategy for maintaining the shop floor? And do you consider it to be improved?
8.2 Appendix 2:

Interview questionnaire
Date: May 29, 2012

The interview intended to be a method for understanding the organization structure, policies and how it is operated in order to achieve the customer satisfaction. The data will be used in our master thesis conducted at dept. of. Industrial engineering and management at Jonkoping university and will not be used for any other purpose.

Interviewers: Kalyanchakravarti, Jally., Vamsikrishna, Todeti.

Interviewees: production manager, planning manager, quality manager and maintenance manager: Talentplastics Gislaved AB

Questionnaire:

1. As a production manager & planning manager which responsibilities do you people pursue to run the organization affectively? Can you briefly explain?
   a. Intake of order
   b. Confirming the order
   c. Releasing the order
   d. Shop floor control
   e. Setup time control
   f. Inventory control
      i. Raw material
      ii. Work-in-process inventories
      iii. Semi-finished goods
      iv. Finished goods
   g. Maintenance (men, machine, material, flow)
      i. Preventive maintenance

Planning:

2. Can you explain the order precedence criteria with each step/stage briefly?
   a. Do you maintain any routing map for order precedence? If so, can you provide us a copy of it?

3. How do you release the orders to the shop floor? Do you maintain any particular system for releasing the orders and how do you control it?
   a. Scheduling

4. How much time it takes to process the order and release it to shop floor? As you have a wide variety of products on which criteria does the order processing time vary?

5. Which type of software’s/strategies do you use to plan production after you received order?
6. Does your customer always provide you with the forecast regarding order and time?
   a. Do they provide with long term forecast (year/months)
7. Do you have to deal with the order by splitting into batches? If so, how do you deal with it?
8. Based on the forecast do you plan the purchase of material and components forehand?
9. How do you deal with the customers who are not forecasting?
   a. In this case, do the customers provide you with the time to be consumed by your suppliers?
   b. If your customer do provide with time that can be consumed by your supplier, how do you plan the supplier time? What is the average time of supplier over here?
10. Beside your customer provided forecasting details, do you also forecast for orders?
11. After releasing the order to shop floor do the orders wait in a que to be manufactured? If yes, why?
   a. Is there any inconsistency in availability of machines?
   b. Is there any inconsistency in availability of raw material?
   c. How much time generally the orders wait in the que?
12. Along with the order quantity do also maintain the safety stocks? If so, how do you evaluate the amount of stock to be build?

Production:
1. Which measures you take before starting the production? How much time it consumes to prepare the machine for production?
2. Do you measure manufacturing lead time before? If yes, what is the avg. time?
3. Do you measure and maintain the documentation for cycle times, setup times for each product?
4. Do you categorize the products? If so, on which basis did you?
5. Which products/ customers considered as leading? How do you vary the importance?
6. How do you involve in the setup time period?
7. Does the setup’s happen frequently? If so, how frequent and on what basis?
8. Do you build scrap quite often? If so, why and which measures you are taking to optimize them?
9. Is there a waiting time/queuing time between the operations? If yes, how much in general?
10. Is there inventories building between the operations on shop floor? If so, what are the reasons?
11. How often you get the new products to be manufactured and do you face any problems regarding them?
12. Considering the preparation of tools and components do you perform it before the production started or in between?
13. Do you ship the products right away from machine after they finished manufacturing?
14. Do you maintain the single-piece flow on the production line or batch?
15. What measures will you take if there is delay in manufacturing? Do you document them?
16. Can you explain the each production operation performed in the organization briefly?
17. In general, how many operations does the product need to undergo?

General:
1. Do you perform any operations outsourced? If so, do you document the time consumed for those along with the in-house manufacturing time?
2. Does it affect the time provided by the customer? In which manner does it?
3. Do you also involve in warehouse maintenance? If so, explain?
4. Can you explain in general, how much time the products wait in the warehouse?
5. Do you make any components before order? And, do you stock any components by forecasting between the orders?

