Master thesis

Reducing Takt Time at VMI by Improving the Flow of Supplies

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This research project emerged from my study of Industrial Engineering and Management at the University of Twente. This thesis is the result of counting towards my graduation for my master track in production and logistics. The research was executed at the logistics department of VMI Holland. I am very grateful that I had the chance to work in such an interesting, innovative and technical environment. There was a perfect matching of my studies, my interests and the company. The goal of the research was to reduce the takt time of a specific product family and to improve the logistics flow. The research encompassed the entire supply chain and perfectly suited my range of study. The challenge to realise a practical reduction was motivating. The execution of this research was a very inspiring and challenging learning experience for me. The rare moments of adversity were luckily overshadowed by the joyful moments. Graduating gave me an enormous sense of satisfaction. At the moment of writing, this work is finished and it is time to say thank you to contributors.

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A note of thank to my family and friends for their support during my studies. Thanks goes in particular to my parents, whose unconditional support, patience and encouragement have been a great help to me in successfully completing my studies.

Finally, I hope that reading this master thesis is an interesting and enjoyable experience.

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Management summary

In august 2013 the sales department requested that tooling be delivered more quickly. This request initiated an analysis of tooling and led to the decision to hire a student. During the practical introduction and practical implementation of lean tools, it seems that the production time was around 5 days, the minimal takt time was 47 days and the average takt time was 84 days. The value of the work in process was 1.6 Million euro. Those points of improvement (Kaizen points) led to this thesis with the following research question:

How to significantly reduce the takt time of a drum and optimise the logistics flow by improving the flow of supplies at the internal warehouse and assembly hall?

The project started with delineating the research field. Delineation was made for internal causes in the production hall for a long takt time. Warehouse causes and external causes were excluded.

An explorative analysis of the current situation was carried out in order to find some critical key performance indicators. An alarming key performance indicator was the correlation between takt time and the time spent on non-value adding activities. The main reasons for this were the long delivery times of supplies and the errors in supply. An error is defined as a delivery in wrong quantity or quality. In both cases the entire project came to a standstill while new supplies were expected. The fact that every order was customer-based and the customer order decoupling point was engineer-to-order created problems when there was an error in the production of an item with a long lead time. The average flow was as follows: An order was placed, an engineer started the drawings, supplies were ordered, waiting for the supplies (longest lead time is 55 workings days), an error could occur, leading to an average additional delay time of 30.44 days, and finally the product was completed. This flow results in a ratio between mean production time and takt time with one error as equivalent to 1: 27.34. Even when assuming no errors; the ratio is 1: 20.67. A frequently measured ratio in the industry is 1:3 or 1:4.

The conclusion of the analysis of the current system in space was that the main causes of delay were: The customer order decoupling point of engineer to order, the long lead time of supplies, the errors (made in quality or quantity), the inventory policy and the production capacity.

To solve those delays, alternative solutions are analysed. The CODP is analysed for VMI and a weighted scoring method was applied. The criteria were: speed of delivery, production efficiency, service level

efficiency, degree of customisation, holding cost and certainty of order. The current inventory policy is compared with an anonymous flow. Sensitivity analyses are applied to select the boundary between the current policy and alternative policy. Alternative production layouts are designed by using practical restrictions, four well known layouts from literature and the determination of necessary elements.

At strategic level the alternative was to switch from engineer-to-order to assembly-to-order based on the scoring method. The solution meant that the delivery time of supplies of 55 days was reduced to 0 because the supplies were in stock and some supplies were already partly produced.

At tactical level the alternative was realizing production from an anonymous flow of goods. The sensitivity analysis proved that the new inventory policy seemed to be an improvement even when additional costs arose or the reduction of order lines was less than expected.

At operational level, an alternative for the flow of goods and an alternative production layout was generated. The flow of goods was to use kitting and 2bin to deliver supplies to production and some unnecessary supplies were no longer to be transported to production. The new production layout was based on what was actually needed and to equalize every work station. It generated 17 work stations instead of 9.

All those changes were combined into a merged solution. This merged solution was first tested with a dry run in the enterprise resource planning system. The dry run revealed the needed implementation steps and showed no error. That was the signal to implement the alternative solution.

The new situation was tested in a pilot study. Because of the time restriction of this research the pilot study could not make the recommended long- term analysis. The short-term results were:

1. Takt time becomes 7 weeks or 35 working days (mainly due lead time of non-standardized products)
2. Total delay becomes 0 days for one drum
3. 25,000 euro direct savings made on order costs
4. The new production time becomes 20 hours for 1 drum
5. The new production capacity becomes 12 drums per week

Despite the fact that these results were only short term, they gave enough confidence to hear a long-term project to reduce the takt time from 7 weeks to 2 weeks due to standardization.

Table of Contents

1. Introduction

In the framework of completing my master study industrial engineering and management (IEM) at the University of Twente, I performed a research at the company VMI into the problem of a long takt time.

VMI is a growing company that develops and produces technically advanced machines, mainly for the tyre industry. VMI is leading in the production of complex machines and won the award for manufacturing innovation in 2013. Based on current and expected growth, the following question arises, how can the company best handle this growth? VMI is currently striving for operational excellence, to reach operation excellence they use the improvement program lean 200+. This research is closely connected with growth and operational excellence.

The first chapter provides an introduction to the research at VMI. It starts with an introduction to VMI as a company and the related TKH-group. The second section is a description of the research. Finally an overview of the structure of the research is provided.

1.1. Company profile

This section contains a brief description of VMI and their parent company TKH. Additionally, the relationship between VMI and TKH is described, as well as the influences of TKH on the activities of VMI.

1.1.1. VMI Group

VMI started in 1945 with construction and repair work under the Dutch name "Veluwse machine industrie". VMI developed to become an innovative player in the rubber and tyre industry and a market leader in producing complex machines. They are located in the Netherlands, China, Germany, Brazil and the USA and employ more than 1000 people.

The core business of VMI is developing and building machines for the production of tyres. The actual production is done by VMI's customers. At this moment, one out of every four tyres in the world is produced by a VMI machine.

The passion that drives VMI is the passion for creating technical innovations that keep manufacturers ahead in their market. And VMI feels a strong sense of pride when they achieve this.

1.1.2. TKH group

It all started with the company TKF that was founded in 1930. The main task of TKF consisted of manufacturing medium voltage cables, which developed into telephone wires and power lines. TKF was growing and an acquisition of a number of companies in the Netherlands and Germany in 1980 led to the creation of TKH, "Twente kabel holding". TKH continued to grow and became a leading international player in the field of information and telecommunications technology, electrical engineering and production technology.

VMI is a totally owned subsidiary of the TKH group. VMI shares the policies of the TKH group. TKH is committed to Corporate Social Responsibility (CSR), as is VMI. VMI is not listed on any stock market under that name; it is listed on NYSE Euronext as TKH.

1.2. Project description

This chapter includes a description of the research in order to provide some understanding of it. This description starts with a research motivation. After that, the causes of the research problem are defined; the research is delineated; the research goals are defined; the research problem stated and finally the research deliverables are outlined.

1.2.1. Research motivation

The research description starts with the motivation of the research. Why was this research started? There are three main arguments to answer this.

By using lean six sigma techniques, the company has realised improvements over the last few years. Production is divided into different halls. The lean coordinator improved other halls[1] by applying a "montage afloop schema" (MAS - an assembly completion schedule) in those halls. This is a method of just-in-time management to reduce the work-in-progress. The drum hall is more complicated and the lean coordinator often gets stuck. He finds it difficult to get an overview.

The second reason is the actual takt time of the drum hall. In this hall, the drums are produced and the takt time of a drum is estimated to be half a year. A drum is shown on the front-page and is a technically advanced product. When a customer needs to wait half a year for a product, the risk arises that another company will buy one drum and copies it instead of buying two products. A takt time of six months increases this risk of losing sales and presumably there is room for improvement.

The sale of drums is growing and is expected to grow even more over the next year. This growth means that the capacity of this specific hall becomes a bottleneck during peak demand. That was the last argument for this analysis.

1.2.2. Causes of research problem

In this section, the causes of the research problem are described. Thus, the research problem is described first.

Based on the motivation for this research, the research problem is defined. The motivation shows two potential research problems; takt time and capacity. It's likely that they are dependent, but this research focuses on takt time. The main reason for this is because analysing takt time allows an exploration of the entire supply chain whilst analysing capacity would focus only on a small part of the supply chain. The second reason is that takt time is a well-known and appreciated lean measure. Before the project is described in more detailed, a first analysis is done. The result of this first analysis is a cause-result overview.

[1] VMI has different halls with different functions, for example for assembly, montage, and storage production. The hall used for this research was the one used for the production of drums (i.e. the drum is the product) this specific hall is called a drum hall.

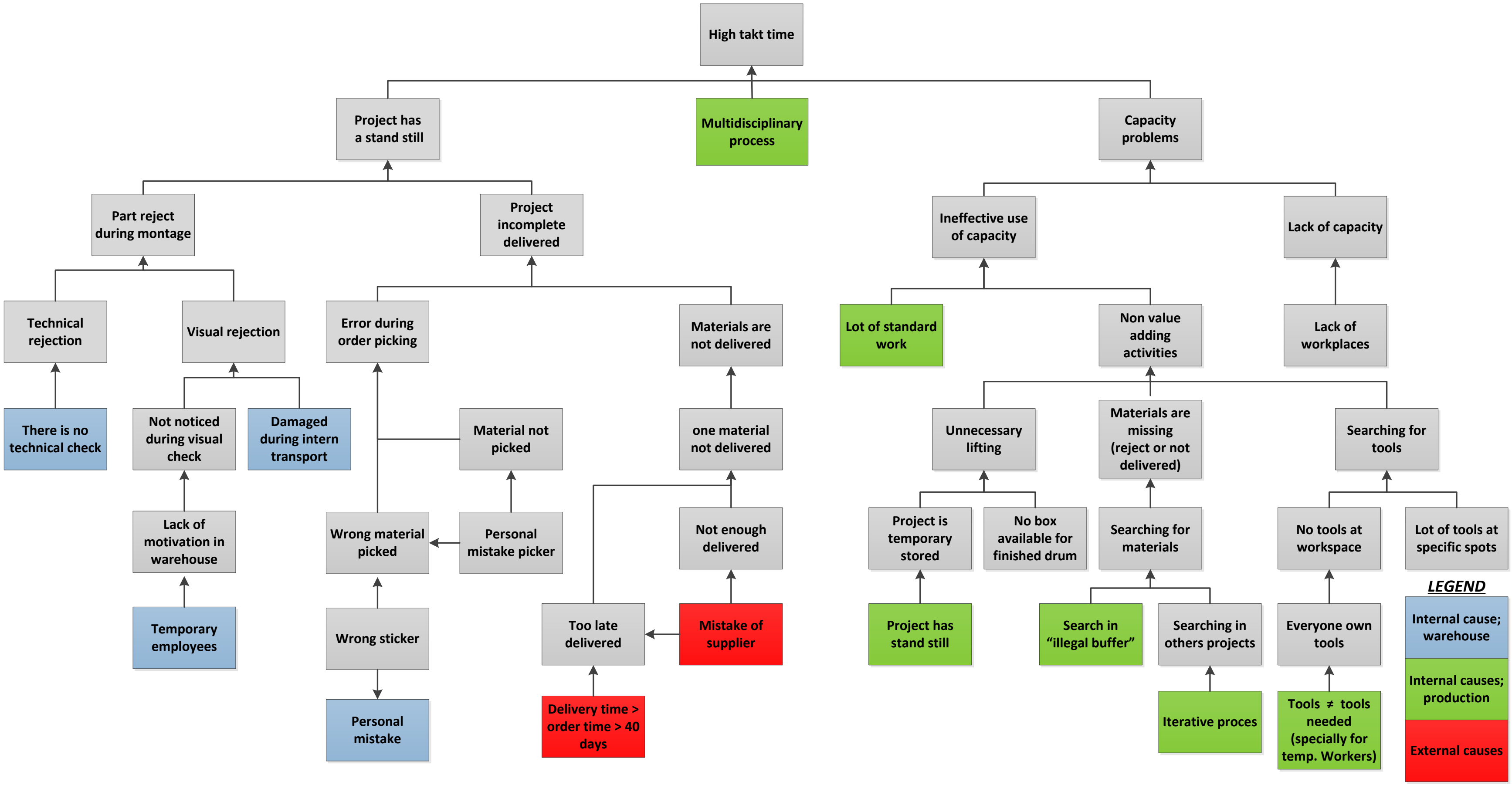


Figure 1.1: Cause-result overview based on first analysis

Now the research problem is defined and quickly analysed and shown in Figure 1.1. The causes are categorised. The first category contains the causes that arise in the internal warehouse. The second category is external causes. The third category contains the causes that arise in the drum hall.

The internal causes in the warehouse for a high takt time seem to be:

1. No technical check
2. Temporary employees
3. Damage due to internal transport
4. Personal mistakes

The external causes for high takt time seem to be:

5. Long delivery time
6. Mistake of supplier

The internal causes during production for a high takt time seem to be:

7. Manufacturing is at a standstill due to error
8. No box available for finished product
9. Mechanic is searching for materials
10. Mechanic is searching for tools

After a quick analysis, ten causes were found and further analysis would find more causes. But I wanted to tackle the main causes and this research was limited in time that prevented researching all the causes in detail. For those reasons, the research is first limited before it is analysed in more detailed.

1.2.3. Delineate research field

To end the diverging of the causes, the research was delineated. The categories of causes were used for delineating.

The first category, causes from the warehouse, was also excluded. The first reason is that the warehouse is delivering goods to all assembly halls and a change will influence all halls and their production. It is not known how such a change will affect all halls, and if it is positive or negative and if all those effects are correlated. This was also a complete research, but the warehouse was analysed in 2009 and the current design of the warehouse is four years old. Of course, there is always room for improvement but it is expected that larger improvements are possible.

The second category, external causes, is excluded. The main reason for that is that the cause is extern and VMI is dependent on the performance of their suppliers. A customer has an influence on the supplier's performance but with complicated supplies there are no substitutes, and delivery time simply cannot be sped-up.

The final category, causes in the hall for drums, is not excluded. The main argument is that the hall is not yet updated by the lean coordinator, in contrast to other halls. So it is expected to generate an improvement. The second argument is the expected growth; they hope to manage this growth with an increase in capacity as a result of this research. The conclusion is therefore that the focus of this research lies in the production hall for drums.

1.2.4. Research goals

Problems were shown in the supply chain but the focus of this research is in the drum hall. The goal of this research is to improve the supply chain of the drum, and the indicator is takt time. Reformulating the purpose for this assignment is that it is to analyse and optimise the takt time, with the focus on the production hall for drums. Two main goals were formulated:

1. Analyse the existing layout of the workplace and the logistics process regarding the drum workshop.
2. Reduce the intensity of the internal logistics by optimising the flow to the drum.

1.2.5. Research question

The purpose of this assignment is to analyse and optimise the takt time of a drum, with a focus on the assembly hall for drums. This research attempts to achieve that goal, which therefore generates the research question. The following research question is defined.

How to significantly reduce the takt time of a drum and optimise the logistics flow by improving the flow of supplies at the internal warehouse and assembly hall?

This question is too large to answer at once. That is why I defined manageable sub-questions. The sub-questions are based on the standard of analysing literature, analysing the current situation, generating a solution and testing this solution. Four sub-questions are defined to answer those questions and those questions are divided again into sub-questions. The following set of question is defined for this research.

Sub1 What does the literature says about reducing takt time?

- Sub1.1 How to position the takt time reduction?
- Sub1.2 According to the literature, how is takt time defined?
- Sub1.3 According to the literature, what does takt time involve?
- Sub1.4 What is written in the literature about the layout of warehouses and assembly halls?
- Sub1.5 What characteristics of the product influence the takt time according to the literature?
- Sub1.6 What optimisation techniques are available in the literature for inventories?

Sub2 What is the current situation of the production of drums?

- Sub2.1 Which processes are currently done to produce a drum?
- Sub2.2 How are processes currently organised?
- Sub2.2 What are the Key Performance Indicators of the processes?
- Sub2.3 How does VMI perform in these Key Performance Indicators?

Sub3 What would be an adequate situation for the production of drums?

- Sub3.1 What alternative solutions exist to improve the performance?
- Sub3.2 What are the advantages and disadvantages of each solution?
- Sub3.3 Which solution applies best to VMI?

Sub4 Does the possible solution work?

- Sub4.1 What options are available to monitor the performance of the implemented solution?
- Sub4.2 What should an adequate monitoring option for VMI look like?
- Sub4.3 What are the performance outcomes of the implemented solution?

Before answering these questions, a few constraints are formulated:

1. The available space of the assembly hall of drums is limited
2. The completeness of delivering materials, incompleteness makes production stop.
3. The sequence of orders, the planning is tight and must be applied to satisfy the delivery dates
4. Some specific vendors are not substitutable and VMI needs to meet their conditions
5. Predicted future customer demands must be met

1.2.6. Research deliverables

The deliverables of this research are defined as follows:

1. The deliverables of this research are clearly defined. The first deliverable is a realistic and academic research that provides a feasible solution. Containing the next elements:
    a. A literature study
    b. An analysis of the current situation
    c. An analysis of the performances of the current situation
    d. Development of a new situation
    e. Implementing plan of a new situation
    f. Comparison between new and old situation
2. The second deliverable is an actual reduction of takt time; the solutions that are found can be directly applied.
    a. Managing of project "takt time tooling"
    b. Standardisation of the product
    c. Change of the customer order decoupling point
    d. Change of the production hall (reduction of wastes)
    e. Developing a new logistic flow
    f. Testing the new solution

1.3. Research layout

The problem is defined, but how does one solve the problem in a structural way? There are well-known methods like the managerial problem solving method (Heerkens, Managerial Problem-Solving Method, 1997), methodological checklist (Heerkens, A Methodological Checklist for the High-Tech Marketing Project, 2004), business process improvement (Rohleder & Silver, 1997) and the "algemeen bedrijfskundige aanpak" (ABP – General business approach to causes). (Heerkens, Algemeen Bedrijfskundige Probleemaanpak, 1999). But those are all general methods and each research is specific in my opinion. I chose to build my own research layout based on the elements of the general techniques and the house of supply chain management (SCM). The result is visible in Figure 1.2.

The fundament of the research is the definition of the research and therefore I choose that to be the fundament of the "house of thesis". The problem definition is done based on the research method interview and by participating actively in the process.

For this research, I use literature to describe the current situation and the future situation. Literature is needed for an equal comparison of both situations. That is why I defined literature as a fundament of my thesis. The research method is a study of the literature and the objective is to build a theoretical framework for this analysis.

The current and future situations are the pillars of the house. Based on the theoretical framework, they can be compared and the differences can be found. The goal of the research is to generate a future situation which solves the research problem and fulfils the research goals.

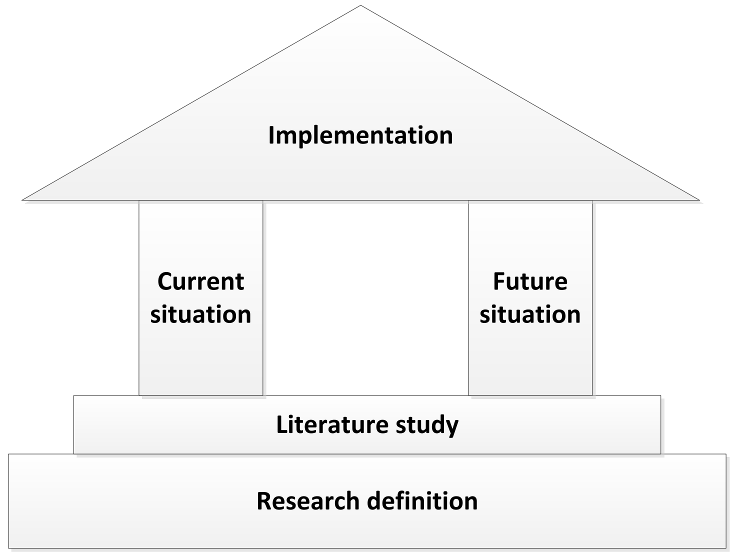


Figure 1.2: House of thesis

The roof of the house is defined as implementation. The research had two deliverables, the research and the practical implementation. This thesis is complete when the last deliverable is reached - the practical implementation. The implementation starts with a pilot study. A successful pilot study would be the roof of the house and the completion this thesis.

2. Literature

This chapter provides a literature review. The literature is analysed in a structured and extensive way to find the answer to the following question: *What does the literature say about reducing takt time?*

To find the answer, several sub-questions were defined. This chapter manages to define the answers to the sub-question of the earlier paragraph. Each question will be answered in a coming section. These sub-questions were:

Sub1.1 How to position the takt time reduction?
Answer can be found in section 2.1
The positioning framework of Hans was used to position this research.

Sub1.2 According to the literature, how is takt time defined?
Answer can be found in section 2.2
This question is answered by defining takt time

Sub1.3 According to the literature, what does takt time involve?
Answer can be found in section 2.3
This question is answered by the definition of supply chain and supply chain management.

Sub1.4 What is written in the literature about the layout of warehouses and assembly halls?
Answer can be found in section 2.4
This question is answered with well-known layouts and the systematic layout planning of Muther.

Sub1.5 What characteristics of the product influence the takt time, according to the literature?
Answer can be found in section 2.5 and 2.6
The answer is based on the relation of the product with the customer and the process. The customer order decoupling point and product-process matrix are the most suitable literature to answer this.

Sub1.6 What optimisation techniques are available in the literature for inventories?
Answer can be found in section 2.7
This question is answered by describing different inventory models and the ABC-classification, which optimises the trade-off between management cost and inventory costs.

2.1. Positioning framework

For positioning the framework there are multiple planning and control frameworks available. Often those frameworks focus on shop-floor oriented manufacturing environments and were they building for project-driven organizations. Rarely can they deal with different objectives and different managerial levels. The hierarchical framework of (Hans, Herroelen, Leus, & Wullink, 2007) can handle different managerial levels.

The Hierarchical framework distinguishes four hierarchical levels and three levels of associated project planning and control. *“As coherently described in Silver et al. [12], Anthony [13] divides the managerial* *activities into three broad categories, whose nam3999es have evolved into strategic planning, tactical planning and operational control. These categories are concerned with different types of decisions and objectives, managerial levels, time horizons and planning frequencies, and also with different modelling assumptions and levels of detail"* (Hans, Herroelen, Leus, & Wullink, 2007). The functional planning's areas are defined; technical planning, resource capacity planning and material coordination. The framework is visualized in Figure 2.1.

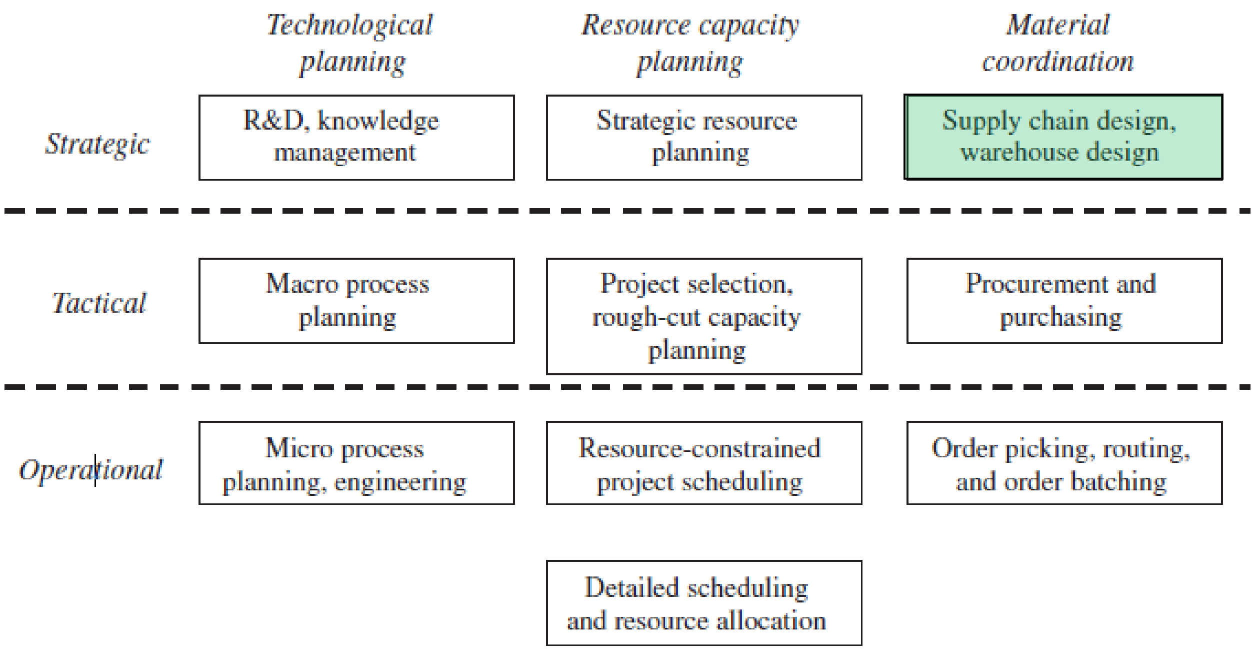


Figure 2.1: Position Framework (Hans, Herroelen, Leus, & Wullink, 2007)

Main conclusive from (Hans, Herroelen, Leus, & Wullink, 2007) was: *"we have pointed out that different levels of hierarchical decision making (strategic, tactical and operational) require different methods and should not always be combined into one 'monolithic' model"*

The argument for this positioning framework is that the hierarchal categorization is interesting and is generates a clear overview of some well-known research areas and there relations. This research does not focus the categories technological planning and resource capacity planning. Those two columns are excluded. In the column material coordination are the remaining options; supply chain design, warehouse design, procurement and purchasing, order picking, routing and order batching.

Based on the remaining options, the goal of supply chain reduction has the most common ground with supply chain design. The position enables the notification when the research becomes multi project management and enables the selection of an appropriate management method.

2.2. Takt time

Takt time is the German word for Baton, which refers to beat, timing and regulation of speed. Takt time is a well-known lean measure and it is recognised as the drumbeat of a process. Quintin Brook cited takt time as:

"Takt time is a representation of the rate of customer demand and is calculated by dividing the available work time in a day, by the number of products required by the customer in a day. Being aware of the takt time is critical when designing a lean process, in order that is provides products at the rate the customers require them." (Brook, 2006)

$$Takt\ time = \frac{available\ work\ time}{customer\ demand}$$

A more general definition is used commonly:

"Takt time is the desired time that it takes to make one unit of production output"

$$Takt\ time = \frac{working\ time}{number\ of\ products\ produced}$$

To give more feeling with takt time: Suppose that during a week of 40 hours, 2 mechanics are working and finish 5 products: The takt time would be in that case:

$Takt\ time = \frac{2*40}{5} = 8$ Hours

The desired time to produce a product is 8 hours. The takt time depends on (available) work time is the variable parameter and based on that the takt time can be influenced. Capacity, walking distances, waiting times and active working time are some examples of influencing factors.

Takt time is the indicator of this research question and therefore this topic is added to the theoretical framework.

2.3. Supply chain management

Supply chain management (SCM) is often explained in Dutch as; "van korrel to borrel, van zand tot klant, etc." This means managing the process from raw material until final product. This description is general and therefore the supply chain will be defined in this section as well as the management of the supply chain (SCM).

A definition of supply chain is:

"Network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hand of the ultimate customer" (Christopher, 1992)

The supply chain can be inter or intra-organisational. Supply chains can cross the boundaries of one firm and multiple organisations can be involved. Movement in the supply chain is defined as upstream and downstream. The downstream movement is in the direction of the customer, upstream move is towards suppliers.

Now that the supply chain is defined, it can be managed. To become more abstract, supply chain management will be described with the definition from Stadler:

: *"the task of integrating organization units along a supply chain and coordinating material, information and financial flows in order to fulfil (ultimate) customer demand with the aim of improving competitiveness of the supply chain as a whole"* (Stadler, 2002)

The definition of supply chain management can be visualised with the house of SCM. See Figure 2.2. The main goal of SCM is to achieve customer service which should beat the competitors. Customer service can be measured by performance indicators such as maximum order lead-time, customer order decoupling point and fill rate.

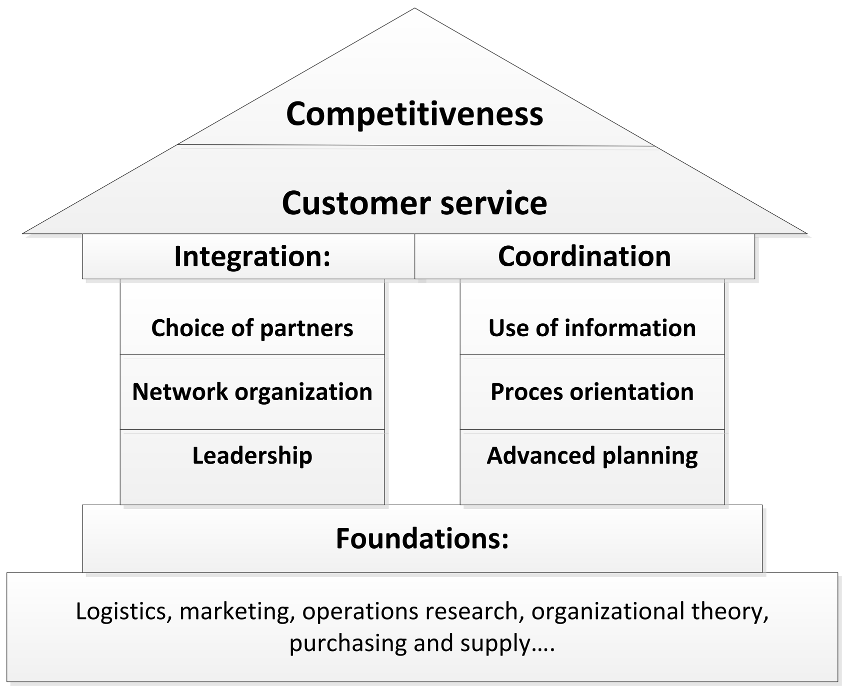


Figure 2.2: House of supply chain management (Stadler, 2002)

There are two main pillars, integration and coordination. Integration involves the fine-tuning between partners and coordination involves all activities along the supply chain like information and communication technology (ICT), enterprise resource planning (ERP), etc.

The theory of SCM is added because the research goal was to optimise the supply chain. The indicator for SCM is takt time. The SCM is added because of the indirect connection with the research question and the direct connection with the research goal.

2.4. Production layout

Fighting through the jungle of literature, a number of lay out types are always in the front. Those simple and basic layout types are often described and linked with the process type. A description and linkage is done by (Slack, Chambers, & Johnston, 2007). The four most common layouts and linked processes will be described in this section.

Fixed position lay out; in this case, the product is too large or sensitive to move. For that reason the product will not me moved and fixed. The layout is built around the product. This layout is limited due planning of availability and the performances of deliveries. A good example is the building of an airplane. The related process is a project base process.

Functional lay out; the product needs a number of handlings, tool or machines. It depends on the type of product whether a handling, tool or machine is used. This layout type is characterized by a functional combination of those handlings. By generating a functional layout, the routing of the product will become efficient. The main process that is used for such a layout is a jobbing process and can be used for a batch process.

Cell lay-out; using a cell lay-out means that all tools and needed components are grouped in such a way that it is clear where the production starts and ends. The lay out in the cell can be arranged according the fixed or functional layout. The cell layout is mainly effective to structure the complexity of the flow. The cell layout can be used for a batch or mass process.

Product lay-out; the product layout has common grounds with the cell layouts. The main difference is that the product layout is optimized for a specific product. The tools, the materials and the needed machines are all arranged in an effective way, it will be placed in a structured way for this specific product. The routing is determined for the product and the activities at each station are known. A standard product is needed for this type of layout. The process that suits such an layout is a mass process or a continue process

Those basic principles form the input for designing a layout. Designing a layout can be done with the systematic layout planning (SLP) of Muther. (Muther, 1973) The three main fundamentals of systematic layout planning are: (Muther, 1973)

1. Relationships; Relationship between the activities in the layout
2. Space; Space for each activity area
3. Adjustment; Adjustment of relationship and space into an effective plan.

According to Muther; applying those three fundamentals in the order they are written about, the planner assures a better decision and better layout. Zooming in at each level shows the underlying subjects, starting with relationships.

1) Relationships;
    a) The collection of data
    b) Analysing the flow of materials
    c) Analyse the activity relationships
    d) Create the relationship diagram
2) Space; Space for each activity area
    a) Determine the space required
    b) Determine the space available
    c) Create a space relationship diagram

3) Adjustment; Adjustment of relationship and space into an effective plan.
    a) Modify the considerations
    b) Apply practical limitations
    c) Evaluation of concepts and selection of final design.

The systematic layout planning does also define multiple phased, namely location, overall layout, detail layout and installation. Applying SLP for designing a new layout, the overall layout and detailed layout are the two phases that will be used.

The lay-out question is answer with four common layout types and a description of the systematic layout planning for designing a layout. The layout is not directly related to the research question. But reducing takt time, improving the logistics flows are both topics which are likely to be connected with the layout. That is why the lay topic is discussed in this chapter.

2.5. Product-Process matrix

The product-process matrix was originally introduced by Hayes and Wheelwright; they suggested that the product life cycle was not only connected with marketing, but it can also be connected with the production process (Hayes & Wheelwright, 1984). The suggestion of this connection between production process and product life cycle was surveyed amongst 144 managers. Based on this survey the conclusion was that the suggestion of the connection was true, when the connection was not there, the company had a poor performance (Safizadeh, Ritzman, Sharma, & Wood, 1996). The optimal connection is visualized in Figure 2.3.

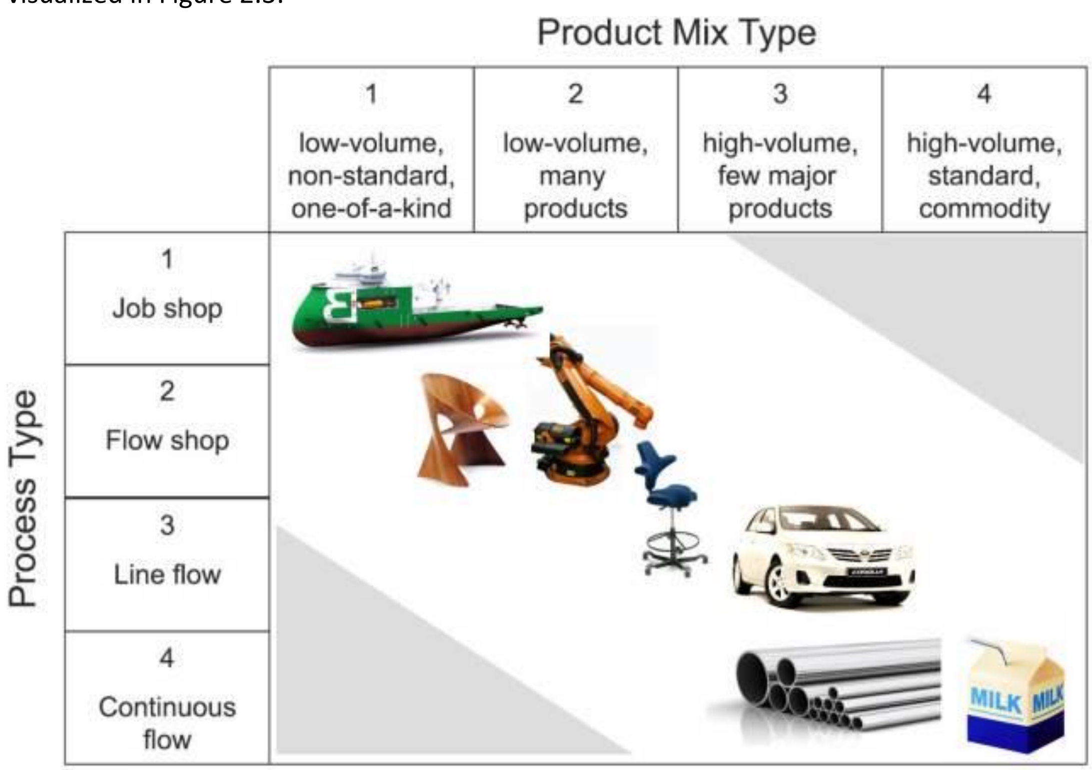


Figure 2.3: Product-process matrix (Hayes & Wheelwright, 1984)

The conclusion offered by the Figure 2.3 is that a fit between products and processes is needed for good performance of a company.

The product-process matrix is added for understanding the product and process. The research question is about the takt time of the production of a drum. The connection with the drum (the product) and the process is obvious.

2.6. The customer order decoupling point

The customer order decoupling point (CODP) indicates where production changes from push to pull. Push production is “pushing” products to the next workstation and pull production needs a signal from the next workstation before the product is moved on (Özbayrak, Akgün, & Türker, 2003). This description of CODP starts with the definition by Hoekstra and Romme (Hoekstra & Romme, 1992):

“The point in the product axis to which the customer’s order penetrates. It is where order driven and forecast driven activities meet. As a rule, the CODP coincides with an important stock point from which the customer has to be supplied. “

The definition defines a separation between forecast-driven and order-driven activities. The forecast-driven side is also characterised by the fact that it is upstream in the supply chain, that it is optimising processes and that it generates efficiency. This makes sense because production can be planned based on the forecast. The order-driven side is characterised as downstream, it involves customer specific products, meeting customer service levels and generating flexibility. Figure 2.4 shows those contradictions clearly and shows five CODP’s (Olhager, 1994).

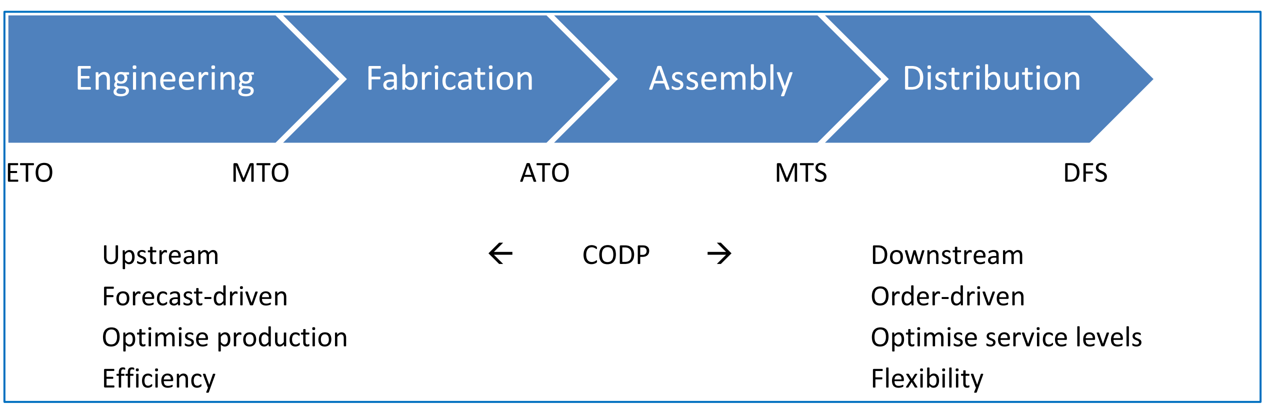


Figure 2.4: Contradictions of customer order decoupling points (Olhager, 1994)

Acronyms

- Engineer-to-order (ETO)
- Make-to-order (MTO)
- Assembly-to-order (ATO)
- Make-to-stock (MTS)
- Delivery-from-stock (DFS)

The left side of Figure 2.4 is the supplier side; the right side of the figure is the customer side. A CODP point is a stock point, where supply needs to fulfil customer demand. The main characteristic of a CODP point is the location of the stock.

The first CODP is ETO, engineer-to-order. This point is characterised by having no stock at all. The engineering, the ordering of materials, fabrication, assembly and distribution all takes place after a specific customer order is received. It all depends on the specification of the customer and is often used for highly specialised products. The second is MTO, make-to-order. In this case, there are only raw materials and basic components in stock. Those stocks are based on forecast, all others stocks are based on customer demand. MTO is often used for small batches in metal industries, where the metal is held in stock. The point ATO, assembly-to-order, has more stock. In that case, there are sub-assemblies, and modules are kept in stock. Only the final production is order-driven. The MTS point, make-to-stock, is completely forecast driven. Finished products are kept in stock at the end of the production process. The last point is DFS, delivery-from-stock. In this case the delivery is done partly on forecast. The goods are produced and distributed to a distribution centre located close to the customer. This is often done for goods with limited use-by dates, such as milk. The five CODPs that are discussed show three more characteristics. The first is that the degree of standardisation of the product is increasing, the amount of stocks are increasing and also that the delivery time is decreasing appropriately.

The CODP theory is added here because it answers the question of where to locate stock in the SCM and it influences inventories, the degree of standardisation and the takt time. The takt time is directly associated with the research question.

The CODP answers the location of inventories. But is does not discuss inventory at all. That will be described in the next section.

2.7. Inventory

With the CODP of the previous section it can be determined where the inventories are located. But what types of inventories are there and are they needed?

There are many types of inventory, and the common types are described here: The first is safety stock; this stock is held to cover uncertainty in demand and uncertainty of supply. The second is anticipation inventory; this inventory is accumulated in advance of an expected peak in demand. The pipeline stock is inventory in transit. This transport can be external or internal. Internal transport between workstations is often called work-in-process. The last common type of stock is decoupling stock, which allows decentralised decision-making where inventory becomes the boundary phenomenon (Zipkin, 1995).

The argument for inventory is to prevent uncertainty in demand and supply. Inventory provides a buffer for similar uncertainties. The second argument is that stocks are the result of uncertainty in demand and supply. As the result of this uncertainty, there exists stock that is not desirable. A final argument is to have stock for the waiting time on new supplies, to cover lead times of supplier.

The different types of stock and the purpose of the stock are known. But how much stock is needed? It is likely that this stock will be (should be) minimised. The next sections are about minimising stock due two theories, namely the “ABC-classification” and inventory control.

2.7.1. ABC-classification

The ABC classification is mainly based on the distribution by value curve. This curve is based on the variables: percentage of total number of stock keeping units (SKU) and percentage of total annual dollar usage. The SKU are sorted in descending order, starting with the highest value of dollar usage. From the value curve, all SKUs can be categorised. This categorisation will be assigned with different priorities. This classification can be used for an efficient allocation of management time and financial resources in any decision system. Reynolds provides a classification scheme, and generated the following priority ranking (Reynolds, 1994); see Table 2.1.

	% of total number of SKU	% of total dollar usage
Group A	20%	80%
Group B	30%	15%
Group C	50%	5%
Total	100%	100%

Table 2.1: Classification scheme (Reynolds, 1994)

SKU is mentioned in the previous section and is correlated with stock: A stock consists of stock-keeping units (SKU). An SKU is defined as an item of stock that is completely specified as to function, style, size, colour and usually location.

Class A is the important category and should receive personal attention. Class B is the moderate category and class C is least important. Class C items make up only a minor part of total dollar investment. The decision systems for these SKUs must be kept as simple as possible.

The categorisation of products does not need to be done on the basis of distribution by value curve alone, in contrast with the priority ranking of Reynolds. Managers may shift goods to another category because they are critical in some way. Products can be crucial for the process, extremely large etc. For example, an extremely large warehouse could not fit in the warehouse and it is likely that stock of this item should be minimised.

The advantage of ABC categorisation is that management time and financial resources are divided in an efficient way. The result is often that the stock (based on value) decreases and the performance of stock (based on number of stock outs, fill rate etc.) remains the same or improves.

The reason for including this ABC classification is that it indirectly relates to the research question. ABC classification is directly related to the topic of inventory, which in turn is related to the research question.

2.7.2. Inventory control

The location of inventory, the types of inventory, the reason for inventory and efficient inventory management are discussed. But there are still some questions that arise (Silver, Pyke, & Peterson, Inventory Management and Production Planning and Scheduling, 2007).

1. How often should the inventory status be determined?
2. When should a replenishment order be placed?

3. How large should the replenishment order be?

All of these questions can be answered by inventory models developed by Axsäter. He developed four main inventory models. These are summarised in Table 2.2.

The four inventory models: (Axsäter, 2006)
1. (*R,s,Q*): Review inventory position every *R* period and reorder the fixed quantity *Q* if inventory position drops below s.
2. (*s*, *Q*): Replenish when the inventory position drops below reorder point *s* and reorder fixed lot size *Q.*
3. (R,S): Release replenishment order every R period and the size of an order is such that the inventory position is raised to the order-up-to level S.
4. (s,S): Release replenishment order as soon as the inventory position drops below the reorder point s
   (*s,S*): Release replenishment order as soon as the inventory position drops below the reorder point s

	Periodically review	**Continuous review**
Fixed lot size	(R,s,Q)	(s,Q)
Variable lot size	(R,s,S) or (R,S)	(s,S)

Table 2.2: Inventory models Axsäter (Axsäter, 2006)

The main advantage of inventory control is that the stocks are located in one station and not in the entire supply chain, which leads to a reduction of stock and stock outs, a reduction of expensive backorders and a reduction of takt time.

This topic is connected to the research question in two ways. The first is that it offers the advantage of reducing takt time. The second is that it allows the minimisation of inventory in the local warehouse. Minimising inventory can be done by controlling it.

2.8. Theoretical framework

In this chapter there are many topics discussed. At the end of every section is an explanation for why that particular topic is relevant for this research and how it relates to the research question. This section is an explanation of how all those elements form the theoretical framework.

The elements that are available for the framework are: Takt time, SCM, positioning, product-process matrix and inventory models. All elements are related to the research question, the research question being: *"How to significantly reduce the takt time of a drum and optimise the logistics flow by reducing temporary storage of supplies at the internal warehouse and assembly hall?*

It can be derived from the research question that the main element is takt time. The other elements predominantly represent methods to achieve the goal of a significant reduction of takt time. That is why takt time is defined as the main element of the theoretical framework. The result is shown in Figure 2.5.

Figure 2.5: Theoretical framework

2.9. Summary

In this chapter, literature is reviewed and the relations are shown in theoretical framework. The subjects are chosen because they are related with the research question in some way and because they will be used in this research. The relation with research question is already discussed in the past section. Looking forward will be done at this moment.

The positioning framework is mentioned to keep an overview during the research. The takt time is defined to eliminate space for discussion about takt time. Both subjects are mentioned to keep on track.

The supply chain management is used to give insight in the process for producing a drum and everything involved. In the coming chapter, the supply chain will be analysed.

The literature of product and process matrix expresses the importance of the product, which is the reason that the coming chapter is started with an analysis and description of the product. The process is analysed in more detail with the theory of production layout.

The customer order decoupling point is used to analysis the breakpoint between push and pull. This characteristic of production will be analysed in chapter three and different options are analysed in chapter four.

The inventory models, ABC classification and inventory control, are used to analyse the current inventory models and analysis the different options. Results are presented in chapter three and four.

The next chapter will use these literatures directly and indirectly, the next chapter will start with a description of the product and the entire supply chain, including the process and production layout.

3. Current situation

The research is defined and the theoretical framework is completed. Now it is time to analyse the defined research area. The research question immediately relevant to this analysis is defined in the first chapter: *What is the current situation of the production of drums?*

This is a very broad question which involves the entire supply chain of the defined product family. The product family in this research was a drum, not an entire tyre-building machine (TBM). The main question of this chapter was split in the first chapter into sub questions, those questions were:

Sub2.1 Which processes are currently used to produce a drum?
Answer can be found in section 3.2
Sub2.2 How are processes currently organised?
Answer can be found in section 3.3
Sub2.3 What are the Key Performance Indicators of the processes?
Answer can be found in section 3.3
Sub2.4 How does VMI perform in these Key Performance Indicators?
Answer can be found in section 3.3

Section 3.1 will start with a description of the product. This provides an aid to understanding the processes discuses later, unless it is no research question.

Sections 3.3.1 to 3.3.11 are designed to help answering the sub questions 2, 3 and 4. Each section will be structured as follows.

- Describe each process
- Define key performance indicator for each process
- Apply the key performance indicator for each process

The structure of this chapter is:

- Section 3.1 Description of product
- Section 3.2 Shows all processes with a supply chain overview
- Section 3.3 Detailed supply chain overview – a close look at each process
    - Describe each process
    - Define key performance indicator for each process
    - Apply the key performance indicator for each process
- Section 3.4 Conclusion

At the end of this chapter the current process of drum production will be understood.

3.1. Product description

The product family is a part of a tyre-building machine, but it is an important module. To give an indication of its importance, it is called the heart of the machine. The function of the drum is to shape the tyre. The shape of the tyre is more complicated than simply saying that it must be round. The shape is difficult to describe, is patented and is not necessary to describe here. To allow the reader to develop some understanding, consider the inch size of a tyre. Whether a 14 or 16 inch tyre is produced depends on the drum. To switch from 14 to 16 inch, rather than replace an entire machine a new drum is bought and installed.


Figure 3.1: Picture of a drum

There are different types of drums. The focus of this research is on the production of drums for tyres. Not for truck tyres. To produce a different size of tyre, a different drum is needed. To build a different drum, different supplies are needed. The number of different supplies for the product family varies between 176 and 212. The amount of each supply also varies for different drums. For example, a product named "lever" is required 102 times in one specific drum but is required 108 times in a larger drum. There are different supplies, and different quantities needed.

Different supplies and quantities are certainly required but when I built a drum of my own I noticed that a lot of common products are used. That led to further analysis. When a quick comparison was between products it became clear that 58.9% of all products are the same type, and require the same supply. Generating a pivot table confirmed a lot of common supplies.

The conclusion is that a drum consists of many standard supplies, which are represented in almost every drum but in different quantities.

3.2. Supply chain overview

The goal of this section is twofold. On the one hand present an overview of all processes necessary to produce a drum. On the other hand perform a value stream analysis yielding the takt time of a drum as well as extends of non-value adding activities.

This internal supply chain is shown in Figure 3.2. The departments that are involved are: Sales, operational control, engineering, Infor (this is the enterprise resource planning software (ERP software), work preparation, purchasing, warehouse, transportation (no actual department), production, quality assurance and expedition.

The processes that are visualised are the core processes. Two main flows are visualised; an information flow, and a flow of concrete supplies / products. The information flow is represented by a dotted line.

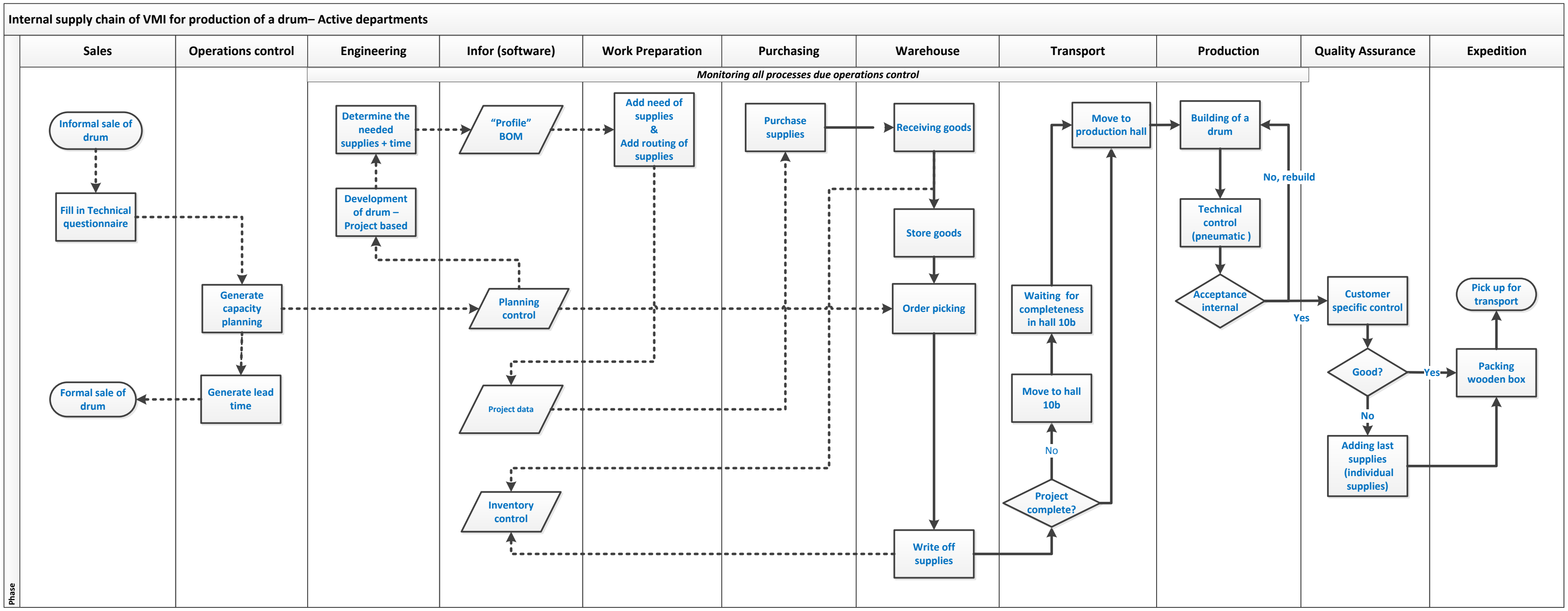


Figure 3.2: Total supply chain of the production of a drum

A similar analysis is done based on value stream mapping. Those can be found in Appendix A.2 and Appendix A.3. The first analysis was for the warehouse and the second analysis was for the total value stream. The first value stream map was used in the second value stream map. The reason that the warehouse stream is used is that this stream analyses any errors. An error in quality or quantity should be found in the warehouse. Any delays that are found are summarised as "wasted time in the warehouse". Based on this existing value stream, a new value stream map is made for the total supply chain of the production of the drum.

- Mean production time: 36.5 hours
- Time of value adding activities: 41.2 hours
- Time of non-value adding activities: 89.16 working days (assuming no error)
- Time of non-value adding activities: 119.6 working days (assuming one error)
- Time of non-value adding activities: 34.16 working days (assuming no error and excluding the standard waiting time for supplies)
- Takt time: 94.31 working days (assuming no errors)

An error is defined as: When a supply is not of the right quantity or quality. Lateness can be discussed but what lateness means here is that at the planned production date, the supply quantity was incorrect. The result of an error is that a product cannot be built and all of the supplies are waiting in production for the one product. How long this takes depends on multiple factors; the speed of the denial process (the process from deny to new order), the delivery time, internal receiving and transport to production. The time for this is estimated to be 30.44 days. Keeping in mind that delivery is between 5 and 55 days and some additional processes are involved, this seems a realistic estimate.

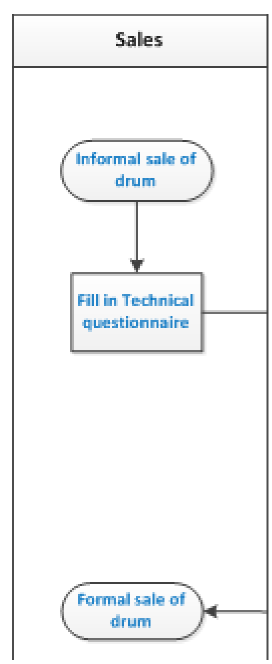
The ratios between production time, time taken by value-adding activities, time taken by non-value-adding activities and takt time are alarming. The ratio between mean production time and takt time with one error is equivalent to 1: 27.34. Even when assuming no errors (which is a utopian dream); the ratio is still 1: 20.67. A frequently measured ratio is the industry is 1:3 or 1:4 and it is a challenge to reach that ratio. (Groep, 2014)

The two main causes that are found are long delivery times and errors during production. But why is it a challenge to overcome those difficulties? The reason for this is the structure of the organisation. Every product that is sold is allocated a project number and is sold individually, ordered individually, transported individually and built individually. But that means that every product also needs to wait 55 days for all supplies to arrive and when an error arises this individual product has to wait further for new supplies. This type of individual production is called project-based production. Referring to the literature chapter (Chapter 2.6), the CODP is engineer-to-order (ETO).

3.3. Detailed overview

This section is mentioned to answer sub-question 2, 3 and 4. The sections 3.3.1 up to 3.3.12 are built up as follows:

- A detailed description of each processes / department
- The key performance indicators (KPIs) are defined
- The scores on each KPI are determined
- A conclusion will be given for each of the processes.



The coming sections are related with the supply chain overview (see Figure 3.2) and the relation is shown with the snapshots. The first department that is discussed is sales.

3.3.1. Department sales

As shown in the supply chain overview in the start of this chapter, the core processes are the informal and formal sale of a drum and the completion of the technical questionnaire.

Why is a difference made between informal and formal sales? The informal sale is the first moment of sale. When a customer is close to buying a product, it is called an informal sale. The technical details of the product are discussed and determined. Only the lead-time is unknown and therefore it is an informal sale.

Based on the informal sale, the technical questionnaire is filled in. This is a file that asks the client for all of their technical wishes and options. The input is from the customer. This file translates the information and forms the input for operation control and engineering.

For a formal sale, the lead-time is needed. The lead-time depends on capacity planning and is determined by operations control. Operations control forms the input for the department sales and based on this value, the customer is contacted. Once the customer agrees on the lead-time, the sale becomes certain and the sale is formal.

The KPIs for the sales and technical questionnaire are:

- Total number of drums sold
- Number of E1 sales (sales with a machine)
- Number of E3 sales (sales directly to customer)
- Other sales (R&D, stock, maintenance etc.)
- Growth of sales
- Percentage of technical questionnaire completed
- Changes to the order after a formal sale of drum

How does VMI perform in the field of sales?
The sales results are shown in Table 3.1.

- The growth of sales in 2013 was 31.06%
- The technical questionnaire is always completed, so this result is 100%
- The sales department allows a customer to change specifications after formal ordering. The value of this KPI is estimated to be 2-3%

Sales	2010	2011	2012	2013
Total drums sold	39	96	103	135
Deliverd with machine	21	78	34	89
Delivered seperately	13	16	47	46
Others (stock, R&D)	5	2	22	?

Table 3.1: Overview of Sales

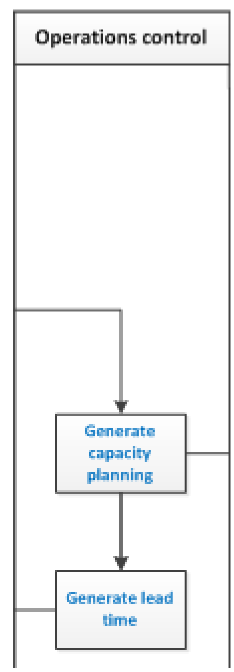
The split between the drums for machines and the drums intended directly for the customer is interesting. The drums for machine take more time because building a machine requires more time and the drum that is delivered directly to the customer has the main advantage of a reduced takt time. A drum built for internal use has also advantage of a reduced takt time, namely that internal delays at a tyre building machine are reduced. The advantage of drums that are sold directly there is an opportunity to gain more market share. For all sales, the takt time reduction will be positive due to less work in process.

The number of drums that are delivered directly to the customer was underestimated at VMI, which creates an argument in favour of this project. Direct sales represent a value of EUR 3 million. At this moment, the feeling is that VMI is missing sales due to the high takt time involved. Therefore, it is relevant and is an appropriate benchmark to check whether the ratios between E1 and E3 remain stable or change.

The conclusion is that the department is performing well. Sales are increasing, but the main outcome of this chapter is to pay attention to the prevention of internal delays and the opportunities for extra sales.

3.3.2. Department operations control

Operations control has two main tasks that are to generate the capacity planning and monitor the process.



The department operations control gets input from the technical questionnaire. Based on the technical questionnaire, the number and types of products are known. For each product, production time is known. Based on the required capacity and the available capacity, planning can be implemented. This plan determines when a product can be completed. This date of completion then enables the lead-time to be determined. Operations control creates capacity planning, not the detailed planning, and determines the lead-time. This lead-time is input for the department sales to realise a formal sale.

A task of operations control is to monitor all processes during the production process. See Figure 3.2. The goal of controlling all operations is to secure quality, to prevent mistakes being made, and to ensure the fulfilment of the promises that are made to the customer. In practice this means that when something interrupts the flow or something goes wrong, people contact operations control.

The KPIs for these processes are:

- Number of orders
- Total number of days of lateness[2]
- Total number of days of tardiness[3]
- Estimated number of days of lateness
- Average number of days of lateness

[2] Lateness is defined as the difference between planned completion date and actual completion date.
[3] Tardiness is defined as the maximum of the difference between planned completion date and actual completion date and zero.

- Average number of workings days of lateness
- Delivery on time

The first five performances were calculated based on the sales history of the last several years. The results are shown in Table 3.2. The last performance, delivery on time at VMI, was not available for this current product family. The desired delivery date of customer (when customer wants and-/or expects the product) was not available at this product level, but at a level higher (for the complete tyre-building machines). But over the last several years it was always above 90%, and often above 95%.

Lateness	2010	2011	2012	2013
number of orders	31,0	93,0	91,0	123,0
Total days lateness	1992,0	4299,0	3613,0	10220,0
Total days tardiness	1992,0	4267,0	3497,0	10088,0
Estimated working days lateness	1422,9	3070,7	2580,7	7300,0
Average lateness (days)	64,3	46,2	39,7	84,4
Average lateness (working days)	45,9	33,0	28,4	60,3

Table 3.2: Lateness performance of a drum

Remarkable point from the table above is the growth in lateness in 2013. The past years showed a decreasing trend of lateness and but 2013 showed a large increase. The lateness seems to be caused due a high number of orders which drives the utilization towards hundred per cent. The capacity intern and the capacity of suppliers are educated guesses at this moment but not proven.

A critical note can be stated regarding the table above: There are two different types of sales:

- A drum that is delivered directly to the customer as an individual product.
- A drum delivered with a tyre-building machine (TBM).

For the critical not, consider the case when a drum is delivered with a TBM, this is about fifty-five per cent of the cases. In those cases, it is possible that the TBM is not yet finished at the time the drum should be finished. That means that the lateness of a drum is not a problem; TBM and drum are still internally in production. On the other hand, when a tyre-building machine is completed and drum is not finished, testing and finishing cannot start without a drum and the WIP increase with millions due the TBM.

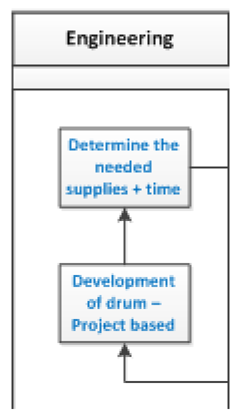
The second critical note is the difference between lateness and delivery on time. An average lateness of between 5 and 12 weeks is not acceptable for a production time of 4 days. The lateness is checked on ups and downs. The significant difference between delivery time and lateness is unusual. An explanation could be that planning builds in a buffer between the completion date and the delivery date, but this would go against the principles of just-in-time management of inventory control. Not to mention creating unnecessary pressure on purchasing, and unnecessary emergency orders etc. To really explain the significant difference in these numbers would require an entire research project in itself. However, it is clear that planning is not functioning well.

The conclusion for operations control is that the lateness is a signal that planning is not functioning well. The planned completion date is broken with multiple weeks for the main part of products and the average delay last year (2013) was 84.4 days. Quality control is not immediately visible and the tasks for quality control are also not concretely defined. So operations control should be the watchdog, but it seems to be a sleeping dog.

3.3.3. Department engineering

The main tasks of the engineering department are to develop a product and determine the supplies required.

The first task of developing a product is based on the technical questionnaire. The questionnaire reveals the technical details. The tolerances of the custom requirements are detailed, technically spoken; a tolerance of 1mm is often used. These tolerances must be calculated. Engineering is performing calculations and generating technical drawings based on customer requirements. The technical drawings are made in a specific program, called 'Profile'. But the question arises, is it necessary for every product to be drawn from scratch? Taking into account the fact that 250 men work in this department, which is globally speaking 20-25% of all employees, it begs the question about how necessary and efficient this is. A main disadvantage that is correlated with takt time is that it takes about 4-5 days before an order is drawn.



The second task is to generate a list with the supplies required. Based on the technical drawings, a list of the required supplies can be generated. An engineer will generate a list of parts that are needed, and when. According to capacity planning, this results in a bill of materials (BOM). This BOM is generated by engineering software, namely 'Profile'. That is why the result is referred to as a "profile" BOM.

It is difficult to define and analyse the performance of the engineering department. There are no concrete KPIs and the department is too large to evaluate within the time I was there. I had a total of 3 days to get an indication of how they work. It seems that the communication between engineers is not well organised. (For example two project groups were developing a machine for the same function except a different size). The machines that are developed are technologically advanced and almost every competitor tries to copy VMI's machines. The performance measurements of a VMI-machine cannot be achieved by a competitor's machine. For example, a VMI machine takes just 32 seconds to produce a tyre. The engineering department is performing well within the field of research and development.

The conclusion for the engineering department is that their strength is in research and development and the correlated level of technical complexity, but communication and efficiency seem to be areas for improvement.

3.3.4. Enterprise resource planning system “Infor”

In the previous chapter (Chapter 3.1), the engineering software “Profile” was mentioned. For the enterprise resource planning (ERP) other software is used. The program used by VMI is “Infor”. “Infor” is used for multiple functions.

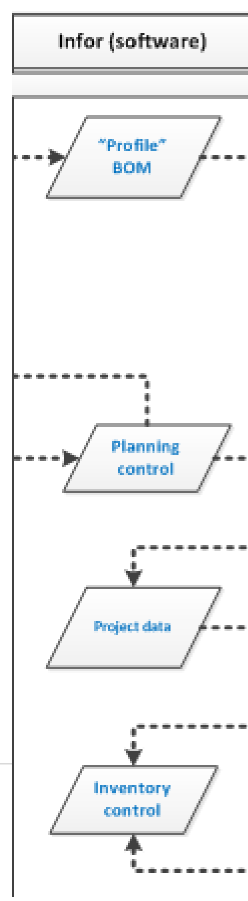
The data that the software controls is planning. A plan is generated for the project and the goods need to be delivered at that time. Planning is performed before the sale is formal. Based on this planning a lead-time is given.

The second data that is controlled is known as the “Profile” bill of material (“Profile” BOM). This is a list of all of the supplies that are needed. This includes purchase items and make items and the top of the BOM is a make item, namely “make a drum”. The structure is as follows:

Make a drum

- *Buy item a*
- *Buy item b*
- *Make item c*
    - *Buy item d*
    - *Buy item e*

Work preparation translates the “profile” BOM and the planning into a “stuklijst” (“stuklijst” – “overall” bill of material). In other words, the “Profile” BOM is translated in an “overall” BOM. An internal routing is also added, it is an indication of internal routing, which building is the destination. So the combination of “Profile” BOM, planning and routing are combined into an “Overall” BOM. This data is bundled together in Infor as project data and related to a project number.



This list contains a lot of information. The following data are known:

- Position (just a sequence code)
- Quantity
- Article number
- Description
- Length
- Width
- Material
- Signalling code

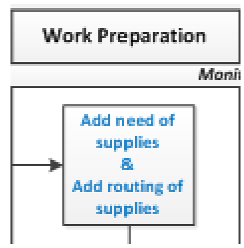
- Make (this is the article code of the built article)
- Spare part (yes / no)
- Lead-time
- Status

The last and main task of Infor is inventory control. This task is discussed in more detail within the purchasing department description.

In 2011, the software was changed from BAAN to Infor. At this moment the basic processes are working well but the software is not used optimally. Many more options are available in the program but are not used.

3.3.5. Department work preparation

The BOM is generated using software from the engineering department, namely profile. That is why the result is called a "profile" BOM. This software is different from the ERP software and this bill of materials needs to be translated. This translation is the main job of the work preparation team. Work preparation not only translates the supplies, it also adds a routing the delivery of the supplies to the right buildings. For instance, large parts are moved to an external warehouse. The chosen product family contains only small parts and all supplies follow through the normal routing. The work preparation department is necessary but not likely, and VMI is currently analysing whether this department can be excluded and replaced by an ICT-portal.



For this specific department the KPIs are:

- Processing time
- Waiting time

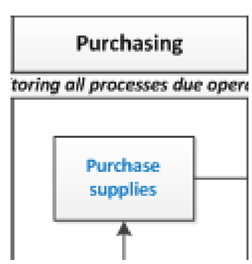
The performance results of this department are:

- The processing time for this product family = 10-120 minutes
- The waiting time depends on the planning = 0-3 days

It is concluded that this department does not add value, but at this moment it is still necessary. The main bottleneck at this moment is the waiting time, which can be a few days.

3.3.6. Department purchasing

The purchasing department receives all of its information from the Infor software. The project-based information is the input for the purchasing department. Based on the project-based list, a buyer places orders with the suppliers. Sourcing buyers analyse the suppliers and searching for new suppliers. The selection of suppliers and their comparison is done well. The ratio of buyers to sourcing buyers is 1: 1..
The purchasing of goods is done based on the project-based data. Each supply has an order line and almost each line is ordered separately. Cheap items that are used in every drum are



order separately. Some suppliers use a minimum order quantity or a minimum order value, otherwise an additional payment must be made. For example, some O-rings valued at 7 cents are purchased one by one. The suppliers require a minimum order of € 7.50. So suddenly the ring cost at once € 7.50. And such a ring is needed in every drum, so a few hundred times a year.

The fact that the purchasing process is project-based, is not ungrounded. In the past, VMI did sell a few machines a year and each machine was customer specific. The increasing flow of orders increases the standard. The explanation for this increase is as following; if a machine was sold twice, it can now be sold twelve times.

The trade-off between project-based and standard order policy has not yet been calculated, but VMI is conscious of this trade-off. That was one of the main reasons for switching the ERP software. The ERP system distinguishes between “anonymous” and “to-order” ordering.

A number of fast movers are selected for this project. The current policy is to order on a project-based policy (“to order”) and the performance results of this policy are evaluated based on the following KPIs:

- Order cost
- Holding cost
- Ratio order cost : holding cost
- Total cost

The actual performance results for the selected KPIs are:

- Order cost: € 74,760
- Holding cost: € 27,902
- Ratio order cost : holding cost = 2.67 : 1
- Total cost: € 102,662

If everything is ordered individually, theoretically there should be no inventory but in fact there is. This can be explained because of differences in lead-time. The difference in lead-time between the fastest and slowest delivery was 50 working days. So this automatically generates an inventory because all orders are placed equally.

The order cost is not alarming. The fact that the order cost is higher than the holding cost is unusual. The main explanation is that almost everything is ordered individually.

The main conclusion for the purchasing department is that there is room for improvement and a change in the order policy could be profitable. Thereby, the main advantage of a switching to another policy (for example, anonymous flow) is that the lead-time of 55 days will be excluded and this is a likely advantage for the takt time.

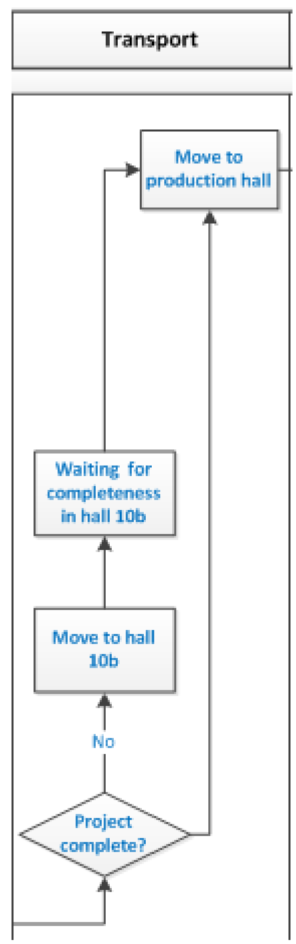
3.3.7. Department warehouse

The warehouse was analysed in 2009 and causes for a long takt time that arise in the warehouse are excluded in the first chapter (Chapter 1.2.3). A detailed analysis is not done for the warehouse but the factors that influence the takt time and some other important considerations are described in this section.

The warehouse not only involves storage, but handling may also need to be done. The handlings are not described in detailed in this section but are summarised as follows:

1. Empty truck
2. Transport goods in the warehouse
3. Search and check the delivery receipt
4. Check the product
5. Book the product
6. Transport to location
7. Pick-up from location
8. Store at production order
9. Write off the supplies

All of these handling tasks must be done for each order line. The handling tasks show the importance of the number of order lines. To take the example of the O-rings again, each handling task must be performed for each separate ring. A reduction in the order lines will not only reduce the order cost, but also the handling cost in the warehouse.



3.3.8. Process transport

The transport from the warehouse seems to be straightforward. However, it involves an additional check that is done before transport and that process is of interest. A meeting between production (foreman) and a material planner will decide whether a project is transported to the production site or to another warehouse. This depends on the level of completeness of a project order. If too many items of significant importance are missing, the project is moved to another warehouse (hall 10b). An analogy can be made to building a house; you cannot work on the roof if the fundament is missing. The interesting result of this process is that moving supplies to another warehouse, the takt time will directly increase.

Another interesting conclusion is that the entire project is moved to production. But not all of the supplies are used in production. The movement supplies is visualised in Figure 3.3. The movement of supplies is always through the storage hall. If it is stored in the storage hall, that depends on the completeness.

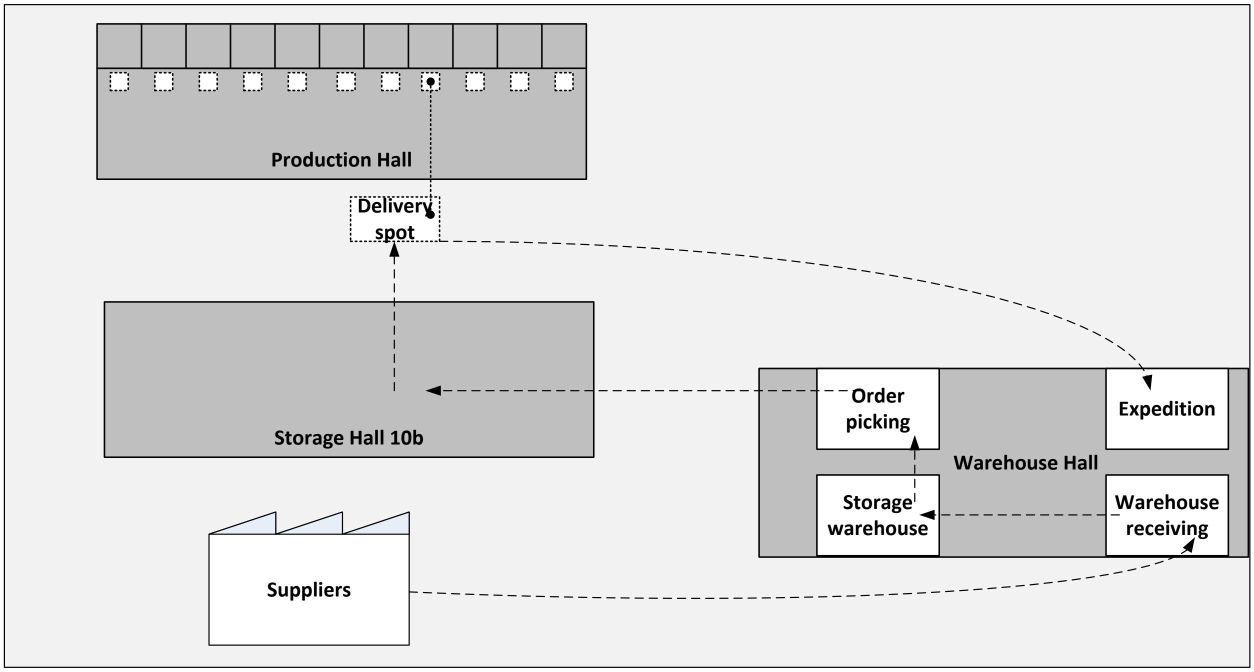
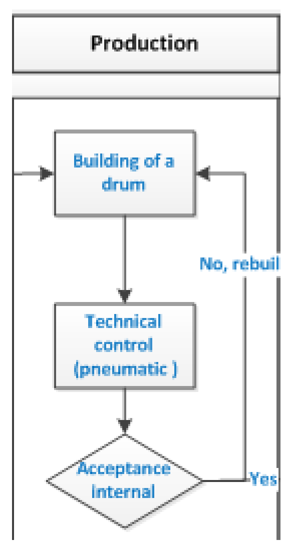


Figure 3.3: Current transport of supplies

The KPI here is the percentage of products that are directly moved to production. At the moment this value is about 60%. Comparing to the just in time (JIT) principle, the goal is to desire at the right moment at the right place. The ambitious goal is like Scania, delivery based on minutes of time. That means no stock and 100% of the products are directly moved to production.

The conclusion is that a lot of unnecessary transport is done. The movement to an additional warehouse is unnecessary, even as the movement of goods to production when they are not required in production.

3.3.9. Department production



At the moment, warehouse is responsible for delivering the products. A pallet with multiple levels contains the supplies. There are separate workplaces and the products are delivered according to workplace. Every workplace is different. A mechanic arranges his or her own workplace. Small tables, long tables, closets, one table, two tables, three tables, desks, tool-box, tool-chest etc. There is no standard and the size of each workplace is also different. Some mechanics use a few square feet and some use much more. The pictures show the differences clearly.

Figure 3.4: Example of a workplace

Figure 3.5: Example of workplace

The production process start with the delivery: A mechanic receives a pallet full of supplies and starts building. The sequence is free and 4 days later he has finished his product. The same mechanic is required to test his own product, and as it is a pneumatic product it is tested with air. This is the main reason that one mechanic builds one product. When he makes an error during production, the product will not pass the pneumatic test. So a mechanic is responsible for his own drum. The production process can be split up, with the main tasks being:

- Receiving pallet
- Building shaft
- Building “fingerholdingring”
- Building levers
- Assembling levers
- Assembling air hose
- Testing (acceptance internal)
- Packing

A spaghetti diagram is made and can be found in the Appendix A.4. The mechanics do a lot of walking around outside their workplace. The main reasons for walking were:

- To search for a tool from another mechanic
- To search for supplies in another project
- To search for supplies in an illegal stock in the corner of the production hall
- Asking the foreman something

A project is not transported to production if it is not complete, so why would the mechanics need to search for supplies? This happens when an error was found in supplies during production. This happens often because of the strict qualities and the large number of quantities. It is visibly noticeable in the production hall due a large number of pallet, products and partly finished products. The amount of work in this process is analysed by counting the number of products, and number of pallets.

The KPIs for production are:

- Production time
- Production capacity
- Value of work-in-process
- Value of work-in-process in production
- Value of work-in-process standing still

The performance results are:

- Mean Production time: 36.5 hours
- Production capacity: 9 workplaces
- Value of work in process: EUR 2,080,000
- Value of work in process in production: EUR 480,000
- Value of work in process standing still: EUR 1,600,000

Within the production process the amount of stand-stills is huge. Often products are half built by a mechanic and then the mechanic must stop due to a lack of supplies. The capacity of the production hall is also limited, with only 9 workplaces. The target for the end of this year is to produce 10 drums within a week. This would mean that the required capacity is 365 hours. For 365 hours of production capacity, $9\,\frac{1}{8}$ workplaces are needed. This will become a bottleneck.

The main conclusion of the current production is: The number of errors is large and has a dramatic effect in production, the number of workplaces and their arrangement are not efficient but the quality of the mechanics is good because they are all experienced. The production time is not the main bottleneck or improvement point.

3.3.10. Department quality assurance

Once a product is finished and the mechanic has tested the product it is time for a final quality check. This quality check is called the “afname-moment” (“afname-moment” – the handing over of a drum from production to transport with control of operations control). At this moment operations control, mechanic, foreman and often sales are involved. They have a meeting with a checklist. The first part of the checklist is a technical check. The second check is a check between the finished product and the order of the customer. The finished product must meet the customer’s specifications.

In practice the first check will never find a fault. There are two reasons for this. This first is that a mechanic has more technical know-how than the people from the office. The second reason is that a product must be tested by a mechanic and a mechanic writes a test report. When the testing and test report are finished, a meeting request is sent. So any technical faults are found during the testing, not by going through the checklist during the meeting.

The second check may find an error. This could be due to the customer changing their mind after the sales moment and once the product has been built. There is no earlier moment in the supply chain where this is checked. When the product does not meet the customer's specifications, new products must be ordered and the product does not leave the production floor. One customer specific supply is not needed in production and it is often too late. The customer buys the product drum and some additional parts which are needed for installing the drum at a TBM. When those additional parts are missing, the product is still not approved, but in fact the job of the mechanics has been completed successfully.

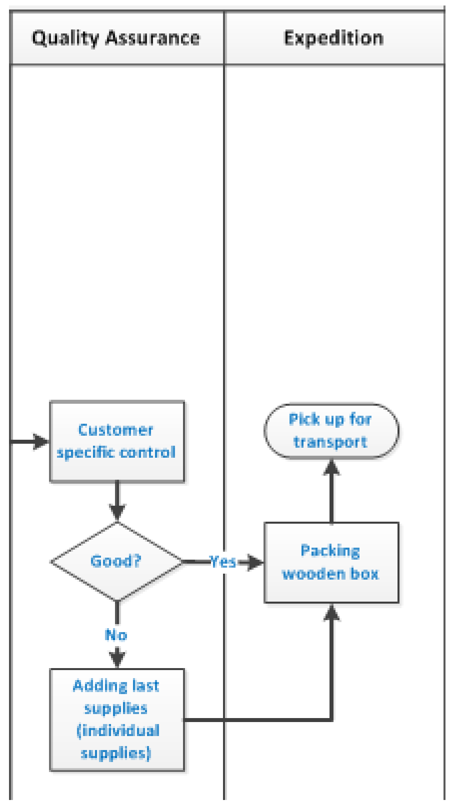
The KPIs for quality assurance are:

- Technical faults
- Customer specific faults.

The performance results for quality assurance are:

- Technical faults: there have been zero technical faults found over the last 3 years
- Customer specific faults: 20% of the orders are rejected, mainly due to missing one of the customer-specific supplies.

The quality assurance is done by a meeting of 4-5 people and takes a half hour, or sometimes even one hour. The technical check is effectively irrelevant because the test is already conducted by the mechanics; including a check on customer specific wishes makes sense. Rearranging the process of quality assurance is advised.



3.3.11. Department expedition

The process of expedition is simple in the case of a drum product. The drums are transported in wooden boxes and leave the production hall in the same wooden box. The expedition has just a few tasks left:

- Fill the box with packing material
- Close the box
- Weight the box

This process takes about half an hour and is not exciting. No time was spent analysing this process.

3.4. Summary

The current situation was analysed and the main points for improvement were found, or in other words, which key performances indicators (KPIs) were alarming, were identified.

An alarming KPI is the takt time and the correlating time spent doing non-value adding activities. The main reasons were the long delivery times of supplies and the errors. In both cases, the entire project comes to a standstill and waits for new supplies. The fact that every order is customer-based and the CODP is engineer-to-order makes for long delivery times and when an error occurs during production, it is a large problem. The current flow is as follows: An order is placed, an engineer starts the drawings, supplies are ordered, there is a waiting time for supplies of 55 workings days, an error can occur and on average the waiting time is another 30.44 days and finally the product is completed. The ratio between mean production time and takt time with one error is equivalent to 1: 27.34. Even when assuming no errors (which is a utopian dream); the ratio is still 1: 20.67. A frequently measured ratio is the industry is 1:3 or 1:4.

The next alarming KPI was inventory control. A ratio where the order cost is higher than the holding cost is interesting. The main reason for this ratio is that for every product the orders are placed separately. The current policy can be compared with an anonymous flow. The main advantage of anonymous flow would be a reduction of the takt time of 55 days. But is it profitable?

The warehouse process was not that alarming but each handling must be done for each order line. So a reduction of order lines will lead to a reduction of order handling.

Transport has two alarming points. The first is that goods are transported to another warehouse when a project is not complete. The second point is that some goods are travelling a logistic route that is redundant.

The production hall is more alarming. The main alarming point is that the capacity of the hall becomes a bottleneck at the end of the year. The main points of concern are: The number of errors are large and have a dramatic effect on production; the number of workplaces and their arrangement are not efficient but the quality of the mechanics is good because they are all experienced.

The quality assurance is done by a meeting of 4-5 people and takes half an hour or sometimes even one hour. The technical check is irrelevant because the mechanics already perform a test; the check on the customer specific wishes makes sense.

Overall it can be concluded that a number of alarming points continue to return. The combination of these is the main cause for a long takt time. These main causes are:

- The CODP of ETO
- The long lead time of supplies
- The errors (wrong quality or quantity)
- The inventory policy
- The production capacity.

4. Adequate situation

The research is defined, the theoretical framework is completed, the current situation is analysed and some alarming key performance indicators (KPIs) have been found. In the first chapter the research question was defined for this chapter: *What would be an adequate situation for the production of drums?*

Generating an adequate situation can be complicated, which is why some sub-questions are defined in order to realise an optimal solution in a structured way. The sub-questions are:

Sub3.1 What alternative solutions exist to possibly improve the performance?

Sub3.2 What are the advantages and disadvantages of each solution?

Sub3.3 Which solution applies best to VMI?

Based on the sub questions, it can be concluded that the simplified structure of this chapter will be.

- Generate alternatives
- Advantages and disadvantages of alternatives
- Selection of solution for VMI

The alarming KPIs found in the previous chapter will return. The KPIs were CODP, long lead-time, errors, inventory policy and production capacity. Long lead-time and errors in production are both external causes and are caused by the supplier. As discussed in the first chapter, those causes are excluded in this research. The three remaining KPIs are CODP, inventory policy and production layout.

The structure of the chapter is a combination of research questions and selected KPIs. The structure of this chapter is:

- Section 4.1 discusses the CODP
    - Generate alternatives
    - Advantages and disadvantages of CODP
    - Selection for VMI
- Section 4.2 discusses the inventory policy
    - Generate alternatives
    - Advantages and disadvantages of the inventory policy
    - Selection for VMI
- Section 4.3 discusses the production layout
    - Generate alternatives
    - Advantages and disadvantages of production layout
    - Selection for VMI
- Section 4.4 discuss the entire supply chain for drum production
    - Discuss all small changes to the merge solution for each department or process, it is a description of the implementation

At the end of this chapter, an adequate situation for the production of drums should be generated.

4.1. CODP

The topic of this section is the customer order decoupling point (CODP). The sub-questions are used in this section and the structure will be: a section on alternative solutions, a section outlining the advantages and disadvantages, and a determination of the best solution.

There are five different CODPs possible. The first CODP is engineer-to-order (ETO). This point is characterised by having no stock at all. The engineering, the ordering of materials, fabrication, assembly and distribution all takes places after a specific customer order is placed. It all depends on the specification of the customer and is often used for highly specialised products. The second is make-to-order (MTO). In this case, there are only raw materials and basic components in stock. Those stocks are based on the forecast, whilst all others stocks are based on customer demand. MTO is often used for small batches in metal industries, where the metal is in stock. The CODP assembly-to-order (ATO), has more stock. In that case, there are sub-assemblies, and modules are kept in stock. Only the final production is order-driven. The CODP make-to-stock (MTS), is completely forecast driven. Finished products are kept in stock at the end of the production process. The last CODP is delivery-from-stock (DFS). In this case, delivery is partly based on forecast. The goods are produced and distributed to a distribution centre that is located close to the customer. This is often done for goods with limited use-by dates, such as milk.

The five alternatives are:

1. ETO; engineer-to-order
2. MTO; make-to-order
3. ATO; assembly-to-order
4. MTS; make-to-stock
5. DFS; Delivery from stock

Some advantages and disadvantages have just been mentioned. The advantages and disadvantages of each option are often correlated. The criteria for scoring the disadvantages and advantages are:

- Certainty of order (risk); when the production is forecast driven, it can happen that an expected sale does not arise. There is a risk of an order being cancelled. Holding up production until the order is confirmed will reduce this risk.
- Degree of customisation; this is the level of customer specific wishes that can be realised or not. Producing a standard order which is an approach to the customer demand or producing exactly the customer specific demand.
- Production efficiency; if the production does not wait for an order, but produces at a fixed beat. The process can be arranged in an efficient way. This is the common trade-off between flexibility and efficiency.
- Service level efficiency; this is the degree to which a customer is satisfied. The difference between this and the degree of customisation is; customisation focuses on the product and to what degree the product meets the customers' demands. Whereas service level efficiency focuses on all secondary elements such as whether it was delivered in right quantity, the right quality, on time, with good packing etc.

- Speed of delivery; if a product is completed and waiting for a customer's demand delivery is faster than when a product must be developed, built and shipped.
- Holding cost; when product or sub-assemblies are kept in stock, the holding cost will increase.

In the first section, five alternatives are mentioned and the second section described six alternatives that represent the advantages and disadvantages. Each alternative is scored for each criterion. Those scores are shown in Table 4.1.

CODP	Certainty of order (risk)	Production efficiency	Service level efficiency	Degree of customisation	Speed of delivery	Holding cost
ETO	3	3	7	10	2	9
MTO	4	4	6	8	5	8
ATO	6	6	5	6	7	6
MTS	8	7	4	4	8	2
DFS	9	8	3	2	9	1

Table 4.1: Alternatives CODP and advantages and disadvantages for each alternative

The last sub-question involves determining the best solution for VMI. To select the best solution for VMI, a scoring method is used. To apply this method, the weights need to be determined. Which criterion is most important for VMI and which is not? Each criterion is discussed separately.

- Speed of delivery; the goal of this thesis is reducing takt time. Speed of delivery is correlated with takt time and therefore important. It gets the highest priority.
- Certainty of order (risk); the selected product family is stable for many years and the sales are currently increasing. Therefore, a major part of sales is secured and based on the stable demand; the forecasting error will be small. Finally, the customer-relation is often long term and they will not cancel an order quickly. The risk of cancelling is low at VMI and therefore this criterion is not so important for VMI.
- Production efficiency; VMI is implementing the lean principle. Projects lean 100 and lean 200 were finished in the past years and at this moment lean 300 is being introduced. Reduction of wastes and efficiency is important for VMI. And the production capacity becomes a bottleneck this year. Based on lean principles and the bottleneck, production efficiency is seen as important.
- Service level efficiency; this is important for every company but for VMI it is not special and therefore neither more nor less important.
- Degree of customisation; the product is customer specific and a customer orders a specific product. For that reason it is important, but the customer specific elements are not used in production, which balances the importance.
- Holding cost; as found in the current situation, the holding costs are higher than the ordering costs and the product family of this thesis is just a small part of an entire tyre building machine TBM. The holding costs are not the main problem for VMI, for this specific product family.

The main goal of this thesis is reducing takt time, so speed of delivery is the most important criterion. The drum product family is stable in demand and the certainty of risk is ranked with the lowest level of importance. The sequence of importance is as follows:

- Speed of delivery; weighted with a 10
- Production efficiency; weighted with a 9
- Service level efficiency; weighted with a 6
- Degree of customisation; weighted with a 6
- Holding cost; weighted with a 4
- Certainty of order; weighted with a 1

Based on the weight of the criterions and the scores of the alternatives on each criterion, the best option can be found according to a scoring method. The calculation of the best alternative is shown in Table 4.2.

CODP optimisation	Certainty of order (risk)	Production efficiency	Service level efficiency	Degree of customisation	Speed of delivery	Holding cost	Total score
Weight	1	9	4	6	10	4	
ETO	3	3	7	10	2	9	168
MTO	4	4	6	8	5	8	190
ATO	6	6	5	6	7	6	208
MTS	8	7	4	4	8	2	199
DFS	9	8	3	2	9	1	201

Table 4.2: Scoring of alternatives for CODP

A clear winner with a total score of 208 can be seen. The best solution for a CODP for VMI is assembly-to-order. With ATO, the CODP is moving towards the middle. The main characteristics are:

- Engineering does not wait on an order. The product is already designed.
- Purchasing does not wait on an order. The supplies are already ordered.
- Assemblage does wait for an order. Building a drum commences only after an order is received.
- Delivery does wait for an order (it waits on assembly).

A mathematical check is done for a sketched case, namely for one product. For one drum, the yearly demand is forecasted. Based on this forecast there were 3 options; the actual situation, the situation of supplies on stock (ATO) and the situation of making entire products on stock (MTS). The ordering cost and the holding cost were taken into account. This was a quick and dirty analysis but it showed clearly that a saving is possible. The calculation correlates with the next section and is not explained in this chapter, see results in Table 4.3

CODP	Takt time	Holding cost	Order lines	Total cost
ETO	84	€ 76,070.06	1300	€ 89,070.06
MTS	3< wdays <40	€ 49,807.78	1300	€ 62,807.78
ATO	3< wdays <40	€ 32,648.49	196	€ 34,608.49

Table 4.3: Results of a developed case

The CODP point ATO had the highest score; a quick analysis confirmed that a change of would likely result in a saving. So moving the CODP downstream in the supply chain will lead to a reduction of takt time, reduction of cost and the correlating reduction of order lines. The main advantage between make-to-stock and assembly-to-order is the fact that a lot of parts in a drum are the same. Having a stock of supplies (ATO) is useful when those supplies serve multiple products. When building end products (MTS), each of those multifunctional supplies is needed on stock. The multifunctional supplies in combination with ATO will lead to a lower value for holding cost. The practical conclusion is that the delivery time of supplies of 55 days is reduced to zero because the supplies are on stock and some supplies are already partly produced.

4.2. Inventory control

The inventory policy is detected as a cause of the high takt time. A change of inventory policy is probably going to generate an improvement. As discussed in the literature (Chapter 2), it does not make sense to apply inventory control for every bolt and nut. For that reason the ABC classification is done before the inventory models are applied.

4.2.1. ABC classification

The supplies of the drum are analysed and a list of different types of supplies is generated. The result was a list with 414 different supplies with a value between 0.024 and 1550 euro. The yearly demand varies between 2 and 30056. Based on the value and the demand, the yearly usage value was calculated. After sorting and selection of classes was done on the yearly usage value, the ABC classification resulted in:

- The A-items
  - 87 different type of supplies
  - Total yearly value of 3,681,048 EURO
- The B-Items
  - 87 different type of supplies
  - Total yearly value of 694,698 EURO
- The C-items
  - 240 different type of supplies
  - Total yearly value of 228,194 EURO

A comparison with literature can be made. Table 4.4 showed that the results confirm the literature and the other way around. The classification will be used by inventory models in the coming section.

	% of total number of SKU (literature)	% of total number of SKU (practice)
Group A	20%	21%
Group B	30%	21%
Group C	50%	58%
Total	100%	100%

Table 4.4: Comparison ABC of literature and practice

4.2.2. Inventory model

The ABC-classification is used to select the goods that are suitable for inventory control. The structure of this section correlates with the questions at the start of this chapter, which was; generating alternatives, advantages and disadvantages and the selection of an alternative.

The description of alternatives for inventory control is described in section 2.7.2, see Table 2.2. The alternatives were:

1. (*R,s,Q*): Review inventory position every *R* period and reorder the fixed quantity *Q* if inventory position drops below s.
2. (*s*, *Q*): Replenish when the inventory position drops below reorder point *s* and reorder fixed lot size *Q.*
3. (*R*,*S*): Release replenishment order every *R* period and the size of an order is such that the inventory position is raised to the *order-up-to* level *S.*
4. (*s,S*): Release replenishment order as soon as the inventory position drops below the reorder point s and *order-up-to* level *S*.

In the literature there are already 3 questions defined which are mentioned to choose the best alternative. Those questions are defined in section 2.7.2. Those questions will be used to select the alternative. The questions and relating answers are as follows:

How often should the inventory status be determined? The possible answers relate to either a continuous or a periodic review. The continuous review is more complete but the periodic review saves management time. The enterprise resource planning (ERP) system can apply a continuous control and cost no management time. For VMI, continuous control is the most suitable approach.
When should a replenishment order be placed? The options are ordering when the inventory drops below a determined level or ordering periodically. This question is related to the first question, it makes no sense to order periodically and review continuously. Thus, a continuous review and ordering based on inventory level is chosen as the most suitable approach for VMI.
How large should the replenishment order be? The options are a fixed or variable order quantity. VMI tries to buy order quantities that save money with order size, by matching the supplier's batch size et cetera. To keep those advantages, a fixed order quantity is preferred and the purchasing team specialises in ordering that way.

Based on the answers above and Table 2.2 in Chapter 2, it seems that the most suitable inventory policy for VMI is the (s, Q) policy. It is a commonly used policy for A and B items but for C items it could be overly complicated and so a waste of management time. The options for C items is to choose another policy or simplify the (s,Q) policy. The other options are still complicated so a simplified (s,Q) policy is chosen. See the results in table 4.5. The next paragraphs will start with the match needed for the policies and some critical views and checks.

	Inventory model VMI
Group A	s, Q policy
Group B	S, Q policy
Group C	Simplified S, Q policy

Table 4.5: Inventory models for VMI

VMI is currently ordering project-based. For each project a bill of material (BOM) is generated and those supplies are ordered in the required quantity. Changing an inventory position affects the entire company, not just purchasing. It also affects departments prior to purchasing. Making a change in product has consequences for the inventories. It has consequences for purchasing, but also for logistics and warehousing. Goods are received in different quantities, in different packages and at different times et cetera. It is hard to predict all consequences and calculate the exact financial consequences. An analysis, comparing the old and new situations is done in the next paragraph. Comparing those situations will find a breakpoint and will give an indication of the quantitative difference between the solutions outcomes. To prevent the reader from getting lost in the upcoming mathematics, this section starts with a “roadmap” that will serve as a guide to the reader.

Roadmap:

- ***Step 1.*** Calculations for order quantities and reorder points for groups A,B and C
- ***Step 2.*** Argumentation for the addition of the inventory policy for VMI
- ***Step 3.*** Uncertainties for VMI
- ***Step 4.*** What if the cost increases in the new situation?
  - ***Step 4.1.*** Definition of the current and future cost
  - ***Step 4.2.*** Definition of breakpoint of current cost and future cost
  - ***Step 4.3.*** Future costs are unknown, how to calculate?
  - ***Step 4.4.*** Apply the solution for the selected product family
- ***Step 5.*** What if the number of order lines decreases less than expected in the new situation?
  - ***Step 5.1.*** Addition of the current and future cost, add percentage order lines reduction
  - ***Step 5.2.*** Definition of breakpoint of current cost and future cost
  - ***Step 5.3.*** Applying mathematics to solve the breakpoint
  - ***Step 5.4.*** The solution visualized and explained
- ***Step 6.*** The conclusion

Step 1: *Calculations for order quantities and reorder points*

The inventory control is currently project-based. Almost all supplies are ordered individually and this results in a large number of order lines and a high cost of ordering. To prevent a waste of management time, the supplies can be classified with an ABC-classification. For the A and B items, an inventory control can be selected, this is (s,Q) systems. For the C items, the main target is to secure supplies and save management time. The categorisation of products is done on the basis of distribution by value curve alone; the categorisation was explained in Chapter 2.

The selected supplies are divided into 2 groups, based on the ABC-classification. The first group contains the A and B items and 95% of total annual euros usage. The last 5% contains the C items and represents 50% of the supplies. These supplies must be secured and management time reduced. The items are not large for the specific product family and they consist mainly of screws, schnors (small toothed ring that is fitted by screw) and O-rings.

The question of when to order remains. The material levels will be managed by the software and will be ordered when the inventory drops below a certain inventory level. Those items will be MRP-driven. The moment an order must be placed is called a reorder point, with parameter s. The reorder point includes the demand of the lead-time and a safety stock to prevent shortages.

$$Reorder\ point = s = \hat{x}_L + \ safety\ stock = \hat{x}_L + \ k * \sigma_L$$

The value of demand during lead time $\hat{x}_L$ is based on the forecasted yearly demand and the actual lead time. The assumption is made that VMI is producing 50 weeks per year. In the summer the production continues and the production stops only at Christmas (Except for showstoppers[4]).

$$\hat{x}_L = \frac{yearly\ demand * lead\ time}{5 * 250}$$

The variation of the demand can be estimated with a simple rule according to Silver, Pike and Peterson (Silver, Pyke, & Peterson, Inventory Management and Production Planning and Scheduling, 2007). For VMI, there is less variation in demand. The product is not related to trends and the demand shows a stable growth year on year. When an order is placed, the order is planned over a longer time period. This reduces the variances. This variance is estimated with the next formula.

$$\sigma_L \approx \sqrt{\hat{x}_L}$$

Specified Fraction (P2) of Demand to Be Satisfied Routinely from the Shelf – Fill Rate
(Silver, Pyke, & Peterson, Safety Stocks Based on Minimizing Cost, 2007)

The last unknown parameter is k. The safety factor depends on normal distribution and a decision rule. The rule applied for VMI is fill rate P2 which can be seems like a supermarket. A supermarket may not be empty, the shelf must be filled. The percentage of time that the shelf is filled is named the fill rate. Based on the supermarket idea, fill rate is defined as: Fill rate is defined as the fraction of time that a bin is filled. For VMI is chosen for a high fill rate of 99%. The reason is financial. If a drum is not finished on time, an entire tire building machine (TBM) could not be completed. A project of million gets a standstill, the ratio of cost of drum versus cost is around 1:500. And a standstill would make that 40 mechanics have a stand still. A shortage of product leads to high WIP value and lot of labour cost which are unnecessary. The safety factor k is found with formula of fill rate P2.

$$1 - p2 * \left(\frac{Q}{\sigma_L}\right) = G(k)$$

It results in the value of G (k), which represent the normal loss function. This can be looked op in a table, see appendix A.10. Now the value of k can be put into the reorder point formula.

[4] A showstopper is a planned production order which will be finished too late without adjustments.

$Reorder\ point = s = \hat{x}_L + \ safety\ stock = \hat{x}_L + \ k * \sigma_L$

The reorder point can be found for A, B and C items in this way. Now the order quantities must be determined. Inventory control would cost mainly management time. For that reason a simple inventory control rule is applied for each C item - namely that the goods are ordered for a demand of 3 months. 3 months is chosen as that timescale is consistent with new releases from engineering. There are no difficult calculations for order quantity; order quantity has the parameter Q and the following formula is used:

$Prespecified\ order\ quantity\ for\ C - items = Q = \ 0.25 * yearly\ demand$

The inventory position for C items is calculated using the following formula. For C items the reorder point s and the order quantity Q are found. For the A and B items, the reorder point is calculated in the same way but the reorder quantity is yet unknown.

The order quantity could be calculated using the formula for economic order quantity. The formula in that case would be based on the following parameters:

A= the fixed cost component incurred with each replenishment

D= the demand rate of the item in units per year

v= the unit variable cost of the item, not the selling price but the value in Euros

r = inventory carrying charge, the cost of having 1 Euro of the item tied up in the inventory for a year. In € /€ / year

$$Prespecified\ order\ quantity = Q \ = \sqrt{\frac{2AD}{vr}}$$

***Step 2:**. Argumentation for addition and an addition of the inventory policy for VMI*

A critical note can be made on this formula; the amount of a supply is different for each drum. It can, for example, be 4, 92, 96 or 118. Applying the formula, it uses the yearly demand, which can be approximately 3500 for example. The order quantity can be 91 for example and this is not optimal. The use of supply is smaller than the refill, in most cases two refills are needed for building one machine. That would mean that even more orders are placed than is currently the case. An adaptation of the formula is needed to order a minimum quantity that is larger than the amount needed for one drum. To determine the different quantities that are possible for a drum, an analysis is done for the product family and the minimum, maximum, average and median values are calculated. The economic order quantity (EOQ) formula is adjusted with the median.

$$Economic\ order\ quantity\ VMI = Q \ = maximum \left\{ median\ needed\ quantity \middle| \sqrt{\frac{2AD}{hr}} \right\}$$

***Step 3:** Uncertainties for VMI*

This formula could be applied but there are two critical notes:

- In 2008 there was an analysis of department data management control (department DMC) and a project group for the value of parameter A (parameter A = the fixed cost component incurred with each replenishment) the outcome of department DMC was a value of € 6.14 (Nauta, Have, &

Mennink, 2008). The outcome of a project group was € 9.40. (Nauta, Have, & Mennink, 2008). In 2013 an analysis of inventory control offered a value for order cost of € 10 (Steenwoerd, 2013). The conclusion is that here are 3 different values for parameter A. An acceptable conclusion is that the fixed cost component falls somewhere between € 6 and € 10. There is not one value for parameter A that is certain and that can be applied for calculations.

- Based on the argument above, the value of parameter A is uncertain. A change of inventory policy from project-based to an anonymous flow will influence the entire company. VMI has always produced on project-base, but due to its growth it is now more appropriate to consider ordering in larger quantities. A change from project-based to anonymous flow inventory policy will also influence the fixed cost component.

Step 4: *What if the cost increases in the new situation?*

The uncertainty of the exact value of parameter A and the uncertainty due to the change of policy led to the decision to carry out a sensitivity analysis. The goal of the sensitivity analysis was to answer the following question: *What if the order cost increases in the new situation?*

Step 4.1: *Definition of the current and future cost*

The current cost and future cost are dependent on the type of flow. The current flow is based on project based ordering and the future flow is based on an anonymous flow of goods. The definition of the cost can be seen in the next paragraph and will start with the parameters for current and future cost:

$A_{current} = The\ total\ order\ cost\ with\ the\ current\ situation$

$A_{Anonymous} = The\ total\ order\ cost\ with\ the\ future\ situation\ of\ an\ anonymous\ flow\ of\ supplies$

The main advantage of an anonymous flow is a reduction of the number of order lines. You buy 5 goods at once instead of 1 unit of goods on 5 separate occasions. There are possible savings brought about by buying larger amounts and creating fewer order lines. There will be a higher cost due to higher holding costs. Therefore, there are no obvious cost advantages of adapting an anonymous flow. The following costs are independent of the distinction between anonymous flow and current flow.

B = Delivery cost per order line
C = Registering of received goods per order line
D = Cost of transportation to place of storage per order line

Some costs will change due the new policy. The following costs are applicable to the anonymous flow and the current flow.

E = Holding cost per order line
F = Order picking per order line
G = Risk of out-dated goods per order line;
H = Risk related to transportation per order line

It is not certain how those cost will change but the there are some expectations.

The holding cost per order line will change due to different storage policies and different storage locations. It is estimated that the cost of the storage location will be similar to that at present. The storage policy means more stock held for longer periods causing an increase in costs. The expectation is that the holding cost will increase.

$E_{current} \leq E\{E_{Anonymous}\}$

T*he cost for order picking will change due to different management and different handling of anonymous flow. Multiple items will be delivered using a 2 bin system and this will reduce the cost of order picking.*

$F_{current} \geq E\{ F_{Anonymous}\}$

The cost of the risk of outdating will change due to different time periods of inventory. The expectation is that the larger inventories will lead to a higher risk of out-dated goods. The cost for the risk for each order line will increase.

$G_{current} \leq E\{G_{Anonymous}\}$

The cost of the risk of transportation will change due to different routing and quantities. In general we may expect that the cost will decrease. Larger amounts will be transported and that means fewer journeys which will mean fewer cases of damage. But the value of damages will increase due to the fact that more goods are transported on each journey. Arguments for higher and lower cost are available. The expectation is that the saving will negate the extra costs so creating an overall decrease in costs.

$H_{current} \geq E\{H_{Anonymous}\}$

Now the costs are defined for each order line, but the total number of order lines for each policy is different. The number of order lines is defined with the next parameters:

X = Number of order lines used by the current policy
Y = Number of order lines used by the anonymous policy

The anonymous policy optimizes the amounts ordered. The new policy will lead to a reduction of the number of order lines due to the ordering of larger amounts. The number of orderliness will decrease.

$X \geq Y$

The cost can be defined by multiplying the number of lines by the cost per line. In mathematical form it looks like this:

$A_{current} = x\ (B + C + D + E_{current} + F_{current} + G_{current} + H_{current})$

$A_{Anonymous} = y\ (B + C + D + E_{Anonymous} + F_{Anonymous} + G_{Anonymous} + H_{Anonymous})$

Step 4.2: *Definition of breakpoint of current cost and future cost*

The question was: what if the cost increases? This can be answered by finding the breakpoint between current cost and future cost (cost with an anonymous flow). In which case are the costs of both situations equal? The breakpoint is defined as followed:

$A_{current} = A_{Anonymous}$

The breakpoint can be defined as:

$$x\ (B + C + D + E_{current} + F_{current} + G_{current} + H_{current}\ =\ y\ (B + C + D + E_{Anonymous} + F_{Anonymous} + G_{Anonymous} + H_{Anonymous}\ )$$

Step 4.3: *Future costs are unknown, how to calculate?*

Comparison between current and future cost contains a lot of unknown parameters, because all anonymous parameters are unknown and can only be estimated. Estimation should be based on the current policy plus the value of any change. This change is unknown and can be positive or negative. The difference is defined as delta. The definition is:

$$\delta_E =\ E_{current} - E_{Anonymous}$$
$$\delta_F = F_{current} - F_{Anonymous}$$
$$\delta_G =\ G_{current} - G_{Anonymous}$$
$$\delta_H =\ H_{current} - H_{Anonymous}$$

Al those formulas can be reformulated:

$$E_{Anonymous} =\ E_{current}\ +\ \delta_E$$

Substitute the anonymous parameter in the comparison.

$$x\ (B + C + D + E_{current} + F_{current} + G_{current} + H_{current}\ =\ y\ (B + C + D + E_{current}\ +\ \delta_E + F_{current}\ +\ \delta_F + G_{current}\ +\ \delta_G + H_{current}\ +\ \delta_H\ )$$

Reformulating:

$$x\ (B + C + D + E_{current} + F_{current} + G_{current} + H_{current}\ -\ y\ (B + C + D + E_{current}\ +\ \delta_E + F_{current}\ +\ \delta_F + G_{current}\ +\ \delta_G + H_{current}\ +\ \delta_H) = 0$$

$$(x - y) *\ (B + C + D + E_{current} + F_{current} + G_{current} + H_{current}) -\ y\ (\ \delta_E +\ \delta_F +\ \delta_G +\ \delta_H\ ) = 0$$

Reformulate the previous formula in words:

$$Reduction\ of\ order\ lines *\ \ Current\ order\ cost - n\ number\ of\ order\ lines * change\ \ order\ cost$$
$$Saving\ due\ to\ new\ order\ policy - extra\ cost\ due\ to\ new\ order\ policy = 0$$

Step 4.4: *Apply the solution for the selected product family*

For the chosen product family, the number of actual order lines is known and the future number of order lines is estimated with an educated guess. The results were that x equals 7476 and y equals 2026. A sensitivity analysis was carried out based on those numbers and those results can be found in appendix 9.A. The result is that when the current policy is 6 euro, an extra cost of 16 euro is allowed per order line. This solution depends on the number of order lines and a reduction of order lines. But what if the reduction of order lines is less than estimated? To answer this question, a second sensitivity analysis is carried out.

Step 5: *What if the number of order lines decreases less than expected in the new situation?*

The reduction of order lines is expressed in a number. A reduction of 100 order lines is significant when the current number is 120 but negligible when the current number is 1 million. For this reason the sensitivity analysis starts with reduction of order lines in percentage steps. At this moment the number and not a percentage of reduction, of order lines is defined. The percentage reduction can be found based on the number of order lines. Before expressing the percentage reduction, the mathematics starts with an important assumption. Namely that x exceeds y. Without this assumption there is no reduction but an increase of the number of order lines.

$Restriction: x > y$

Step 5.1: *Addition of the current and future cost, add percentage order lines reduction*

Define a new delta, the difference in number of order lines between the new and old policies.

The percentage reduction of number of order lines can be defined as:

$$Percent\ reduction\ of\ number\ of\ order\ lines = \frac{x-y}{x} = \frac{\delta_{xy}}{x}$$

Step 5.2: *Definition of breakpoint of current cost and future cost*

The breakpoint formula in the previous section contained the number of order lines and this needs to be reformulated to contain percentage reduction of order lines. This is done by substituting the new delta in the breakpoint which rewrites the formula as:

$$\delta_{xy} * (B + C + D + E_{current} + F_{current} + G_{current} + H_{current}) - y(\delta_E + \delta_F + \delta_G + \delta_H) = 0$$

$$y(\delta_E + \delta_F + \delta_G + \delta_H) = \delta_{xy} * (B + C + D + E_{current} + F_{current} + G_{current} + H_{current})$$

$$(\delta_E + \delta_F + \delta_G + \delta_H) = \frac{\delta_{xy} * (B + C + D + E_{current} + F_{current} + G_{current} + H_{current})}{y}$$

$$(\delta_E + \delta_F + \delta_G + \delta_H) = \frac{\delta_{xy}}{y} * (B + C + D + E_{current} + F_{current} + G_{current} + H_{current})$$

Step 5.3: *Applying mathematics to solve*

The comparison formula is rewritten but the input factor, percentage reduction of order lines is not yet found. An unknown ratio is found and it is shown that the unknown ratio is blocking the sensitivity analysis. Applying some mathematics will find the value of the unknown ratio. The basic mathematics used can be found in the appendix A.7.

$$unknown\ ratio = \frac{\delta_{xy}}{y}$$

Recall from new delta, that the value of y equalizes:

$$y = -\delta_{xy} + x$$

Substitute y in the formula of the unknown ratio;

$$\frac{\delta_{xy}}{y} = \frac{\delta_{xy}}{-\delta_{xy} + x}$$

Rewrite the previous formula:

$$\frac{\delta_{xy}}{-\delta_{xy}+x} = \frac{\frac{\delta_{xy}}{x}}{-\frac{\delta_{xy}}{x}+\frac{x}{x}} = \frac{\frac{\delta_{xy}}{x}}{-\frac{\delta_{xy}}{x}+1} = \frac{\frac{\delta_{xy}}{x}}{1-\frac{\delta_{xy}}{x}}$$

Recall that:

$$\%\,reduction = \frac{\delta_{xy}}{x}$$

Substitute the percentage reduction in the rewritten unknown formula;

$$unknown\ ratio = \frac{\delta_{xy}}{y} = \frac{\frac{\delta_{xy}}{x}}{1-\frac{\delta_{xy}}{x}} = \frac{\%\,reduction}{1-\%\,reduction}$$

Substitute the unknown ratio in the comparison formula for the sensitivity analysis.

$$(\delta_E + \delta_F + \delta_G + \delta_H) = \frac{\frac{\delta_{xy}}{x}}{1-\frac{\delta_{xy}}{x}} * (B + C + D + E_{current} + F_{current} + G_{current} + H_{current})$$

$$Output\ of\ the\ sensitivity\ analysis = input\ \%\,reduction * input\ current\ cost\ per\ orderline$$

***Step 5.4:** The solution visualized and explained*

A comparison with all known parameters at the right side is known. Now the sensitivity analysis can be applied. The input of the sensitivity analysis is the current cost per order line and the percentage reduction. The output of sensitivity analysis is the extra cost that is allowed for the new policy. The results of the sensitivity analysis are presented in Table 4.6 and Figure 4.1.

	-10%	-26%	-42%	-58%	-74%	-90%
1	0,11	0,35	0,72	1,38	2,85	9,00
2	0,22	0,70	1,45	2,76	5,69	18,00
3	0,33	1,05	2,17	4,14	8,54	27,00
4	0,44	1,41	2,90	5,52	11,38	36,00
5	0,56	1,76	3,62	6,90	14,23	45,00
6	0,67	2,11	4,34	8,29	17,08	54,00
7	0,78	2,46	5,07	9,67	19,92	63,00
8	0,89	2,81	5,79	11,05	22,77	72,00
9	1,00	3,16	6,52	12,43	25,62	81,00
10	1,11	3,51	7,24	13,81	28,46	90,00
11	1,22	3,86	7,97	15,19	31,31	99,00
12	1,33	4,22	8,69	16,57	34,15	108,00
13	1,44	4,57	9,41	17,95	37,00	117,00
14	1,56	4,92	10,14	19,33	39,85	126,00
15	1,67	5,27	10,86	20,71	42,69	135,00

Table 4.6: Results of sensitivity analysis

The meaning of the table can be shown by using an example. Take the left-upper corner. Take an order cost of one dollar and a reduction of number of order lines of 10 per cent. The corresponding value is 0.11. The meaning of this number is:

- When the cost per order line increases with 0.11, the new and old policies are exactly the same.
- When the increase of cost per order line is smaller then 0.11, the new policy is advantageous.
- When the increase of cost per order is larger than 0.11, the old policy is advantageous.

Each value can be interpreted this way. The current order reduction was 74%; the extra costs that are allowed depend on the cost. When the value of 6 is true, the allowed increase per order line is 17.08.

If the reduction of number of order lines is less, the allowed increase of cost per order line is also less. It can be explained as follows: When less order lines are saved, fewer savings are realized and fewer extra costs are allowed. Suppose the estimate reduction of 74% drops to 58%, the allowed increase of cost per order line decrease from 17.08 to 8.29. The table does not show all possible values; these are shown in Figure 4.1.

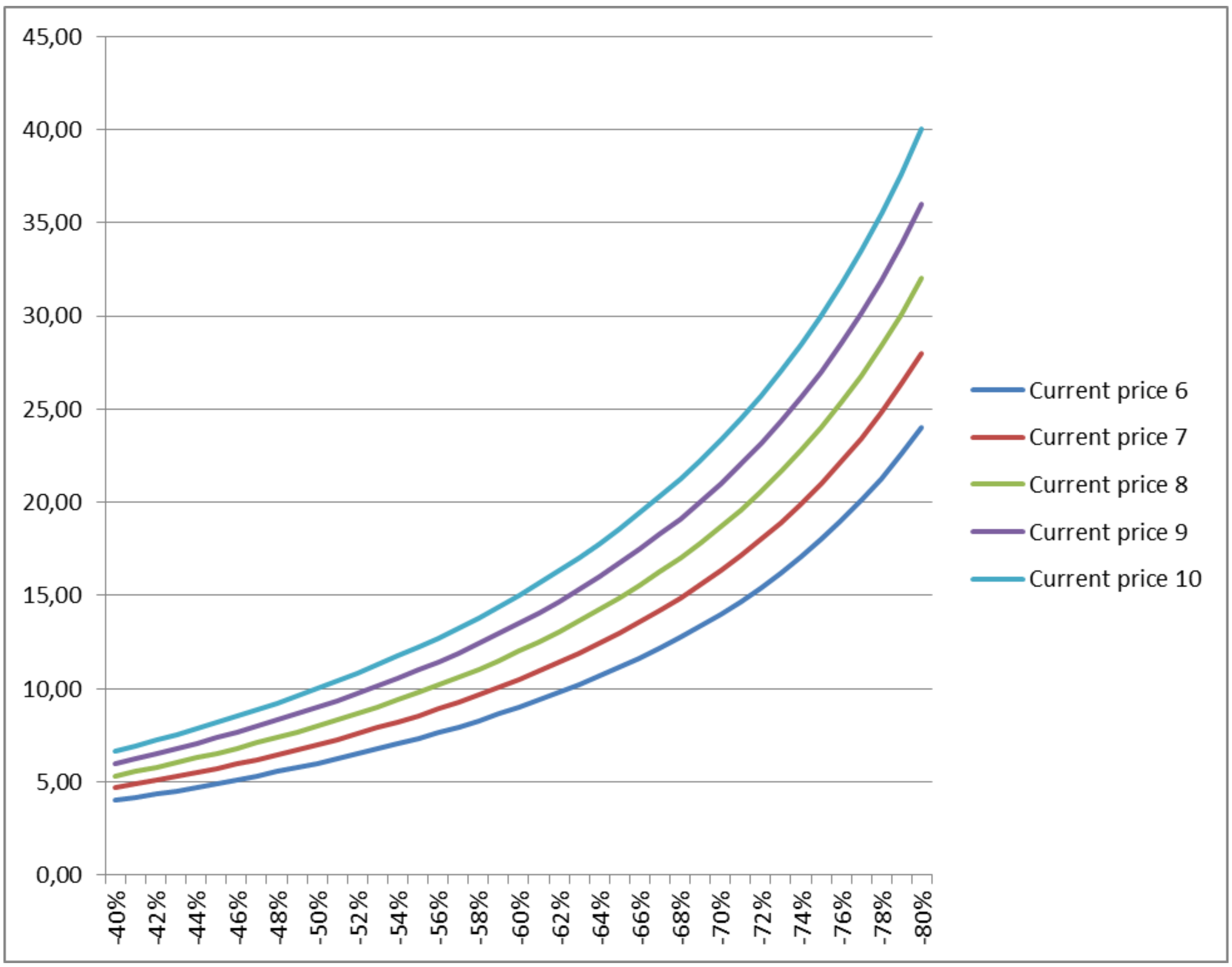


Figure 4.1: Results of the sensitivity analysis

Step 6: Conclusion

The value of the cost is not certain. The value of the future cost is even more uncertain and the reduction of order is estimated. What if the future situation is worse? We can imagine a worst-case scenario and determine whether the new inventory policy would still be advisable. The expected situation is a cost of 10 euro (based on most recent research) and an order reduction of 74 %. This means that a cost increase per order line of 28.46 EURO is allowed before the new order policy is rejected. This margin is sufficient but what if the order cost is 6 euro and the cost reduction is 58%? In this case a cost increase per order line of 8.29 euro is allowed. This margin is sufficient but the margin shrinks. But suppose that the current order cost is 4 euro and the reduction is 42%, in that case the allowed increase per order line is 2.90 euro. The chance that the costs per order increase with more than 2.9 euro (and the old policy is better, that chance is small.

In conclusion, the new inventory policy is always positive because it is assumed that a reduction of order lines is always reached. The new inventory policy is an improvement; the breakpoint depends on the additional cost per order line. Supposing that reduction and current costs are less than expected; there is still an 8.29 euro margin.

4.3. Production layout

The production layout was not structured and the workplaces were different. These were the reasons to redesign the production. Redesigning the production can be done in one of two ways: Choosing one of the common layouts or using system layout planning (SLP). The common layouts are used to and a number of practical restrictions will be used by designing a new production layout. This paragraph starts with the four alternatives and their advantages and disadvantages.

Type	Advantage	Disadvantage
Fixed position	• Very high mix and product flexibility • Product or customer not moved or disturbed • High variety of tasks for staff	• *Very high unit cost* • Scheduling of space and activities can be difficult • Can mean much movement of plant and staff
Process	• High mix and product flexibility • Relatively robust in the case of disruptions • Relatively easy supervision of equipment or plant	• Low facilities utilization • Can have very high work-in-progress or customer queuing • Complex flow can be difficult to control
Cell	• Can give a good compromise between cost and flexibility for relatively high-variety operations • *Fast throughput*	• Can be costly to rearrange the existing layout • Can need more plant and equipment

	• Group work can result in good motivation	• Can give low plant utilization
Product	• Low unit cost for high volume • Gives opportunities for specialization of equipment • Materials or customer movement is convenient	• Can have low mix flexibility • *Not very robust if there is disruption* • Work can be very repetitive

Table 4.7: Advantages and disadvantages for production layouts (Slack, Chambers, & Johnston, 2007)

Before drawing the layout, a look is taken at the location. The selected production hall is 18 meters by 35 meters long. In the middle is a wall with a large opening. There are two doors for moving in and out. The restriction of walls is visualized in Figure 4.2.

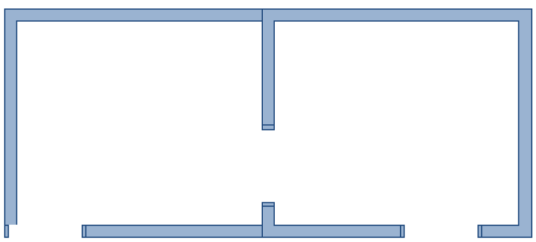


Figure 4.2: The basic layout production hall (18 by 35 meters)

The current layout is seen. A second restriction is that the left entrance is blocked by an entire tire building machine (TBM) building in the adjacent hall. The building blocks are assigned for building a tire building machine. Changing that layout for using two doors would lead to the loss of an entire station for the production of TBM. Capacity for building TBM is already rare (even short and hiring external locations) and the value of a TBM is much higher than the selected product family drum. For these reasons the moving of a TBM is not possible meaning there is only one opening left.

There are four common layouts. The first option in mind is the product layout. The reason for this is that the product contains a lot of standard elements. This product layout is not chosen because the product is too complicated, mainly because it is pneumatic. It is important that the product is good but not easy due pneumatic. An example is when rings are moved within each other and both sides are greased with a brush. When a hair from the brush gets into the grease, the testing will give an error. The testing is done with a pressure of ten bars. The mechanic is responsible for building the drum. When he makes an error he needs to correct it himself. This means that the mechanic works precisely. This contributes to the argument in favour of keeping drum production the responsibility of one mechanic rather than dividing it. A product layout as above would split the task of building a drum. Of course, it is possible to split it up but when mechanics become slightly nonchalant the error will increase mainly because it is no longer clear who made the error. In conclusion, a product layout is possible but it is expected that the production errors will arise when choosing one. A Chinese colleague was cycling in the Netherlands and was ill the day after due to the bad weather. He spoke the magic words: "*The process was good; the* *result is not so good"*. The same result is expected as choosing a product layout will mean an increase of errors. It matches with the disadvantages of not very robust if there is a disruption of a product layout.

There are three remaining layouts, namely fixed position, process and cell. A fixed position layout is not an option because it is only relevant for large items (such as TBM at VMI). For smaller items the costs of such a layout are too high. A fixed position layout generates more flexibility and variety of tasks, which leads to higher costs. The remaining options are process and cell layout.

When choosing between process and cell layout, cell layouts are deemed superior. The main reason for this is the faster throughput of a cell layout. Sub arguments are the compromise between cost and flexibility of cell layout and the disadvantages of high work in process and complex flow of a process layout.

The selected layout is a cell layout. A cell must be designed. Before designing, a list is generated comprising the parts that the mechanics deem absolutely necessary. By consulting the mechanic we decided what was absolutely necessary:

- Rack, a rack with bolt and nuts and other small items
- Toolbox, a box with tools like wrenches, screwdrivers etc.
- Working bench, a table for assembling small parts
- Movable working bench, a movable table for assembling the drum
    - Drawing (pc), a drawing of the product that must be assembled. Currently hard copy, soon to become digital

The layout started with these four elements. First one cell was designed. The rack, toolbox, pc and working bench all have a front and back. The mechanic needs only that the front and the back can be put against a wall. The movable working bench is needed everywhere. (The final product is round and the mechanic needs to work at every side). That is the reason that the movable table is put in the middle. One cell was designed but the working space was not sufficiently big. A combination of two cells means that mechanics have a common space but the space increases directly. The path between two cells can be used by both mechanics and the middle space for both mechanics doubles. The idea of a cell becomes less isolating for the mechanics. A combined cell is even better against the feeling of being locked up.

An alternative was a production layout with a production island. The product moves around the island and the supplies encircle the island. We saw this idea at SEW when looking for alternatives. A first drawing of the product and related handling represented as a circle was made. The necessary supplies were added in the circle, at the outside and inner side is tried. The first drawings revealed that this alternative used too much space and that it was not possible to store large items around the island.

Another idea was a production line with the small supplies behind the working bench and the larger supplies behind the mechanic. The large items can be delivered in this way, solving the problem encountered with the production island. Generating multiple lines would mean problems with the wall in the middle of the hall, the resistance from the mechanics would be very high and the number of errors would be expected to increase.

The final layout became a cell layout, visualized in Figure 4.3.

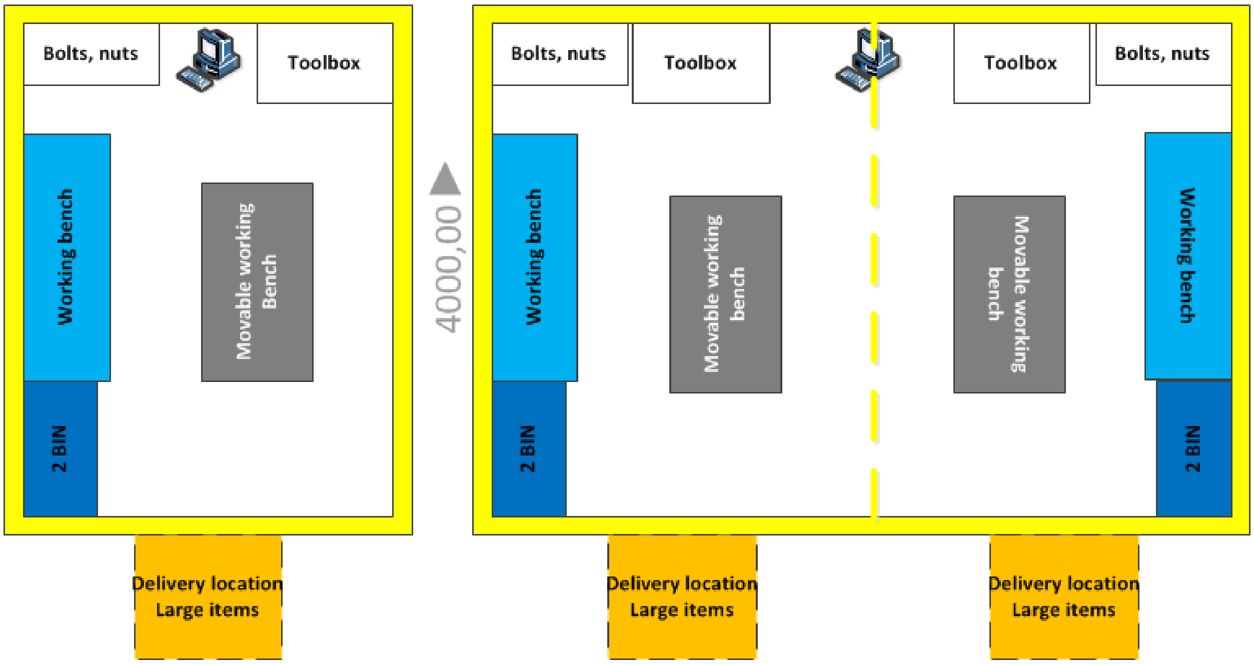


Figure 4.3: The designed cell layout. On the left a single cell of 4 by 3 meter, on the right a double cell of 4 by 6 meters.

The application of this layout is compared with multiple alternatives. The alternatives were different layouts like project based process and product layout. Practical comparison is made with assembly lines and Production Islands. The new setting will standardise the process and give insight into the process.

4.4. Merging Solutions

The main causes are analysed and solved in the first paragraph. How to combine those solutions and what does the final solution look like? This paragraph will discuss the entire supply chain process step by step. Some departments will barely notice the changes.

4.4.1. Department sales

The Sales department does not have large changes. The technical questionnaire remains the same for the sales department. Only a few changes are made:

- The technical questionnaire gets an additional rule that a standard drum can be delivered in 8 weeks.
- The technical questionnaire is adapted in such a way that not all options are available. Some options are excluded and a standard is defined in this way. A non-standard drum will be bought, but sales will not by using the technical questionnaire and the purchase becomes a special.
- Sales is tasked to use the takt time reduction to increases sales and to stimulate the sale of a standard drum, mainly when the differences between standard and specific are very small.

These are the concrete changes for sales. The short lead time and the promotion of the standard drum will lead to an increase of sales of drums, particularly of standard drums. The expectation is that a clear group of standard drums will grow to dominate sales. The variation in product family will decrease.

4.4.2. Department operations control

The working of the Operations control department does not change radically. The main difference is for the planning. Normally the planning is done for the long term. The planning department is planning the start of production 10-12 weeks in advance and the planned finished date is further ahead still. This generates flexibility in the planning but the planning performance is not outstanding. The planning for this product family will become short term and the principle stays the same. Though a reduction of flexibility is realized, it is easier to oversee this planning. In conclusion, the planning changes but the changes are not radical or significant.

4.4.3. Department engineering

The engineering department did change. The current engineering department exist of 250 people. To generate high standards a select group of engineers is chosen to engineer the drum. When every engineer can draw the product, small differences can appear. For example, drawing a bolt to hold something but not differentiating between an M4 or M5 bolt. The change is applied and now only four people are allowed to change or draw the product family drum.

A long-term project is started in the engineering department. In response to this project a standardisation project is started at the engineering department. The customer specific parts can be of every value but a few values are often used. A Pareto result is expected, in other words, it is expected that with 20% of the option, 80% of the demand will be fulfilled. The project at engineering is monitoring the customer specific parts and reduces the variance in customer specific parts. The main options are generating stock of the parts or reengineering the drum to reduce customer specific parts. Both options are estimated to be realistic.

The last change at engineering is that all supplies that are needed for a drum are frozen. This means that an engineer cannot change a supply of a drum. There were two options:

- The first options was using a “work flow status” in the engineer’s software
- The second option was using a “s-code” in the software
-

The advantage of the first option was that it could automatically generate mails if a supply (the drawing of a supply) had to be changed. The advantage of the second option is that VMI is already using it. The first option was advised but the second option was implemented.

The engineering department assigned four people as responsible for the engineering of a drum, started a long -term project for standardisation and froze the supplies for a drum.

4.4.4. Enterprise resource planning system "Infor"

The software must be changed for an anonymous flow of goods. (Argumentation for anonymous flow of goods was in section 4.2). The ERP-system must be adapted for this new situation. First the options will be shown in Figure 4.4.

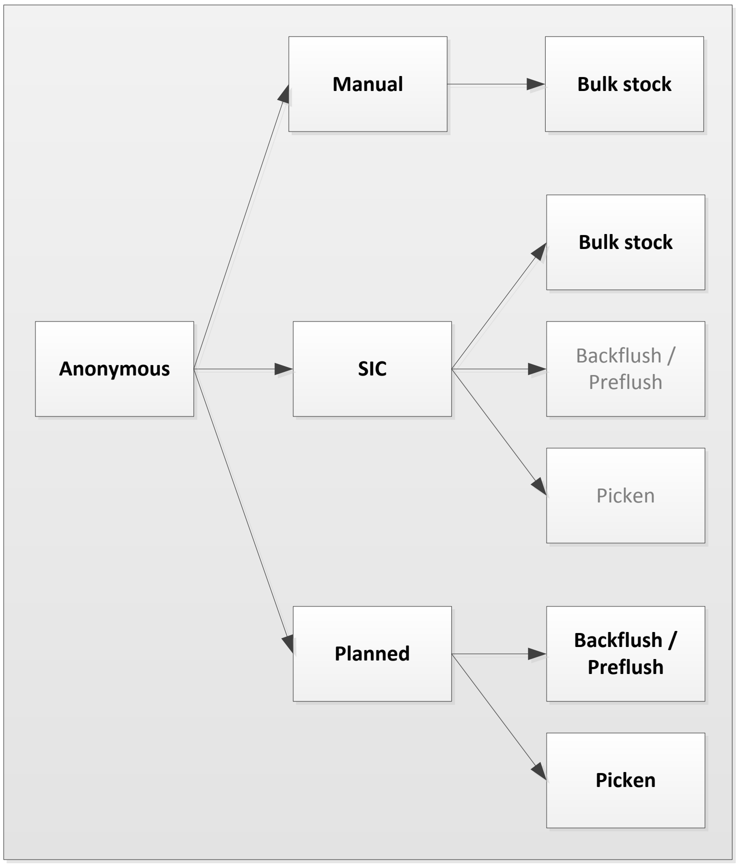


Figure 4.4: Options of ERP for anonymous flow

Figure 4.4 shows the different options, but what are the differences? The main decision points that make the difference were;

- Handling (should people scan, count the quantities)
- Assigning of cost (are the costs assigned to a project or not)
- Inventory control (does the insight of inventory remain or not)

Based on those points, you want to minimize the handling. But restrictions are found in the assigning of cost and knowledge of inventory level.

- When buying a pen, the assigning of cost can be booked on a common code like "office supplies". But booking the entire product on such a code would mean that in a year about 10 million euro is booked on a common code. The assigning of cost is desirable.

- The inventory level of pen is not dramatic if there is a small deviation. But the estimated inventory is about 800,000 euro. For this amount, it is likely to know your inventory level. So knowing how much inventory there is on a certain moment of time.

Based on those trade-offs of minimizing handling and knowing and assigning inventories, the following decision is made, see Figure 4.5. (The ERP decisions are written in red)

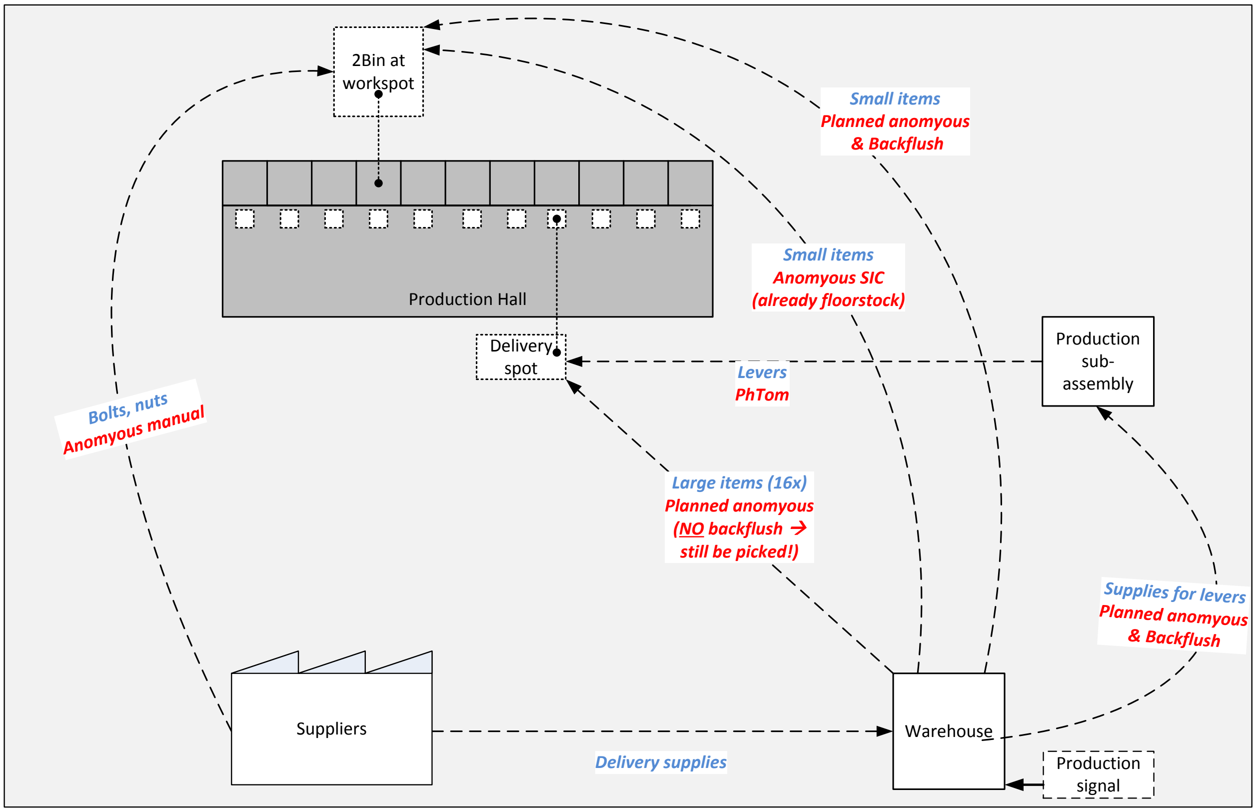


Figure 4.5: Decisions for the ERP-software to create anonymous flow

The options discussed earlier are shown in figure 4.5. A remarkable line is the line of levers with code "PhTom". That code is not discussed. That line is an intern transport, but for the ERP-software nothing changes and for that reason the line does not exist for the ERP-software. This is the meaning of "PhTom".

4.4.5. Department work preparation

The work preparation department does not change that much. The only change is that a preference is made. When this department is working on a complete tyre building machine (TBM), it takes several days and the waiting time can be long. The standard drum is 5 to 10 minutes work. The decision is made that a drum is booked at the beginning or end of the day and the time that the work preparation department needs is a maximum of 24 hours.

4.4.6. Department purchasing

The purchasing department needs to deal with the new inventory control. That is a change that is discussed in section 4.2. The change of policy is the main change. Two correlating changes were the updating of lead-time and application of the new forecast. The lead-time is updated in the software because that influences the amounts that are bought. The forecast is used to prepare the suppliers on the coming order and prevent a shortage.

4.4.7. Department warehouse

The warehouse is currently storing mostly on order and will receive anonymous goods for this project. Currently there are anonymous goods but those are small items with small value which are mainly stored in the lean lift. Larger items will arrive in the warehouse and will be stored in the warehouse. Those will be stored all together in the warehouse. A location is made available and those will be stored together. The number of products and the size of products in the warehouse will increase slightly. But the process of warehousing is not changed. For the warehouse, which needs to bridge the interval between the moment goods are received and the moment that they are needed, there will not be significant change.

4.4.8. Process transport

The transport process is changed. A few comments are made to prevent misunderstandings.

- There are three locations: supplier, warehouse and production hall.
    - The production of subassemblies is done in the production hall but in the corner. (A dedicated and closed room)
    - The storage hall is no longer used in the solution.
    - The expedition is in the warehouse

The flows will be realized as in Figure 4.6. Explanation notes by the Figure 4.6.

- The small items will be delivered to the 2bin at the work station. The 2 bin was visual in the cell layout in Figure 4.3. The bins will be mostly filled by the VMI (internally) and one supplier will manage a part of the 2bin. This is a form of supplier integration.
- The large items will be delivered in a separate way, discussed at page 60
- Some product are delivered to another production group, they will do a simple subassembly
- Not all products are needed in production. The delivery of a drum contains a drum, a set of tools for installation and customer specific products. Those products were always delivered at production hall but are no longer transported. The flow of supplies that are no longer needed in production is visualized in Figure 4.7. A saving on internal transportation costs.

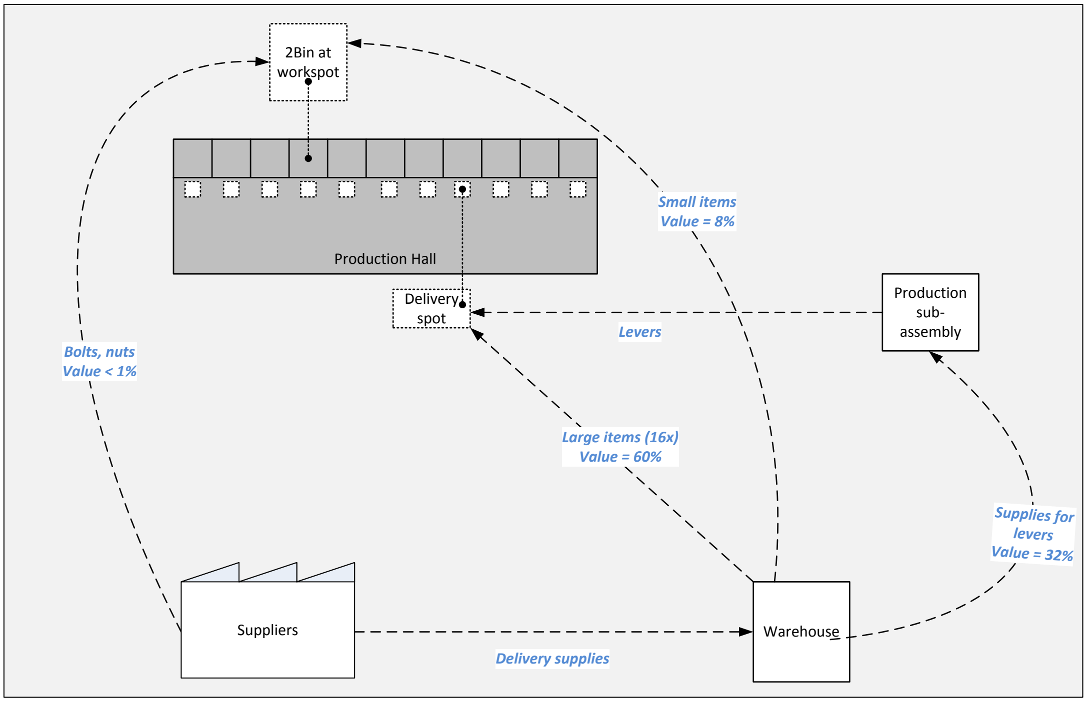


Figure 4.6: Transport of supplies

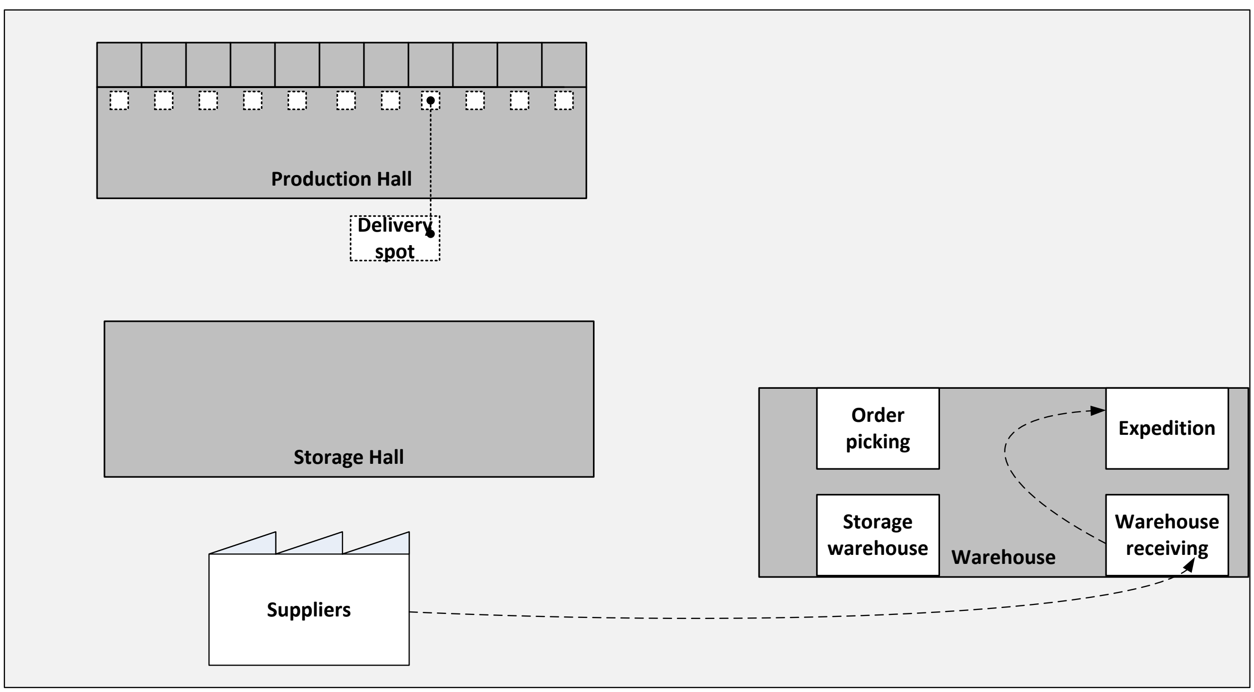


Figure 4.7: Flow of supplies that are not needed in production

The large items are not delivered to the two bins. The large items were transported in a lot of packing material. The goal was transporting without packing material. The items that did not fit in the 2 bin rack were selected. After studying the problem, a kitting box was developed and a few decisions were made:

- The sequence of parts is based on the production sequence.

- The ring are all turned because they use less space
- The chosen material is foam because it does not damage the products.
- Each part has 60% in the kitting box and 40% above the box. With this ratio the products are stable in the kitting box and the mechanic can pick from it easily.

The kitting box for large items is shown in Figure 4.8.

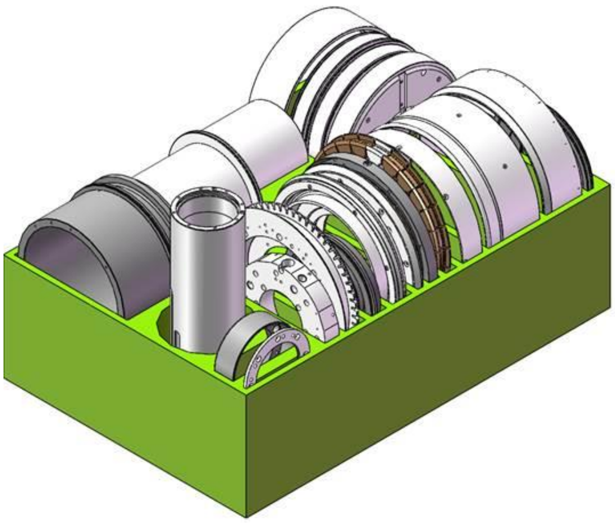


Figure 4.8: Kitting for the transport of large items

4.4.9. Department production

The production department got a new layout. The new layout is discussed in section 4.3. There were big changes resulting in more work places and a leaner production. The production personnel were involved during this project, mainly by producing drums for two weeks under my scrutiny. This involvement helped minimize the resistance to change.

4.4.10. Department quality assurance

The quality assurance department carried out a technical check and a check on customer wishes. The technical check makes no sense and showed no fault for the last years. The technical check will be skipped. The check on customer wishes can be discontinued in the future but is still in place. It is cited as important for quality assurance but proves ineffective. Internally the value of this watchdog is weighted higher than the waste of time and money.

4.4.11. Department expedition

The expedition department does not change significantly. They still need to ship the same products to the customer. The only difference is that previously they received all goods from production and now they receive the products from production and the warehouse.

4.5. Summary

A lot of changes are described in this chapter. But not every project is perfect; sometimes the advised solution was not implemented. This was also the case with VMI, the two main examples were:

- The generation of a work flow status with automatic generation of mails.
- The complete deletion of the quality assurance.

Neither of these options has a dramatic influence on the solution. They are steps that were advised but then applied differently after discussion.

The good news is that the solution is accepted and almost fully implemented. The results of all described changes (small and large) result in a new process for producing a drum, this process is visualized in Figure 4.9.

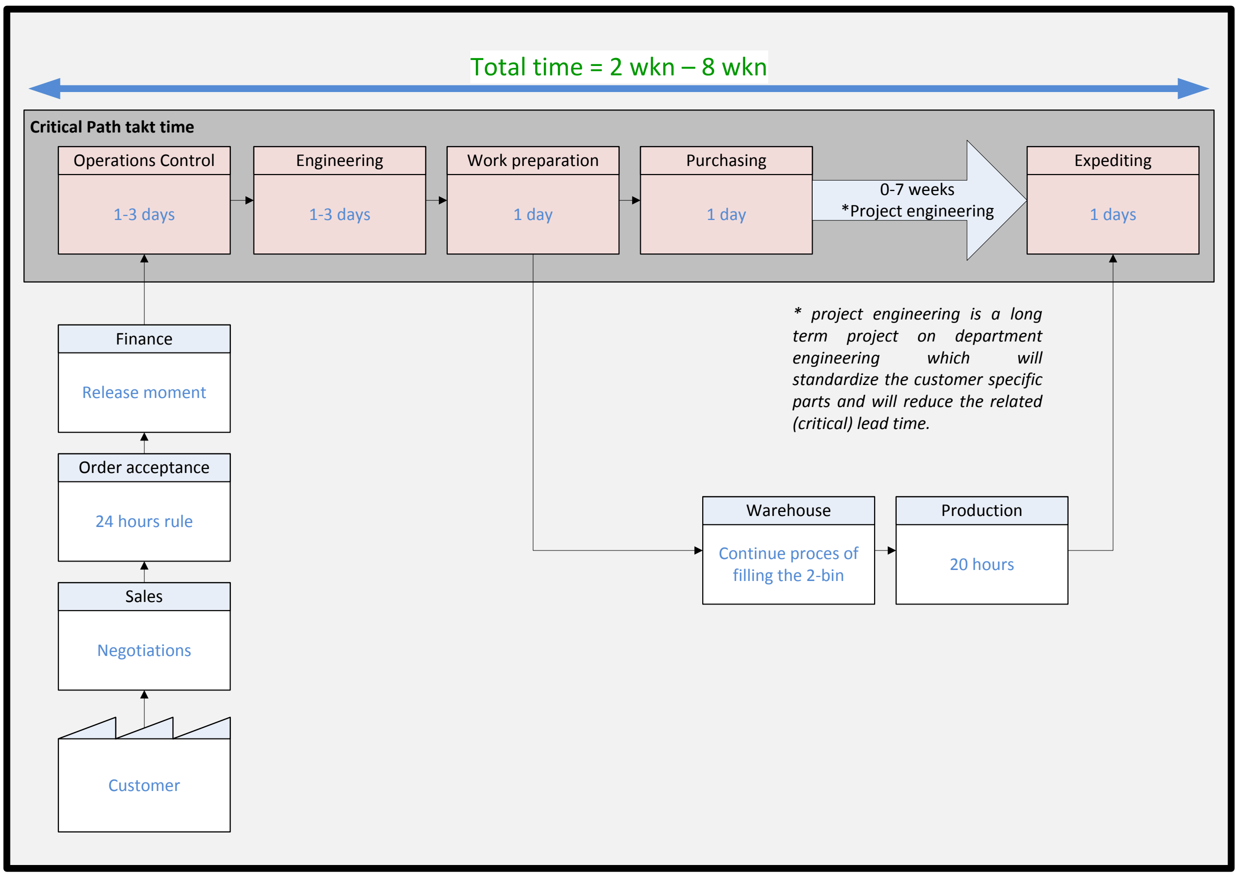


Figure 4.9: Overview of final solution

This chapter discussed the next main topics, which were CODP, inventory control, production layout and merging solutions. But how are these related to the final solution shown in Figure 4.9.

- The CODP change made it possible that an anonymous flow of production was arranged and the warehouse and production are no longer on the critical path
- The inventory control realized the anonymous flow

- The production layout solved the potential bottleneck of production capacity and the internal transportation was reduced mainly through the realization that not all items were needed in production.
- The chapter on merging solutions was applied for fine-tuning the solution and released project engineering. When this project is finished, the takt time will be reduced to 2 weeks.

In conclusion, a new approach, one no longer centred on a project-based production, involved a lot of different departments but led to an entirely new process with is expected to be much better. The next chapter will compare the performance of the newly developed system with the previous one.

5. Results

The research is defined, the theoretical framework is completed, the current situation is analysed, some alarming key performance indicators (KPIs) have been found and an adequate solution is developed.
The solution is developed in the previous chapter and a sensitivity analysis is done to check if the new solution is a theoretical improvement. That was theoretically, the question of this chapter is whether it is an actual improvement or not. The last research question is: *Does the possible solution work?*

To answer this question, some sub-questions are defined. The sub-questions are:

Sub4.1 What options are available to monitor the performance of the implemented solution?
This will be answered in section 5.1

Sub4.2 What should an adequate monitoring option for VMI look like?
This will be answered in section 5.2

Sub4.3 What are the performance outcomes of the implemented solution?
This will be answered in section 5.3

5.1. Monitoring options

This section will answer the first sub question on how to analyse the practical situation. The first sub question is; *what options are available to monitor the performance of the implemented solution?*

There are multiple options to analyse whether the implemented solution is an improvement or not. The first analyses were theoretically and are already completed. There are multiple options for a deeper analysis and practical analyses. Relevant options are:

- Dry run. Testing an airplane but keep it on the ground.
- Pilot Experiment. A small-scale preliminary study.
- Simulation. Imitating the real-world process over time.

It is hard to build a simulation model for the change of processes. A simulation model is more suitable to analyse a new flow. The check capacity with future demand mode simulates different scenarios like high demand, low demand et cetera. A change of CODP is harder to simulate.

The choice between dry run and pilot experiment must be made. The pilot experiment has the advantage that it is closest to reality. The dry run has the advantage that it is a simplified way of testing. To monitor the solution, the pilot experiment is most suitable and therefore advised for VMI. The dry run is not chosen but will be applied to do a dry run in the enterprise resource planning software. In conclusion, the monitoring of the solution and the testing of the complete solution is done with the pilot experiment.

5.2. Monitoring option

As discussed in section 5.1, there will be 2 monitoring options used. The first option takes place before the start of the project. It can be seen as a general repetition. A second monitoring option is designed to monitor over a longer term.

5.2.1. Dry Run

The dry run case is built on the logistic flows and the handlings that must be done. The new logistic route, ordering data and inventory management should be tested. This test is done with a dry run (dry run – "droogzwemmen"). For the dry run the enterprise resource planning software will be used. The software has a trial account and that will be used. The dry run is done by simply generating a new demand. This comprises a new order and all that follows that order. The ordering process, the purchasing process, the warehousing process, the production process, all the processes will be imitated and followed. This way any possible problems can be identified. The first run is done according to the normal procedure. A second run will be done with some more trials, testing how the system responds if someone makes an error et cetera.

The main arguments for a dry run revolve around a few elements that are new for VMI. Those new elements are:

- Backflush for inventory management
- KANBAN order involved in the ordering process
- Outbound priority for prioritization of backflush (the logistic and inventory fields)

The next paragraph will describe the dry run. Starting with describing the details needed for the dry run, secondly the dry run will be described in detail.

Elements of dry run

The elements that are needed for a dry run are: a product that can be made, the subassemblies that are needed, the locations, the outbound priority and a simulated order. The elements that are used are described in two ways: the normal description from thesis and the description that is used in the dry run (written in capital letters)

1. A simulated drum = TPT DRUM ASSY
2. The parts for a simulated drum (only one supply type for each type, does not make sense to test 1000 screws)
    a. TPT LEVER ASSY = levers
    b. TPT 2BIN PART = small items
    c. TPT LEVER 2BIN PART = supplies for levers
    d. TPT LARGE PART = large items
    e. TPT FLOORSTOCK = Bolts, nuts
    f. TPT FLOORSTOCK SIC = small items

3. A number of locations will be:
    a. TB.GO.01 = Location for 2 bin articles
    b. TP.LP.01 = Location for large parts
    c. TP.FC.01 = Location for project storage (virtual, not shown in figure 5.1)
    d. TB.FG.01 = Location for 2 bin in production (Felua)
    e. TB.AB.01 = Location for 2 bin in production (774)
4. Outbound priority
    a. 999 = High priority
    b. 998 = Low priority
5. A simulated project = EPR007355

The case of the dry run visualized in Figure 5.1.

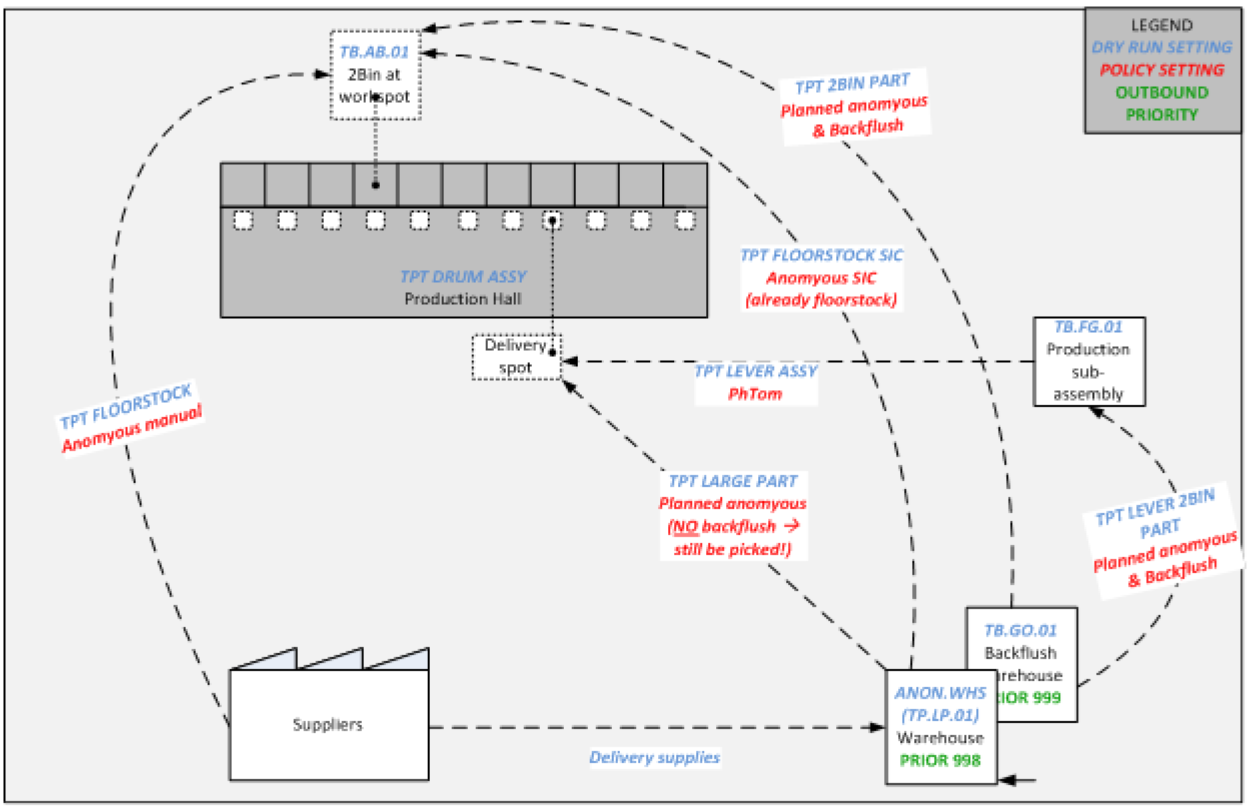


Figure 5.1: Visualization of dry run

The dry run

The dry run cannot simulate the negotiations of sales and potential buyers. It must start somewhere. The start of the dry run is synchronized with the start of using the software information. The next steps are all simulated manually. Simulating manually means doing all steps by hand in a trial environment. To give the reader more insight, the simulation is analysed from the point of view of purchasers, the warehousing department, the production department, etc. etc. Every process step is imitated.

1. The process of ordering stock. Generating a demand of supplies, making of planned order, sending orders, monitoring orders and expediting orders.
2. Processing the supplies in the warehouse. Receiving the supplies, checking the supplies, determination of a location for supplies.
3. Generating of an order, this produces production orders et cetera.
4. All goods for this project were assigned to the anonymous warehouse. The process of inventory movement, the movement from anonymous warehouse to a backflush warehouse. (new procedure)
5. The inventory movement of SIC-articles
    a. SIC-articles are now available in the 2 bin at the production location.
6. Generating a KANBAN route for the assembly of the subassembly lever
    a. According to the system, the order can be delayed. But there will be stock, therefore the inventory level will remain and the order will upgrade the inventory level on the long term. The inventory level will stay stable.
    b. The order picking for the anonymous inventory should be impossible and it is tested and that resulted in the error: "no advice"
7. The completion of a production order of the Felua.
    a. This is scanning of code number 010. Was done by warehouse, now by Felua
    b. Backflush is automatically done with this scan.
8. The release of the existing order
    a. It is the order to pick the large anonymous parts
9. Order picking for the large parts
    a. Picking for the order
10. Handover of goods
    a. The final status should be that the production department has all the supplies
        i. Small items with 2 bin
        ii. Lever with KANBAN order
            1. Lever supplies also with 2 bin
        iii. Large items with kitting

5.2.2. Pilot experiment

A pilot experiment is chosen to analyse the new situation. But before the pilot can be applied it must first be defined. This section is mentioned to define the pilot experiment. The related sub question is: *What should an adequate monitoring option for VMI look like?*

The main decisions that must be made are:
* Selection of a pilot product group
* Selection of performance indicators

A product must be chosen from the product family. Runners must be selected and one of those runners must be chosen. It is expected that there will be no difference in the result. There is no need to test a complete family. The more products that are selected and the more test runs that are done, the more exact the results. The variance in results is expected to be small. The production planning is taken and the first available runner will be selected for the pilot. The selection method is random.

The selection of performance indicators is more complicated. It is necessary to determine which performance indicators are most important. In chapter 3 there are multiple key performance indicators defined. Below is a list of all the key performance indicators used.

- Mean production time
- Time of value adding activities
- Time of non-value adding activities (assuming no error)
- Time of non-value adding activities: (assuming one error)
- Time of non-value adding activities: (assuming no error and excluding the standard waiting time for supplies)
- Takt time (assuming no errors)
- Total number of drums sold
- Number of E1 sales (sales with a machine)
- Number of E3 sales (sales directly to customer)
- Other sales (R&D, stock, maintenance etc.)
- Growth of sales
- Percentage of technical questionnaire completed
- Changes to the order after a formal sale of drum
- Number of orders
- Total number of days of lateness[5]
- Total number of days of tardiness[6]
- Estimated number of days of lateness
- Average number of days of lateness
- Processing time
- Waiting time
- Order cost
- Holding cost
- Ratio order cost : holding cost
- Total cost
- Production time
- Production capacity
- Value of work-in-process
- Value of work-in-process in production
- Value of work-in-process standing still

[5] Lateness is defined as the difference between planned completion date and actual completion date.
[6] Tardiness is defined as the maximum of the difference between planned completion date and actual completion date and zero.

To evaluate each key performance indicator would be a waste of time. A small list of key performance indicators in a range from 5 to 10 measures the performance of operations in the most effective way for industry standards and best practices. (Chae, 2009). The list above can be simplified. A number of key performance indicators are selected, based on the following arguments:

- The previous KPI were defined for each department. Is the key performance suitable for evaluating the complete solution?
- Is the key performance measurable in the short term? The goal of the pilot is to analyse whether it is an improvement for the short term. A second monitoring option must be applied to test improvement in the long term.
- Is the key performance suitable to measure the performance of the production of one product? The time for analysing is restricted. The key performance indicator should be suitable for the time restriction.

Based on the argument above, the following key performance indicators are selected for the pilot.

1. Takt time
2. Total days of lateness
3. Order cost
4. Production time
5. Production capacity

Now the pilot is described. The analysis can be done and the results will be discussed in the next section.

5.3. Results

There are two monitoring options described to test the solution. The dry run and the pilot experiment and the results of both options will be discussed in this section.

5.3.1. Dry run

The dry run had two goals. Firstly, to analyse whether the supposed solution was feasible and secondly to analyse which implementation steps were needed. Small and large feasibility checks were carried out during the dry run. It started with generating all elements and the BOM of the dry run product, see the result in Figure 5.2.

MULTILEVEL BOM.

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5.180.2799T TPT DRUM ASSY Manufactured

Pono.	Seq	Item	Description	Item Type	Quantity	Unit	Eff CO	Eff Date	Exp CO	Exp Date	Opr
3	1	5.180.6877T	TPT LARGE PART	Purchased	2	pc		16-10-08		01-01-38	0
24	1	5.180.3864T	TPT 2BIN PART	Purchased	4	pc		16-10-08		01-01-38	0
101	1	K.202.101129T	TPT FLOORSTOCK	Purchased	16	pc		16-10-08		01-01-38	0
227	1	K.519.026002T	TPT FLOORSTOCK	Purchased	4	pc		08-05-14		19-01-38	0
300	1	5.180.2403T	TPT LEVER ASSY	Manufactured	94	pc		16-10-08		01-01-38	0

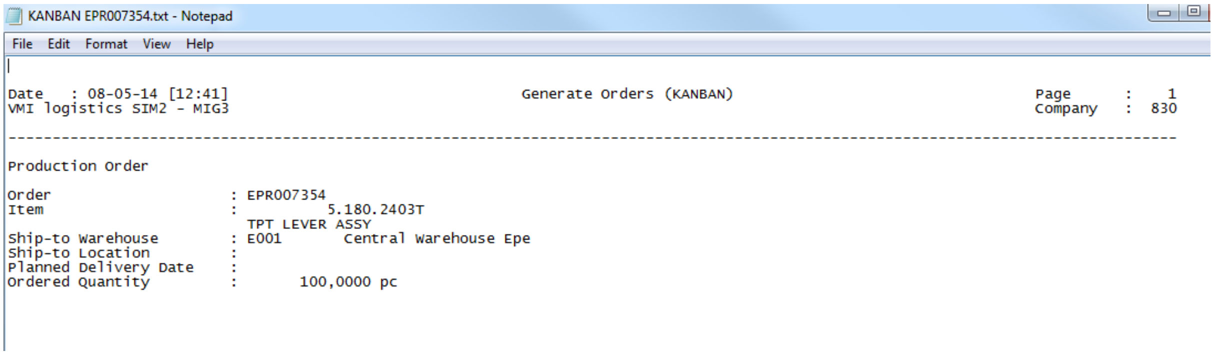
Pono.	Seq	Item	Description	Item Type	Quantity	Unit	Eff CO	Eff Date	Exp CO	Exp Date	Opr
2	1	5.180.6850T	TPT LEVER 2BIN	Purchased	1	pc		03-02-04		01-01-38	0

Figure 5.2: The bill of material of the dry run drum

The demand for the standard products was made, the supplies were ordered and the supplies became available in the anonymous warehouse. After order receiving the supplies are moved internally in the warehouse towards production. This internal movement is not done by forcing the logistics but by generating the normal way of demand. An empty bin which arrives at warehouse can be scanned and that is an example of generating the normal way of demand.

The new elements were tested explicit.

- The KANBAN order settings were set at the beginning. Later on a KANBAN order was imitated and the procedure is written down. The order was generated and was visible in check order. The order was scanned twice later on for start and finish points (in the way the mechanic does), the order was accepted and the stock level was updated. Figure 5.3 shows the KANBAN order.
- The outbound priority was tested explicit. The goal of the outbound priority was to backflush on the right ware house, which mean the figurative backflush warehouse. The reason for this is that the inventory in the actual warehouse is known and the inventory level is known. The outbound priority is shown in Figure 5.4.
- The backflush method is new and tested. The backflush was put on and monitored while it was running and when it was finished. The backflush was monitored to see whether the inventory was actually lower, the goods are used in production and no longer available in supply. At the end, it was checked whether or not there had been a double backflush. The backflush is shown in Figure 5.5.



KANBAN EPR007354.txt - Notepad

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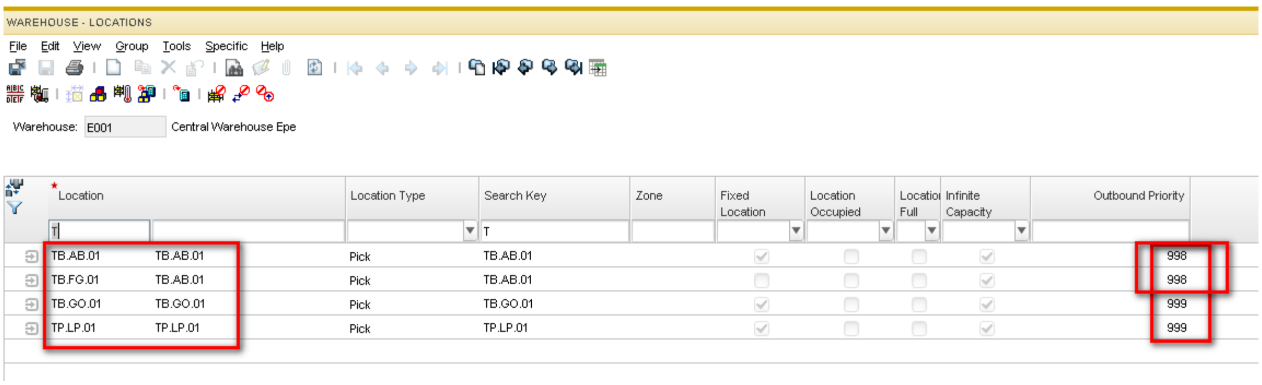
```
Date    : 08-05-14 [12:41]                         Generate Orders (KANBAN)                          Page    :   1
VMI logistics SIM2 - MIG3                                                                            Company :  830
-------------------------------------------------------------------------------------------------------------------

Production Order

Order                     : EPR007354
Item                      :          5.180.2403T
                            TPT LEVER ASSY
Ship-to Warehouse         : E001        Central Warehouse Epe
Ship-to Location          :
Planned Delivery Date     :
Ordered Quantity          :       100,0000 pc
```

Figure 5.3: The KANBAN order



WAREHOUSE - LOCATIONS

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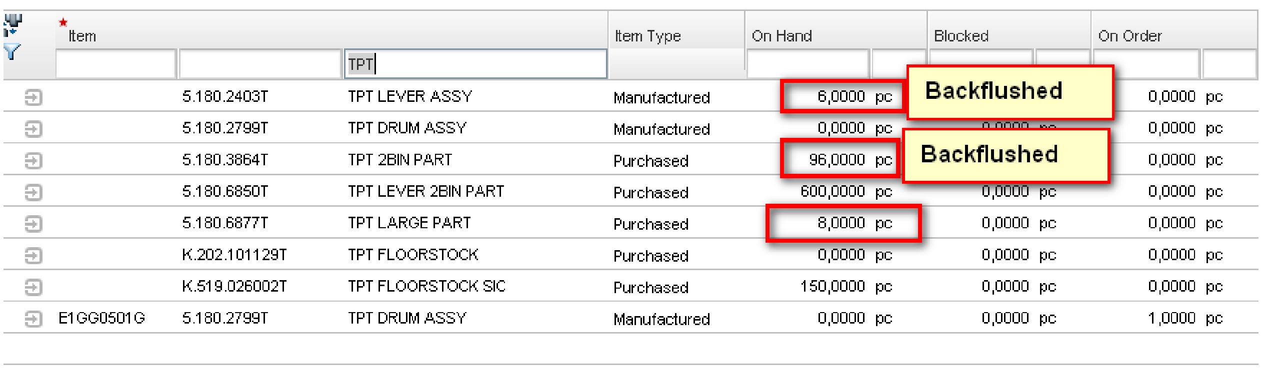
Warehouse: E001 Central Warehouse Epe

Location		Location Type	Search Key	Zone	Fixed Location	Location Occupied	Location Full	Infinite Capacity	Outbound Priority
T|			T						
TB.AB.01	TB.AB.01	Pick	TB.AB.01		✓			✓	998
TB.FG.01	TB.AB.01	Pick	TB.AB.01					✓	998
TB.GO.01	TB.GO.01	Pick	TB.GO.01		✓			✓	999
TP.LP.01	TP.LP.01	Pick	TP.LP.01		✓			✓	999

Figure 5.4: The settings of the outbound priority



Item			Item Type	On Hand	Blocked	On Order
		TPT|				
	5.180.2403T	TPT LEVER ASSY	Manufactured	6,0000 pc		0,0000 pc
	5.180.2799T	TPT DRUM ASSY	Manufactured	0,0000 pc	0,0000 pc	0,0000 pc
	5.180.3864T	TPT 2BIN PART	Purchased	96,0000 pc		0,0000 pc
	5.180.6850T	TPT LEVER 2BIN PART	Purchased	600,0000 pc	0,0000 pc	0,0000 pc
	5.180.6877T	TPT LARGE PART	Purchased	8,0000 pc	0,0000 pc	0,0000 pc
	K.202.101129T	TPT FLOORSTOCK	Purchased	0,0000 pc	0,0000 pc	0,0000 pc
	K.519.026002T	TPT FLOORSTOCK SIC	Purchased	150,0000 pc	0,0000 pc	0,0000 pc
E1GG0501G	5.180.2799T	TPT DRUM ASSY	Manufactured	0,0000 pc	0,0000 pc	1,0000 pc

Figure 5.5: The result of the dry run

The final result is shown in Figure 5.5. It mainly represents the function of backflush.

- The first line (TPT LEVER ASSY) shows that there are 6 on stock. That makes sense because a KANBAN order of 100 is produced and according to the BOM there were 94 levers used. The result is that 6 levers are on stock. This is done with the new procedure backflush.
- The third line (TPT 2BIN part) shows that there are 96 products on stock. This makes sense because we started with 100 and according to the BOM there were 4 supplies used.
- The fourth line (TPT LEVER 2BIN PART) started with a stock of 700 and is used for a KANBAN order of 100, for that reason an on hand stock level of 600 is right.
- The fight line (TPT LARGE PART) shows an on hand stock of 8. A starting stock of 10 and a usage of 2, according to the BOM, make that number correct.

Some additional scenarios where tested. What if the stock is empty? The system gave an error when a strange request was made or "no advice" when an impossible movement was requested. It seems that the software contains the characteristic of poke yoke quite well.

The final results are that all supplies were at the right location and the drum could be built. When the drum was finished, the stock levels were at the right levels. (Those continued to be correct). The dry run can be seen as a success because no structural errors appeared. Only small errors occurred because data was sometimes missing. The action points that must be carried out to apply the solution in practice are listed below.

Action points to become live

1. Adaption on supply level, changes for each supply.
    a. Adaption for all goods to planned anonymous
    b. Adaption of order incremental for each supply (a multiplicity number for order size)
    c. Insert a minimum order quantity for each supply
    d. Insert an order interval (it sums the coming orders and compares with the order when placing an order)
    e. Insert a reorder point for each supply
    f. Activate backflush
    g. Install the settings for the KANBAN orders.
2. Generate the locations that are needed
3. Insert an outbound priority
4. Develop a new production team
    a. Make the new team Felua
    b. Make the jobs for the team Felua (creation of two production orders, position 10 and 20)
    c. Adapt the cycle time for the new production team (practical input)
5. Writing the manuals for the new procedures. The instruction for the mechanics and warehouse personal.
    a. The procedure for inventory movement from anonymous warehouse to 2bin
    b. The procedure to produce KANBAN orders
    c. The procedure to finish orders (position 10 and 20)
    d. The procedure for printing orders

The dry run was a success and the implementation for the actual situation became easy due to the problems of missing data, missing parameters and missing settings being identified and eliminated. The next results are the practical results, the results of the pilot experiment.

5.3.2. Pilot experiment

The implementations are in place but there is not yet a long-term analysis for the pilot. To generate good pilot results it should be monitored for 2 or 3 years. The results would mean good insight into the variance in the process. But due to a lack of research time that is not possible. An analysis of one drum should take 8 weeks and even that time is hard to measure due to the time restriction. The selection of key performance indicators was selected on the time restriction. The results on the key performance indicators are:

Based on the argument above, the following key performance indicators were selected for the pilot.

1. *Takt time; 7 weeks*

1.1. The takt time of an entire product is measured by looking at the delivery time of the customer specific parts. The longest time was 7 weeks

2. *Total days of lateness; 0 days*

2.1. The total lateness was 0 days. The production finished on time and all products were acceptable quality, the quality norms were fulfilled.

3. *Order cost; EURO 25,000 savings*

3.1. An analysis of suppliers was done (see appendix 8.A). Based on the 5 largest suppliers, the current saving is 25,000 euro. The main reason is placing larger orders and optimal quantities.

4. *Production time; 20 hours*

4.1. The production time is measured by following a drum through the production process. A drum started on Monday was finished on Wednesday. It was nearly 20 hours. An average production time for all drums can be set at 20 hours.

5. *Production capacity; 12 drums per week*

5.1. The production capacity can be calculated in a variety of ways, based on: the takt time, the number of work stations, the number of mechanics and the supplies. The number of work stations assigned for this product family creates the bottleneck and is currently 6 work stations

5.1.1. Maximum capacity can be 17*(40/2) = 34 drums per week (assuming infinite supplies)

5.1.2. Actual capacity can be 6*(40/2) = 12 drums per week (based on the current work stations)

The results are looking good, but it must be said that the time spent analysing was short and there have not been many products analysed. The uncertainty of the results is large at this moment and will be reduced with time and with the measuring of more drums.

5.4. Summary

This research was carried out to evaluate whether the new situation is an improvement or not. A number of monitoring options were selected and a choice was made between those options. A dry run and pilot experiment was chosen for the analysis.

The dry run was described and it imitated all processes in the ERP system, from deciding which supplies were needed to the finishing of a drum. The main advantage was that time was not a restriction. The pilot experiment had to run in real time but has as its main advantage activation in the real world.

The final result of the dry run was that all supplies were at the right location and the drum could be built. When the drum was finished the stock levels were at the right levels. (These continued to be correct). The dry run can be seen as a success because no structural errors appeared. Small errors occurred because data was sometimes missing in the test environment (data like no lead time, no price). The action points that must be carried out to apply the solution in practice were noticed during the test run.

The action points of dry run were implemented and the test run is finished. The pilot study is done but it had to deal with some time restrictions. The following results are found:

1. *Takt time: 7 weeks*
2. *Total days of lateness; 0 days*
3. *Order cost; EURO 25,000 savings*
4. *Production time; 20 hours*
5. *Production capacity; 12 drums per week*

6. Conclusion and recommendation

In august 2013 the sales department requested that tooling be delivered more quickly. That request was the signal to hire a student for a project. That resulted is this master thesis. In this final chapter the conclusion will be drawn in section 6.1 and some recommendation will be written in section 6.2.

6.1. Conclusion

The main points to address for the thesis were the long takt time, the lean coordinator who gets stuck and the expected capacity problems in the future. The research started with a practical introduction programme.

In the first weeks of this thesis I underwent a practical introduction. We decided to actually help in the production and build a drum. It was the most intensive, effective and informative way of gathering information. In a short time the product and the process was understood. For the analysing part a lot of lean techniques were directly and indirectly applied. The lean analysis in appendix A.1 was the most direct form. Those analyses led to a list of possible improvements:

- Takt time 4-5 month, production time 4-5 days
- Minimum takt time was 47 days
- Average takt time was 84 days
- Lot of work in process, estimated at 1.6 Million EURO
- Often the mechanic is searching for tools
- No standard production layout
- Lots of paper work
- Most supplies are equal for each product. Random comparison showed 59% were equal.

The list with kaizen points is an argument in support of this thesis and an argument in favour of a structured and extended research.

The research started with a quick root cause analysis and 10 main causes were found and classified. The classes are:

- Internal causes at production
- Internal causes at warehouse
- External causes

Based on the classification, the research was delineated to the internal causes at the production. The warehouse was excluded because it had been recently improved and external causes were dependent on the supplier. The main selected causes for a long takt time were:

1. Manufacturing is at a standstill due to error (product is missing / not good)
2. No box available for finished product
3. Mechanic is searching for materials
4. Mechanic is searching for tools

The main goal of the research was to analyse and optimise the takt time. Based on motivations, delineating and goals the research question was defined. The main call of production was: "if I have supplies" and the main cause is a standstill.

How to significantly reduce the takt time of a drum and optimise the logistics flow by improving the flow of supplies in the internal warehouse and assembly hall?

To answer such a question, research questions and sub research questions were defined. The four main research questions were.

Sub1 What does the literature says about reducing takt time? Answered in chapter 2
Sub2 What is the current situation of the production of drums? Answered in chapter 3
Sub3 What should be an adequate situation for the production of drums? Answered in chapter 4
Sub4 Does the possible solution work? Answered in chapter 5

The total overview of the structure of the research is shown in the house of the thesis, mentioned to keep the research on track. The main elements of the house are the fundamentals of research definition and literature study. The two main pillars of the house are the current and future situation and the roof is the implementation and testing of the generated future situation.

The research started with the first sub question. *What does the literature says about reducing takt time?* To answer this question, the literature was reviewed and the relations are shown in a theoretical framework. The subjects were chosen because they are related with the research question in some way and because they are used in this research.

The positioning framework is used to keep an overview during the research. The takt time is defined to eliminate space for discussion about takt time. Both subjects are mentioned to keep on track.

The supply chain management is used to give insight into the process of producing a drum. The supply chain will be analysed in the next chapter.

The literature on product and process matrixes expresses the importance of the product; the process is analysed in more detail with the theory of production layouts for the reason to standardize the production layout.

The customer order decoupling point is used to analysis the breakpoint between push and pull. This characteristic of production will be analysed in chapter 3 and different options are analysed in chapter 4.

The inventory models, ABC classification and inventory control, are used to analyse the current inventory models and analysis the different options.

The next chapter will use this literature directly and indirectly. They will be used for analysing the current situation and the search for a better situation. First a question is defined to analyse the current situation

What is the current situation of the production of drums?
The current situation was analysed and the main points for improvement were found, or in other words, key performances indicators (KPIs) were identified.

An alarming key performance indicator was the correlation between the takt time and the time spent on non-value adding activities. The main reasons for this were the long delivery times of supplies and the error in supply, namely wrong quality or quantity. In both cases the entire project came to a standstill while new supplies were needed. The fact that every order was customer-based and the customer order decoupling point was engineer-to-order, created problems when there was an error in the production of an item with a long lead time. The flow was as follows: An order was placed, an engineer started the drawings, supplies were ordered, there was a waiting time for supplies of 55 workings days, an error could occur, leading to an average additional delay time of 30.44 days, and finally the product was completed. This flow results in a ratio between mean production time and takt time with one error as equivalent to 1: 27.34. Even when assuming no errors, the ratio is 1: 20.67. A frequently measured ratio in the industry is 1:3 or 1:4.

The next alarming KPI was inventory control. A ratio where the order cost is higher than the holding cost is interesting. The main reason for this ratio is that for every product the orders are placed separately. The current policy can be compared with an anonymous flow. The main advantage of anonymous flow would be a reduction of the takt time of 55 days. But is it profitable?

The warehouse process was not that alarming apart from the fact that a separate handling was carried out for each order line. So, a reduction of order lines will lead to a reduction of order handling.

Transport has two alarming points. The first is that goods are transported to another warehouse when a project is not complete. The second point is that some goods are travelling a redundant logistic route.

The production hall is more alarming. The main alarming point is that the limited capacity of the hall creates a bottleneck at the end of the year. The main points of concern are: The number of errors is large and has a dramatic effect on production and the number of workplaces and their arrangement are not efficient. However, the quality of the mechanics is good because they are all experienced.

The quality assurance is achieved by a meeting of 4-5 people and takes half an hour or sometimes even one hour. The technical check is irrelevant because the mechanics already perform a test; the check on the customer specific wishes makes sense.

Overall it can be concluded that a number of alarming points continue to return. The combination of these is the main cause for a long takt time. These main causes are:

- The CODP of ETO
- The long lead time of supplies
- The errors (wrong quality or quantity)

- The inventory policy
- The production capacity.

Some alarming points were found, but was there a better alternative? That question is asked and answered:

<u>What should be an adequate situation for the production of drums?</u>
The alarming points made clear that there was some room for improvement. A new situation is generated based on the question above. Multiple solutions were generated and analysed and the best solution for VMI was selected and merged.

The main alarming topics were CODP, inventory control, production layout and merging solutions. To reach the new adequate situation, the following changes were made.

- The CODP was changed from engineer to order (ETO) to assembly to order (ATO). This change made it possible that an anonymous flow of production was arranged and the warehouse and production are no longer on the critical path
- The inventory policy was changed from a project based buying process to a specific develop inventory model for VMI (mainly based on the s,Q inventory model). The inventory control realized the anonymous flow
- The new production layout solved the problem of potential bottleneck of production capacity and the internal transport was reduced due to the analysis of the product and production. The generating of a kitting and the selection of items necessary to production reduced the level of internal transportation.

The last step was merging solutions and was applied for fine tuning the solution and released project engineering. When this project is finished, the takt time can be reduced to 2 weeks.

The solution is accepted and almost fully implemented. The results of all described changes (small and large) result in a new process for producing a drum, this process is visualized in Figure 6.1.

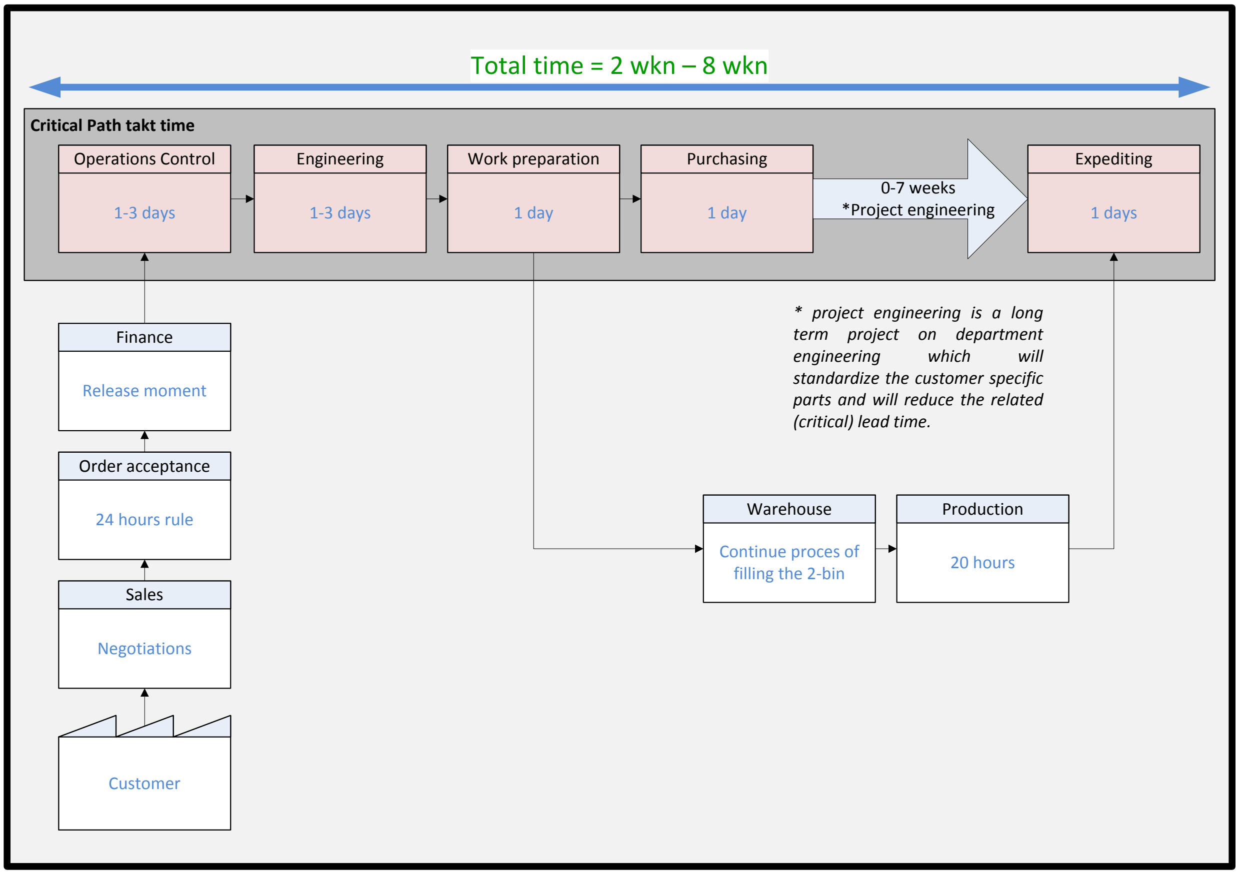


Figure 6.1: Overview of final solution

The conclusion is that a different way of thinking, namely no longer an entire project based production, involves a lot of different departments but leaded to an entire new process with is expected to be much better. The coming question will compare the performance of the newly developed system with the previous one.

<u>Does the possible solution work?</u>

This research was mentioned to decide whether the new situation is an improvement or not. A number of monitoring options were selected and a choice is made between those options. A dry run and pilot experiment is chosen for the analysis.

The dry run is described and is the imitating all processes in the ERP system. From deciding which supplies are needed until finishing a drum. The main advantage is that the time is not a restriction. The pilot experiment had to deal with real time but has as main advantage that it is in the real world.

The final result of the dry run is that all supplies were at the right location and the drum could be build. When the drum was finished, the stock levels were at the right levels. (Those were continuing right). The dry run can be seen as a success because no structural errors appeared only small items because data was sometimes missing in the test environment (data like no lead time, no price). The action points that must be done to apply the solution in practice were noticed during the test run.

The action points of dry run were implemented and the test run is finished. The pilot study is done but it had the deal with some time restrictions. This thesis answers with the

1. Takt time; seven weeks
2. Total days of lateness; zero days
3. Order cost; EURO 25,000 savings
4. Production time; 20 hours
5. Production capacity; 12 drums a week

To secure those results, there are some implementations steps which are not yet applied. A roadmap for future implementations is written for VMI. Applying this roadmap will secure and even improve the current results. This roadmap is shown in Table 6.1.

Roadmap tooling		
Task	***Responsible function***	***Time (weeks)***
Lean production layout (eliminate of wastes, standard set of tools)	Foreman tooling	4
Fine tune the form of the kitting (multiple inch sizes needed?)	Lean coordinator	26
Apply the long term standardisation project	Standardisation engineer	26
Generate standard procedure for updating inventory level	Material planning	26
Generation of KANBAN-order with scan-procedure	Application manager	26
Stimulate the sales of standard drum	All salesman’s	4
Extend the product family	New student / student thesis	26
Monitor/adapt the inventory levels (make automatically)	Head purchasing	52
Monitor/ adapt the inventory parameters settings (make automatically)	Data Management Control	52
Forecast the sales / continue updating the forecast	Forecaster	Yearly
Adapting new releases of supplies in future	Release engineer	Continue

Table 6.1: Roadmap for future implementation

Despite the fact that these results were only short term, they gave enough confidence to hear a long-term project aims to reduce the take time from 7 weeks to 2 weeks due to standardization. Six months ago the takt time was 94.31 working days and it is actually reduced to 35 working days and the realistic goal after the long term project is 10 workings days.

6.2. Recommendations

The last section of this thesis contains overall recommendations that have been noticed during the compiling of this master thesis. Some are related to the research, some have no relation to this research.

The first recommendation is for the fine tuning of this project. This means monitoring the process for long and short term. Fine tuning on the short term can solving some implementations problems, add supplies or delete supplies form the two bins. Fine tuning on the long term can be outsourcing, kitting. The project engineering can be applied to reduce the takt time from 8 weeks to 2 weeks.

The second recommendation is also related to the project tooling. A product family is chosen in the beginning. An almost similar product family is named synchro. It is advised to implement this selected solution above for the same product family. It has the same structure, it is part of a TBM, it can be sold separately and individually, it has the same production process, the same demand structure etcetera. The difference is that the selected family works on air and the synchro drum works mechanical.

A recommendation that is partly related to the project is inventory management. A nice example is found for the tools of mechanics. The inventory policy for hammers is set on an order quantity of 5 but there is no reorder point or safety stock. Currently we wait until the inventory level becomes zero and then order new ones in an order quantity of 5. A safety stock of 1 and order quantity of 4 is likely to have fewer inventories and less stockout. An analysis, structuring and an update of inventory management would be profitable.

The ERP system can be used more. ERP is currently used but most users have no idea of what they are doing. They have learned some steps that they must do, not knowing what they do. For example, for a supply buyer there are multiple settings for inventory management (namely, min order quantity, fixed order quantity, order incremental, order internal and reorder point). But every buyer fills in multiple fields or just every field because they don't know the exact meaning of the options. An explanation would be useful and would reduce errors.

A next step would be to create a link between the engineering software and the ERP-system. Engineering draws a product and from the drawing the need of supplies is determined. This list of supplies is put manually into the Infor software by the work preparation department. They generate the list of supplies and add routings. It takes a lot of time (many days for an entire machine).

Currently at VMI there are a lot of macros built. A macro can reduce the time of handling in a perfect way. It has many advantages but the main disadvantage is that when its source changes, the macro won't work. It often leads to panic because it always happens at a busy moment. The source is the data of the ERP-software (INFOR). From the ICT-point of view a macro is seen as a temporary solution. A long-term solution is to extend the software that is currently used.

The VMI has expanded quickly over recent years. A turnover of 180 million euro two years ago and expected turnover of 360 million euro. In the old situation, the lines of communication were shorter and everyone knew who must be asked. Small things that were previously discussed at the coffee machine must now be expressed in procedures. To deal effectively with such growth it is advisable to rearrange the organizational structure.

The final advice is to become more concrete with the process of lean and continuous improvement. Currently the policy of 5S is being introduced and some flyers are being distributed. Some project groups are working with value stream mapping. It is known internally who is good with lean but questions remain such as: Who is responsible for lean? What is the lean policy? How lean will VMI be? There is no strategic and tactical plan for the lean and continuous improvement at VMI. The validity of this advice is illustrated by supplier SEW; they rebuild their production line every four years and every four years a reduction of takt time of globally 20% is realized. Structuring lean and continuous improvement at all levels (strategic, tactical and operational) is advised.

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Appendix

A.1. Lean analysis

This paragraph is a lean analysis which is not described in the framework of the previous chapter. The lean analyse is done to prevent too much focus on a specific cause and to understand how the process actually works. The importance of understanding the process is confirmed by the following statement.

"First, a company must own the production situation accurately. Only then can they systematically work to apply the functional specifications of an information system will be drawn up" (Wielen, Heere, & Slomp, 2005)

This paragraph contains a theoretical description of the lean analysis, the results of the lean analysis and a conclusion.

Lean analysis theoretical

Analysing the process is done by six techniques according to Quentin Brook. (Brook, 2006) Those techniques are briefly described below

1. Process mapping; the flowcharts contained in procedures and quality manuals show how a process should work. But process mapping helps to show how a process really works.
2. Value stream maps; Value stream mapping (VSM) is an advanced form of process mapping, which focuses on the process using the principles of lean and from the perspective of value
3. Time value maps; A time value maps demonstrates graphically the proportion of time that is spend adding value
4. Five laws of lean; the five laws of lean encapsulate the lean approach and provide key principles for improvements. The five laws are:
    a. The law of market
    b. The law of flexibility
    c. The law of focus
    d. The law of velocity
    e. The law of complexity and cost
5. Seven wastes; the seven wastes are useful structure for identifying, eliminating and preventing waste. Several new wastes have recently been added, along with the wastes specific to service industries. The seven wastes are overproduction, waiting, transporting, over processing, unnecessary inventory, unnecessary motion and defects. Some new wastes are wasted human potential, wasted energy, pollution and wasted space.
6. Spaghetti diagrams; spaghetti diagrams are a simple tool that can help to highlight process waste (particular excessive transportation) by mapping the actual route of a particular resources through a physical environment.

Lean analysis practical

Each technique was applied and the results are shown in this paragraph.

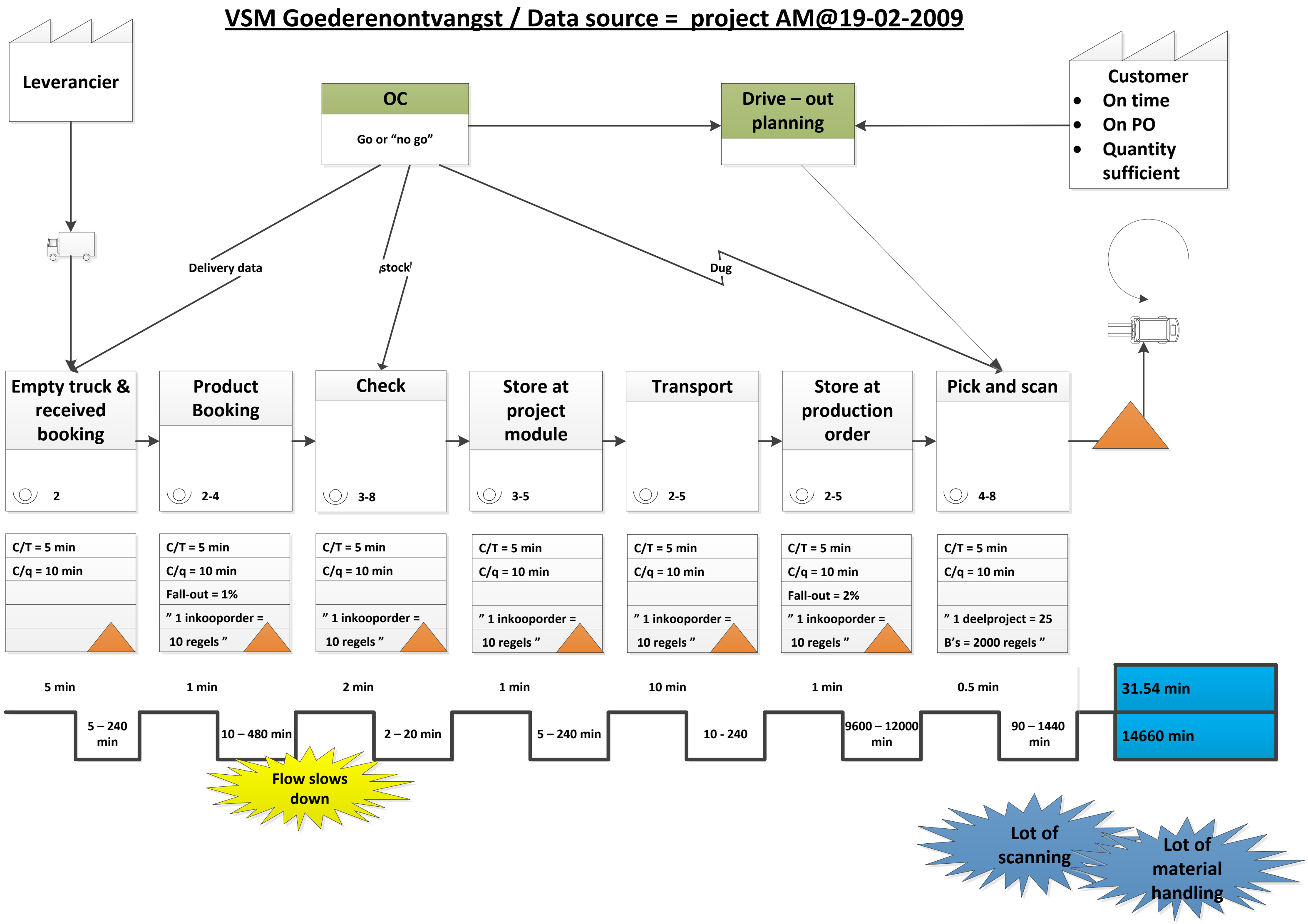
1. Process mapping is applied and resulted in a four level process map. That one is shown in appendix A.5.
2. The value stream mapping is used for analysing the intern warehouse and following production hall. Both value streams are shown in appendix 1.2.
   The first value stream map of intern warehouse started at supplier until it leaves the intern warehouse, the value adding time is 31.54 minutes and the maximum of non-value adding time is 14660 minutes or equally, 5.15 workings days. Remark on this large difference is that waiting time for supplies is included.
   The second value stream zooms in at the production hall. Products are moved from warehouse to production hall. The results of the first VSM are included in the second. The second value stream zoomed in at the production process. The result this value stream is 41.2 hours of value adding activities and maximum of non-value adding activities are 89.16 days assume no errors in delivery. (Errors can be: goods to late delivered, goods in wrong quantity and wrong quality). Assuming a maximum of one error is more realistic and the non-value activities increase to 119.7 days.
3. The time value map summarized the entire process from supplier until it leaves expedition. The time value map showed the same result and is therefore excluded.
4. The five laws of lean are analysed: The law of market and the law of flexibility did not show strange conclusions.
   The law of focus did found some conclusion; I did notice that main delays come due a wrong delivery. The final product must be hermetic and therefore a small damage is directly a problem. Damaged supplies and supplies in wrong quality is directly a problem.
   The law of velocity was also true; there was a lot of inventory in the production hall. There was 1.6 million in stock, waiting for parts. This was excluding the actual work in process, which were around 400,000 euro. The ratio of work in process and waiting stock is 1: 4.
   The law of complexity and cost did also show some interesting conclusion. The product seems complicated but when actually building it, it appeared that lots of supplies are equal. Simply comparing the different types of products, it showed that often 58 per cent of the materials are the same.
5. The seven wastes are taken into account and resulted in a lot of low hanging fruit. A few examples are: no standard set of working tools, a machine that wasn't used anymore due out scouring, a simple handle that can be outsourced (and actually is) and personal closets which contains a coffee machine and even Christmas decorations!
6. The last tool was a spaghetti diagram. The walking of employees is analysed this way. This result can be found in appendix A.4. The main conclusion was that people often walk to an illegal buffer of goods, to the foreman, to a colleague for some tools or searching for missing materials. All those walking distances are not necessary.

Conclusion lean analysis

The conclusion of the lean analysis is that it helped to understand the process and it noticed some important points. The main conclusions were:

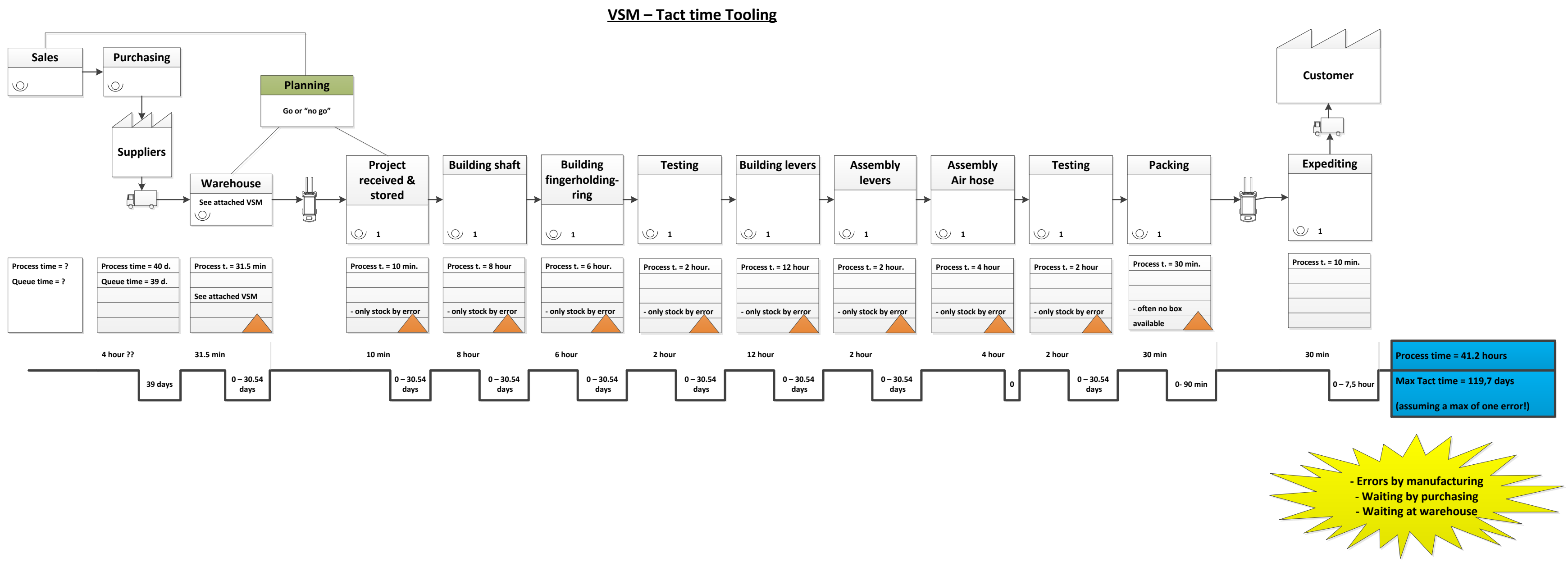
- Low hanging fruit
- 41.2 hours production time & takt time of 89.7 days without errors
- 1.6 million in stocks, waiting for missing parts due wrong quality, quantity or delivery time
- 59 per cent of the materials are standard for the product
- People walk much more than necessary

A.2. Value stream map warehouse

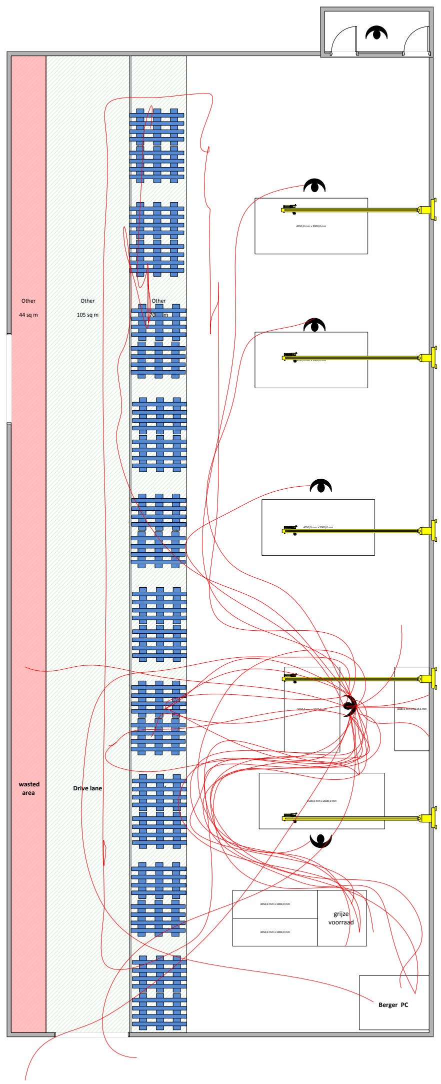


A.3 Value stream map production

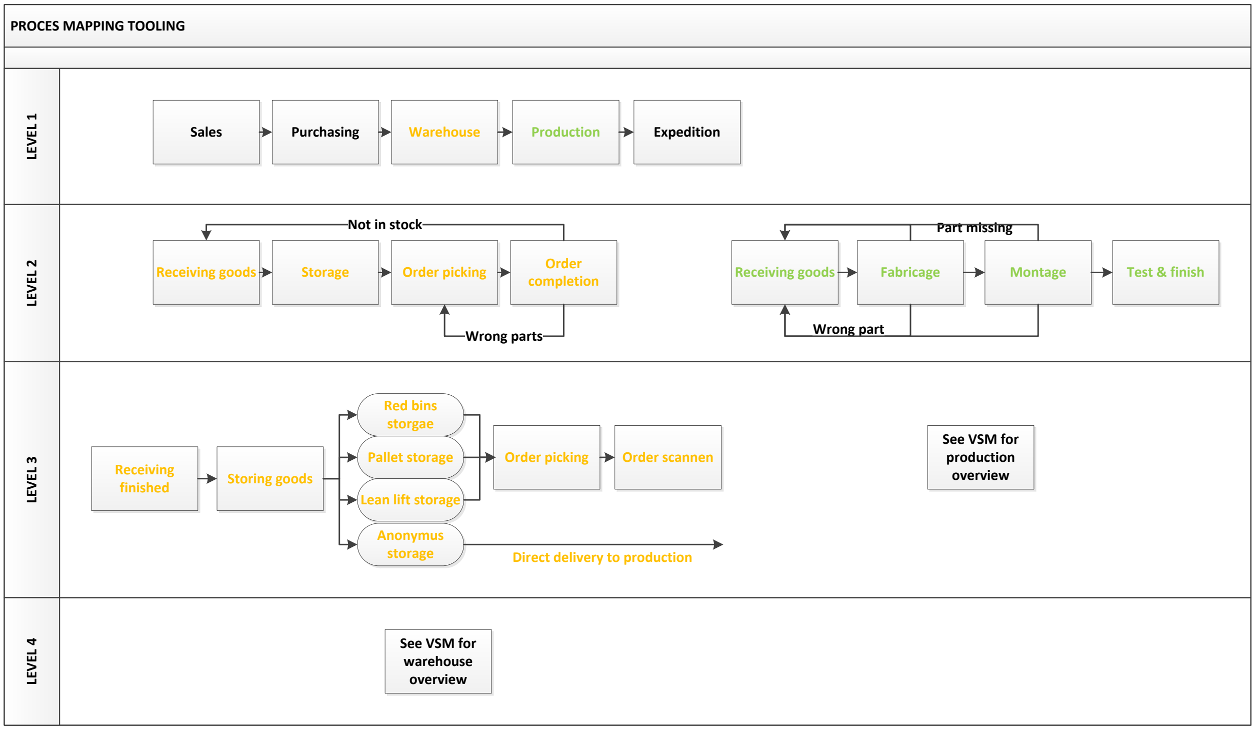
This paragraph contains the value stream map of the production floor.



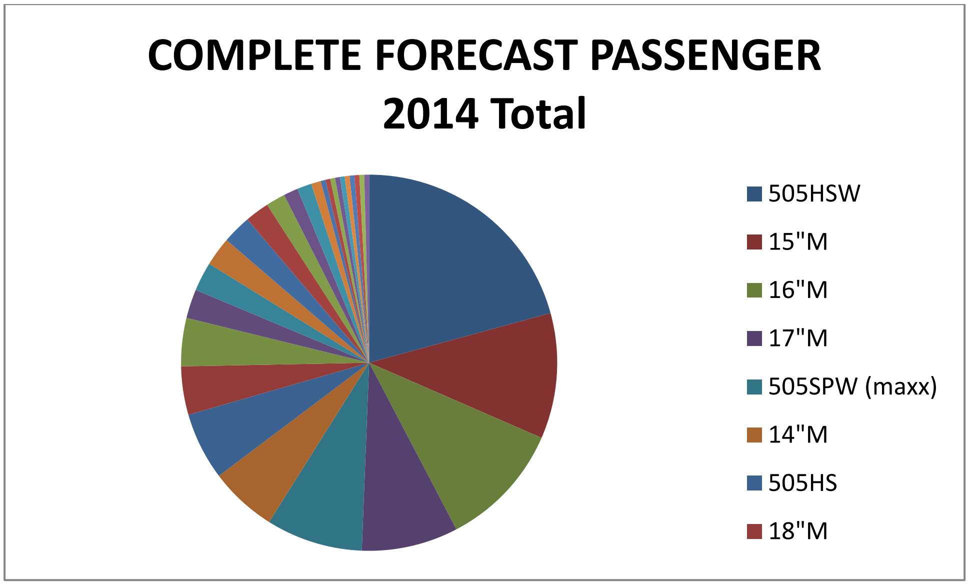
A.4. Spaghetti Diagram



A.5. Process mapping



A.6. Analysis of forecast



A.7. Basic mathematical steps

Replication of mathematical: (source)

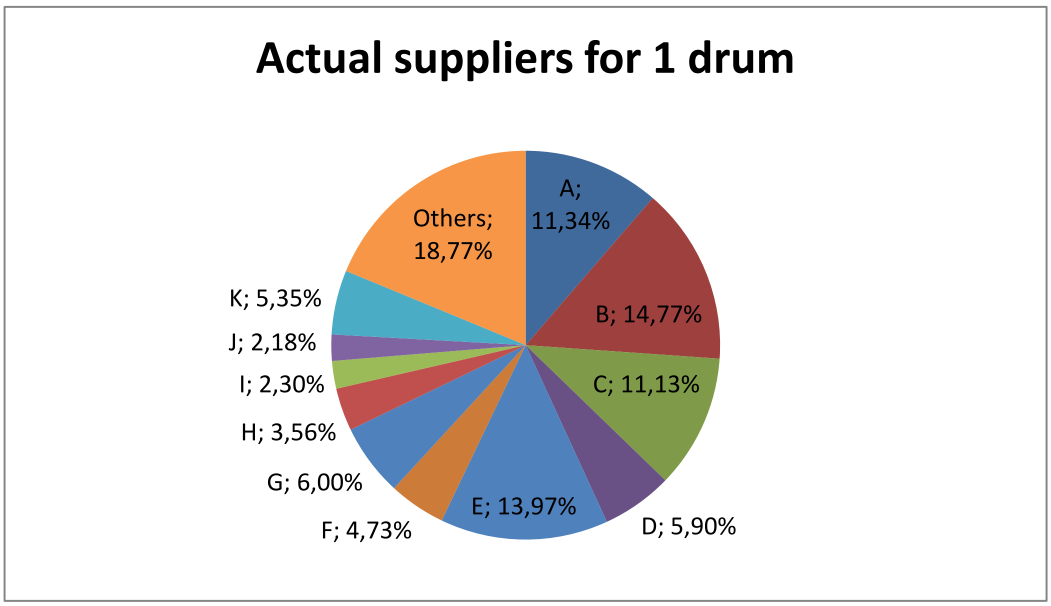
$$\frac{a}{b+c} = \frac{\frac{a}{z}}{\frac{b}{z} + \frac{c}{z}}$$

X can be any value, take delta as value

"$z = x$"

A.8. Analysis of suppliers

Supplier	Actual suppliers for 1 drum	First supplier for 1 drum	Difference
A	11,34%	11,34%	0,0%
B	14,77%	9,97%	4,8%
C	11,13%	27,18%	16,1%
D	5,90%	5,90%	0,0%
E	13,97%	11,86%	2,1%
F	4,73%	4,73%	0,0%
G	6,00%	4,62%	1,4%
H	3,56%	3,56%	0,0%
I	2,30%		2,3%
J	2,18%		2,2%
K	5,35%	2,06%	3,3%
Others	18,77%	18,78%	



A.9. Analysis of suppliers

Sensitivity analysis actual case	
Actual order cost project per order line	*Saving*
1	2,6900
2	5,3801
3	8,0701
4	10,7601
5	13,4501
6	16,1402
7	18,8302
8	21,5202
9	24,2103
10	26,9003
11	29,5903
12	32,2804
13	34,9704
14	37,6604
15	40,3504
16	43,0405
17	45,7305
18	48,4205
19	51,1106
20	53,8006
21	56,4906
22	59,1807
23	61,8707
24	64,5607
25	67,2507

A.10. Normal probability distribution table

TABLE B.1 (Continued)

k	$f_u(k)$	$p_{u\geq}(k)$	$G_u(k)$	$J_u(k)$	$G_u(-k)$	$J_u(-k)$	k
1.81	0.0775	0.03515	0.01392	0.009952	1.8239	4.2661	1.81
1.82	0.0761	0.03438	0.01357	0.009677	1.8336	4.3027	1.82
1.83	0.0748	0.03362	0.01323	0.009409	1.8432	4.3395	1.83
1.84	0.0734	0.03288	0.01290	0.009148	1.8529	4.3765	1.84
1.85	0.0721	0.03216	0.01257	0.008893	1.8626	4.4136	1.85
1.86	0.0707	0.03144	0.01226	0.008645	1.8723	4.4510	1.86
1.87	0.0694	0.03074	0.01195	0.008403	1.8819	4.4885	1.87
1.88	0.0681	0.03005	0.01164	0.008167	1.8916	4.5262	1.88
1.89	0.0669	0.02938	0.01134	0.007937	1.9013	4.5642	1.89
1.90	0.0656	0.02872	0.01105	0.007713	1.9111	4.6023	1.90
1.91	0.0644	0.02807	0.01077	0.007495	1.9208	4.6406	1.91
1.92	0.0632	0.02743	0.01049	0.007282	1.9305	4.6791	1.92
1.93	0.0620	0.02680	0.01022	0.007075	1.9402	4.7178	1.93
1.94	0.0608	0.02619	0.009957	0.006873	1.9500	4.7567	1.94
1.95	0.0596	0.02559	0.009698	0.006677	1.9597	4.7958	1.95
1.96	0.0584	0.02500	0.009445	0.006485	1.9694	4.8351	1.96
1.97	0.0573	0.02442	0.009198	0.006299	1.9792	4.8746	1.97
1.98	0.0562	0.02385	0.008957	0.006117	1.9890	4.9143	1.98
1.99	0.0551	0.02330	0.008721	0.005940	1.9987	4.9542	1.99
2.00	0.0540	0.02275	0.008491	0.005768	2.0085	4.9942	2.00
2.01	0.0529	0.02222	0.008266	0.005601	2.0183	5.0345	2.01
2.02	0.0519	0.02169	0.008046	0.005438	2.0280	5.0750	2.02
2.03	0.0508	0.02118	0.007832	0.005279	2.0378	5.1156	2.03
2.04	0.0498	0.02068	0.007623	0.005124	2.0476	5.1565	2.04
2.05	0.0488	0.02018	0.007418	0.004974	2.0574	5.1975	2.05
2.06	0.0478	0.01970	0.007219	0.004828	2.0672	5.2388	2.06
2.07	0.0468	0.01923	0.007024	0.004685	2.0770	5.2802	2.07
2.08	0.0459	0.01876	0.006835	0.004547	2.0868	5.3219	2.08
2.09	0.0449	0.01831	0.006649	0.004412	2.0966	5.3637	2.09
2.10	0.0440	0.01786	0.006468	0.004281	2.1065	5.4057	2.10

Normal Distribution Probability Table (Silver, Pyke, & Peterson, Inventory Management and Production Planning and Scheduling, 2007)