Quality:
1. Can you explain as a quality manager which responsibilities do you pursue?
2. Is there any established, documented quality management system?
3. Do you maintain any manual for quality? If so, can you explain?
4. Are you included in planning after receiving the order to prepare and discuss the quality plans? If so, how do you?
5. How often do you perform quality audits in the organization? What measures do you include while auditing?
6. Do you aware of the “SIXSIGMA” methodology? If so, how do you perform it in the organization?
7. Do you consider the support of any software for quality management? If so, what is that and explain?
8. Do you also involve in shop floor activities? If so, how?
9. How often do you meet with the production, planning and maintenance department?
10. What measure do you consider to develop the quality management?

Maintenance:
1. As a maintenance manager which responsibilities do you pursue? Can you explain briefly?
2. Which type of measures you consider to prevent the pitfalls in production?
3. Do you monitor and document the maintenance issues in order to prevent them in future?
4. Do you maintain any manual for maintenance? If so, can you explain?
5. Do you maintain any condition based maintenance?
6. How do you control the maintenance issues regarding material, men and machinery?

8.3 Appendix 3:
Interview questionnaire
Date: May 31, 2012
The interview intended to be a method for understanding the organization structure, policies and how it is operated in order to achieve the customer satisfaction. The data will be used in our master thesis conducted at dept. of. Industrial engineering and management at Jonkoping university and will not be used for any other purpose.
Interviewers: Kalyanchakravarti, Jally., Vamsikrishna, Todeti.
Interviewee: Setup personnel, operators (work floor, ware house and assembly): Talentplastics Gislaved AB
Questionnaire:
Setup time:
1. Can you explain, as a setup personnel which responsibilities do you pursue in the organization?
2. Can you explain each step you undergo while setup?
3. Does the tools, components, jigs and fixtures placed close to the machine or do you maintain a tooling box for them?
4. In general how much time will you often consume to perform the entire setup?
5. Does the setup time vary between machines? If so, based on which criteria it does? Can you explain in brief?
6. Do you feel the current setup time is more than the required? If so, why and explain?
7. Do you feel flexible to move and fix the tools etc… while performing setup? If not, why and explain?
8. Do you often measure the time consuming for each machine setup? If so, can you provide us with the data?
9. How often will you meet the production supervisor to discuss the problems in setup?
10. Did you face any major problems in setup during past days? If so, can you explain?
11. Do you document the problems occur in setup in order to prevent them in future?
12. Is there continuous effort in reducing the setup times? If so, who are the people involved?
13. Do you aware of the “Single minute exchange of dies (SMED)” philosophy? If so, can you explain what measures you take to adopt the results of it?
14. Do you also perform cleaning of the machine before and after the setup or the maintenance personnel will do it?

Operators:
1. As an operator along with the initial responsibility of operating the machines do you also pursue any more responsibilities? If so, explain?
2. Do feel flexible with working environment regarding safety, comfort, machines, tools and components, lighting and noise etc…?
3. Do you feel flexible with the previous operation performing operators?
4. Does the tools are placed closer to machines?
5. Do you perform the cleaning of the machine before and after the production or the maintenance personnel will do it?
6. When you have the problems in operating the machine to whom do you report and how will be the response?
7. Do you feel the machines need to be more atomized? If so, which type of problems do you face with the current ones?
8. Are you provided with the training frequently?
   a. Multi-operation performance
   b. Knowledge sharing
   c. Production development
   d. Efficiency improvement
   e. Quality maintenance
   f. Safety issues
9. Do you involve in the meetings with the management? If so, what will you discuss?
10. Does your ideas in order to improve the organization are often approved and appreciated?
11. How do you respond and to whom will you respond when there,
   a. Shortage in material/tools/components
   b. Production finished
12. When there is a situation that you need spend more time than required in order to fulfil the orders do you support?

8.4 Appendix 4: