Creating a Tailored Analysing Methodology for VMI

Bachelor Thesis

Steve Prins
s.a.prins@student.utwente.nl
s2002302

Lead Supervisor:
dr. P.B. Rogetzer

Second Supervisor:
dr. R. Guizzardi – Silva Souza

External Supervisor:
J. Hendriks

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Author
Steve A. Prins
Bachelor Industrial Engineering and Management

Company

VMI-Group

Gelriaweg 16

8161 RK, Epe

The Netherlands

University of Twente:

University of Twente

Drienerlolaan 5

7522 NB, Enschede

The Netherlands

Supervisor VMI:

Jan Hendriks

1st Supervisor University of Twente:

dr. P.B. Rogetzer

2nd Supervisor University of Twente:

dr. R. Guizzardi – Silva Souza

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VMI GROUP

Management Summary

This research has been performed at VMI in Epe. VMI faces a problem which is a delta (or difference) between the estimated and actual man hours in production. However, the delta itself cannot be decreased if the causes for this difference were not found. Therefore, a methodology has been created to try and find the causes resulting in this delta. To perform this research, the following research question was stated:

How can VMI better understand the causes that result in a delta between the estimated and actual production hours?

VMI is a company founded in 1945 in Epe. Originally, the company was founded to help rebuilding the railway network of the Netherlands after the second world war. Currently, they are the market leader within the production of tyre machines with big clients such as Michelin and Bridgestone. Over the lifetime of 76 years, VMI has also expanded to other production facilities in Poland and China in order to fulfil demand.

First, the context of the problem has been understood. This was done by performing unstructured interviews with the required employees and supporting the overall concerns of VMI by analysing some provided data. From this exploratory research, it became clear that VMI wants to have a methodology which would fulfil their demands. Although they already have certain methods implemented, this does not cover the causes of the overrun and therefore something new had to be implemented.

To perform the research, first a literature research has been done on what tools would be beneficial to use for VMI. Following this literature research, it became clear that an Ishikawa diagram, an affinity diagram, an impact effort and/or a cause and effect diagram would be most useful in combination with a possible pareto analysis according to existing literature. Once these most plausible tools/techniques had been found, the general idea of how the methodology should look like was created. This consists of three meetings which all have their own inputs and outputs and which finally results in a selection of causes which result in the delta. Afterwards, flowcharts have been created to give a visual overview of how each meeting should look like and what activities were required to do.

After the initial creation of this methodology, it has been tested at the work floor itself. The goal was to test the methodology three times. The first two tests created clear results and the methodology improved iteratively. However, the third test did not go ahead due to several reasons. Therefore, this test was not performed and expected rewards were given based on earlier performed tests and already implemented techniques within VMI.

By performing the tests, the following conclusions were created:

- The system of having a preparation, observation and evaluation meeting creates a clear structure within the methodology.
- The use of a hybrid between the Ishikawa and affinity diagram would be preferred during the observation phase, whilst combining a cause and effect matrix and pareto analysis would be most efficient during the evaluation.
- It is important to create clear focus points for each observation.

Based on these conclusions, the following recommendations were made for VMI to further implement the designed methodology:

- Create trustworthy data for improving the data analyses on what items need to be investigated further.
- Improve the hour registration both regarding the actual production hours as well as the Q-hour registrations.
- Create a dashboard to create a quick and clear overview of what items are performing below expectations.

Since this methodology has only been tested two times in reality, it is advised for VMI to further test with this methodology based on their experiences and thus to improve this methodology based on the earlier iterations. More validations can be performed once the solutions to found problems, with the use of this methodology, have been implemented.

Acknowledgements

Dear reader,

Before you lies the thesis that I have been working on in my final year of the bachelor's degree of Industrial Engineering and Management (IEM) at the University of Twente. The research was performed at VMI which is located in Epe.

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List of Abbreviations

Abbreviation	Meaning
3M	Muda, Mura, Mudi
5S	Workplace organization method (Seiri, Seiton, Seiso, Seiketsu and Shitsuke)
7W	Seven types of waste
BPR	Business Process Reengineering
CM	Cost Meeting
CMM	Cost Monthly Meeting
CPM	Cost Pulse Meeting
DMADV	Define-Measure-Analyse-Design-Verify
DMAIC	Define-Measure-Analyse-Improve-Control
E-BOM	Engineering Bill of Materials
FB	Function Block
GTRU	Green Tyre Removal Unit (or Green Tyre Removal Assy)
M-BOM	Manufactural Bill of Materials
MPSM	Managerial Problem Solving Method
NC	Nacalculatie (actual man hours)
NOK	Not okay
PE	Production Engineer
Q-Hours	Quality hours
TQM	Total Quality Management
TWVB	Technical Work Planner (Technisch Werkvoorbereider)
VC	Voorcalculatie (estimated man hours)
VMI	Veluwse Machine Industrie
VSM	Value Stream Mapping
XF	Cross functional

Chapter 1 Introduction

This bachelor assignment has been created in collaboration with VMI. A suitable assignment has been created in collaboration with the production department. During this chapter, an introduction will be given on the company (Section 1.1), the problem statement (Section 1.2), research approach (Section 1.3 and research design (Section 1.4).

1.1. VMI

The “Veluwse Machine Industrie”, or better known as VMI, is a company founded in 1945 by Jan de Lange. His intentions were to manufacture machines which would help rebuilding the railways in the Netherlands after the destruction of the second world war (VMI-Group, 2021). 76 years later, VMI is the global market leader in manufacturing production machinery within most of its industries. The company is still located in its birthplace Epe. However, they have also opened production facilities in Poland and China as well as having multiple service centres all over the world. Currently VMI have over 1600 employees over the world whilst 900 of them work in Epe.

VMI is specialised in manufacturing the production machinery needed to produce tyres and its rubber semi-finished products. Companies like Bridgestone, Michelin and Apollo Vredestein are using machines that are produced by VMI. Over the last years, VMI has expanded its operating field. Nowadays, they also manufacture machinery needed to produce metal cans, medicine packaging and cotton pads. With this portfolio, VMI is regarded as the global market leader in the manufacturing/assembly of production machinery within their scope.

During this thesis, also some department names within VMI are used. Therefore, it would be useful to explain these terms and their roles within the company. First, within the production department, the Production Engineers (PE) are mentioned. Their role is to improve and optimize the production process/layout. The parts of the machines themselves are made by the mechanics. A group of mechanics is lead by their foremen. Another department involved are the *“Technisch Werk Voorbereiders”* (TWVB), or better explained as the estimators. This department creates the estimated number of hours that can be spent in production. Also, the Cost Engineers (CE) are involved. These employees perform the data analysis on the acquired data by VMI to analyse the performance of the company.
Although this department is not considered during this research, the Global Field Service is shown in Figure 6. This department assembles the disassembled machines at the factories for the clients of VMI.

Also, it is required to understand that machine is not made in its entirety but is split up into different components. The first level of component are the modules of the machine. For example, a machine can be made up of five modules which can later be assembled. Also, these modules are split up into several Function Blocks (FB). Every FB can also be split up into several other components, but these are not relevant for this research. With this understanding of the company, the problem context proposed by VMI can be explained.

1.2. Problem Context

The production process at a company of the size of VMI is very complicated. As explained earlier, the machines created by VMI involve many different modules. Therefore, they also work on these modules and assemble them afterwards. This creates an exhaustive supply chain and many different departments are involved for the creation of a machine. Therefore, many different variables have an influence upon the production process.

Currently, VMI is noticing a difference ("delta") between the estimated and actual production hours. Currently, the actual hours often exceed the estimated hours without a known reason, resulting in an exceedance of hours (a so-called "overschrijding") which is unfavourable by VMI as this means that the capacity of the production facilities is not reached. This is a problem that VMI wants to solve. However, solving a problem without knowing its causes will be a very inefficient process. Therefore, it will first be vital to find the causes which lead to this phenomenon.

To seek the causes of the delta, VMI already implemented some different methods for creating a better understanding of causes for the excess hours. An example of one of these systems are the Q-hours. Hours labelled in the system as Q-hours represent the production hours that do not follow the "First Time Right" principle. These hours represent the extra hours spent on reworking and correcting mistakes in the production process and used material.

1.3. Problem Identification

Earlier in Section 1.2, the action problem has been described. This action problem is the occurring delta between the estimated and actual production hours. However, solving the action problem was not possible within the ten weeks in which this bachelor assignment will take place. Therefore, solving the core problem was the main focus of this research. To find this core problem, first a problem cluster is created from which the core problem(s) can be deducted.

1.3.1. Problem Cluster

In Figure 1, the problem cluster for the action problem can be found. On the left-hand side of this problem cluster, the action problem is stated. The action problem, the delta between the estimated production hours, occurs because either the production staff is not working efficiently (i.e. at its fullest potential) or because the estimated hours are not a good representation of the actual hours. If the production staff is working in an inefficient way, this can either be because of reported problems in the production facility, which in turn are caused by known mistakes. Also, this inefficiency can be caused by problems that are not known (yet). These unknown causes will also result in an inaccurate estimation of the production hours since the TWVB department is not aware of these problems and thus cannot use this information in their estimations. The unreported problems are caused by a limited indication of the actual occurring problems at the work floor. The limited indication is in turn caused by a knowledge gap in the systems of evaluations/validations.

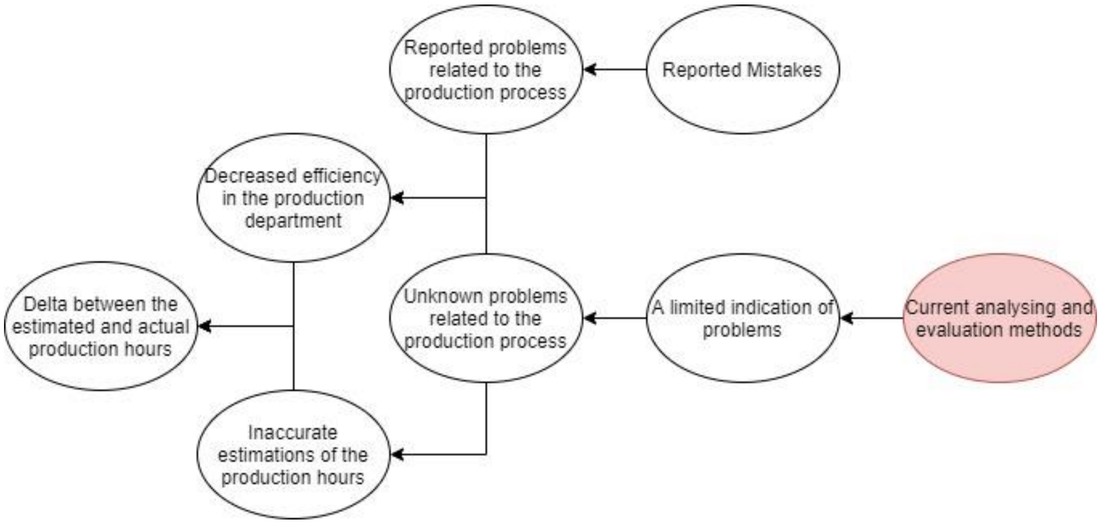


Figure 1 - Problem cluster

1.3.2. Core Problem

The final step of the problem identification is the selection of the core problem. The first requirement is that the core problem should not have any causes itself. As can be seen in the problem cluster in Figure 1, two possible core problems can be chosen. The core problem can either be the insufficient dealing with the reported mistakes or insufficient analysing/evaluation methods. To select the best core problem, the problem whose solution will have the biggest impact whilst having the lowest cost should be chosen as the core problem (Heerkens & van Winden, 2017).

The first possible core problem is to help VMI better deal with the already reported mistakes. Solving this problem should increase the efficiency in the production department. Also, since the problems are already known, the impact can be significant for VMI. The second possible core problem is to deal with the insufficient analysing and evaluation methods for VMI. Solving this problem will eventually result in a better efficiency at the work floor as well as VMI being able to better estimate the production hours. Although the predicted impact is not as big as solving the other problems in the beginning, this will benefit VMI in the long run more than solving the first core problem.

Together with VMI, it has been decided that improving the analysis and evaluation methods to ultimately be able to find reasons for unknown problems related to the production process will have the best cost-benefit ratio for the company. Therefore, this was selected to be the core problem of this research.

1.4. Research Approach

During this section, the research approach is explained. This starts by introducing the main research question, after which the intended deliverables are explained. This will result in the research methodology used. This includes a detailed description of the (sub) research questions and data-gathering methods for every step of the research methodology. Also, the scope of this research will be described.

1.4.1. Research Question

To solve the core problem as stated during Section 0, the following research question has been created:

How can VMI better understand the causes that result in a delta between the estimated and actual production hours?

In order to solve this research question, also further sub-research questions need to be stated. This will be done based on the proposed research methodology and will be described during Section 1.4.3.

1.4.2. Intended Deliverables

The main deliverable of this assignment is a tailored analysis methodology for the production process VMI. This methodology should be an addition to current systems in use and should fill the knowledge gap that VMI has on finding the causes of the delta. For VMI, the creation and testing of this analysis methodology will be seen as a spin-off which, if successful, will be further implemented within their organisation.

As VMI might want to implement this analysis methodology in the entire facility in Epe and afterwards also in other production plants, it will also be important to give a recommendation on how this methodology can be scaled up. This recommendation will entail the experiences that resulted from the test phase as well as the improvements that could be made towards the final design.

The third deliverable will be a recommendation on some possible solutions towards the found problems. Although this is not in the scope of the research and not directly expected by VMI, it will be a proper addition towards this research as this show the benefits that can be yielded from implementing this methodology.

1.4.3. Research Methodology

For this research, it has been decided that the Managerial Problem Solving Method (MPSM) will be most suited for this research. This problem-solving approach has been created by Heerkens and van Winden (2017). However, to better suit the assignment, a small change has been made during this research.

The MPSM itself contains seven different steps. However, for this research, step 4 (Formulating Solutions) and step 5 (Selecting Solution) have been combined. This combined step is called "Design of Solution". This has been done since the creation of the methodology will be an iterative process and not multiple solutions will be created, but one will be created and improved over time.

All the six steps that will be performed have their own challenges. Therefore, sub questions have been created for every step of the MPSM. Also, some sub-research questions have been created, which are indicated with a ●.

1. Defining the problem

During this phase, it will be important to create a better understanding of the problem:

- What is the core problem of this research?
- How can this core problem be expressed in a research question?
- What are the key constructs in which the core problem can be expressed?

2. Formulating Problem-Solving Approach

Next, it will be important to create a problem-solving approach which will suit the problem defined during the first step:

- What is the most suited problem-solving approach for solving the core problem?
- What will the research design look like?

3. Analysing the problem

More context should now be known for the approach of this research. During this phase, it will be important to fill in the gaps in the earlier made problem identification:

- What theories and models are available for solving the core problem?
- What is the gap between the norm and reality?
- What theoretical perspective will suit this problem?
- What earlier and/or current solutions are used?

4. Design Solution

Most of the concepts of the problem should now be understood. The next step is to design the proposed solution:

- What theories will result in a suited analysis methodology for VMI?
- What requirements should the methodology have?
- How can the effectiveness of the methodology be measured?

5. Implementing the Solution

The designed solution should also be tested and implemented. A plan of approach for this step will be created during this phase:

- What implementation steps are needed?
- How can possible resistance be tackled?

6. Evaluation of the Solution

The final step is to evaluate the proposed solution:

- How can the methodology be implemented on a larger scale?
- Is the methodology following the requirements of VMI?
- Does the methodology measure what is wanted?

To answer these research questions, also some data needs to be gathered. Therefore, for each step of the problem-solving approach the data-gathering methods are noted. These can be found in Table 1 together with the deliverables for each step.

Step MSPM	**Data-Gathering Method**	**Deliverables**
1. Defining the Problem	Unstructured interviews	Core problem, research question, key constructs
2. Formulating the Problem Solving Approach	Unstructured interviews, literature research	Problem-solving approach, research design
3. Analysing the Problem	Observations, unstructured interviews, data analysis, literature research	Gap norm and reality, theoretical framework

4. Designing Solution	Literature research, unstructured interviews	Proposed solution for problem
5. Implementing the Solution	Literature research	Implementation plan for the solution
6. Evaluation of the Solution	Observations, data-analysis, semi-structured Interviews	Comparison of effected situation and desired situation, recommendation for further implementation, evaluation of created solution

Table 1 - Steps of the Problem-Solving Approach

1.5. Research Design

During this part, the chosen research design will be explained. This will include the chosen key variables and their operationalization, the theoretical perspective of this research and the research methods that will be used.

1.5.1. Success Factors

This research mainly involves qualitative research. Creating variables and operationalizing them was nearly impossible. Therefore, it was decided to create some factors which could deem this research to be successful.

The first of these factors is to create more collaboration between departments. Currently, most departments perform their own work and there is little cooperation between them. As VMI is a manufacturing company, it will be important that the during Section 1.1 explained departments have more interactions to better understand each other.

Within the current systems of VMI, the involved parties do not investigate the production process together and some departments not at all. Therefore, it is also important for VMI that the departments which mainly work on the office (TWVB and CE) also experience the work floor. This also has the benefit of easier communication between the work floor and these departments.

Since no such methodology exists at VMI, one of the success factors was to have a methodology which was created. Therefore, if a proper methodology is created which can also be implemented within the company, then this research can also be seen as successful.

1.5.2. Theoretical Perspective

In the field of operations management, a lot of different theories/perspectives are constructed. Since this research revolves around the topic of operations improvement, four main theories can be used as a perspective for this research that will suit this research. Following Slack et al. (2013), these are Business Process Reengineering (BPR), Total Quality Management (TQM), Lean and Six-Sigma.

BPR is the first improvement approach. It is an approach which focusses on “a radical redesign of processes in order to gain significant improvements in cost, quality, and service” (Ozcelik, 2013, p.99). This leads to big changes within process, which will, if implement correctly, also result in big improvements. However, the biggest downside is the high risk versus rewards that is at stake. Although big rewards can be yield, the risk for failure is also very high. Since VMI is mostly interested in small but continuous improvements, this improvement approach will not be suited for this research, and thus will also not be used.

The second possible perspective to take is Total Quality Management (TQM). TQM itself is a very broad topic and trying to define it "is like shooting a moving target" (Boaden, 1997, p. 169). However, Zairi (1991) gives a good and broad definition which defines TQM as looking "looks for continual improvement in the areas of cost, reliability, quality, innovation, efficiency and business effectiveness" (Zairi, 1991, p.42). Boaden (1997) also stated that TQM does not have a clear distinction between principles and practices, which makes it hard to define TQM. However, Boaden (1997) stated eleven elements which are involved when TQM is used as a (theoretical) framework. These eleven elements are:

1. Customer focus, with emphasis on the customer-supplier relationship, internally and externally.
2. The commitment of everyone to quality improvement, especially managers.
3. Training and education considered as an investment.
4. The involvement of everyone within the organization in quality improvement.
5. A focus on processes.
6. The use of teams and teamwork.
7. The use of appropriate tools and techniques, reviewed regularly.
8. Goal-setting, measurement, and feedback for all aspects of the business.
9. Continuous improvement as a philosophy.
10. A change in the culture of the organization, i.e. the way people think and behave.
11. The inclusion of quality principles into product and service design.

These eleven elements are clearly implemented within the vision and strategies that VMI are using. For example, their entire improvement strategy regarding the production is revolved around exploiting continuous improvement. Also, no one is working alone, but everyone is part of a bigger team and within the production department there is a lot of commitment towards (quality) improvement. This, together with countless other examples make this theory very suited for this research.

The third perspective is Lean (also called Lean Management or Lean Manufacturing). Lean focusses on the stability, predictability, and the elimination of waste (in Lean terminology also called Muda) (Theisens, 2017). This improvement approach originated in Japan in the 1930s and in the 1950s by two managers of Toyota. Lean Management focusses on five principles. The first of these principles is to identify what is valuable for the customer and also how their products/services meet those values. The second principle is to map the value stream, which is mapping the entire life-cycle of a product. The third principle in Lean Management is to create an efficient product flow by having a strategically organized work floor. The fourth principle is to use a pull-based production system. The fifth and final principle is to seek perfection. However, having a perfect production process is not something that can be achieved. Therefore, one should seek for perfection by constantly improving. The idea of constantly improving is often referred to as continuous improvements.

Lean is a theory that is already widely implemented within the company. With their approach towards continuous improvements and the affinity with some of the tools that Lean will present, this will be a very suited theory to use during this research.

The fourth and final approach is Six-Sigma. Six-Sigma is a philosophy which focusses on the reduction of variety, which will lead to less rejections, a more stable quality, and lower costs (Theisens, 2017). This improvement approach was created in 1979 by Motorola. One of the principles within the Six-Sigma philosophy is the use of data-driven problem solving (Brook, 2014). Six-Sigma usually revolves around drawing conclusions from statistical analysis after performing measurements and thus from here create the data-driven problem solving.

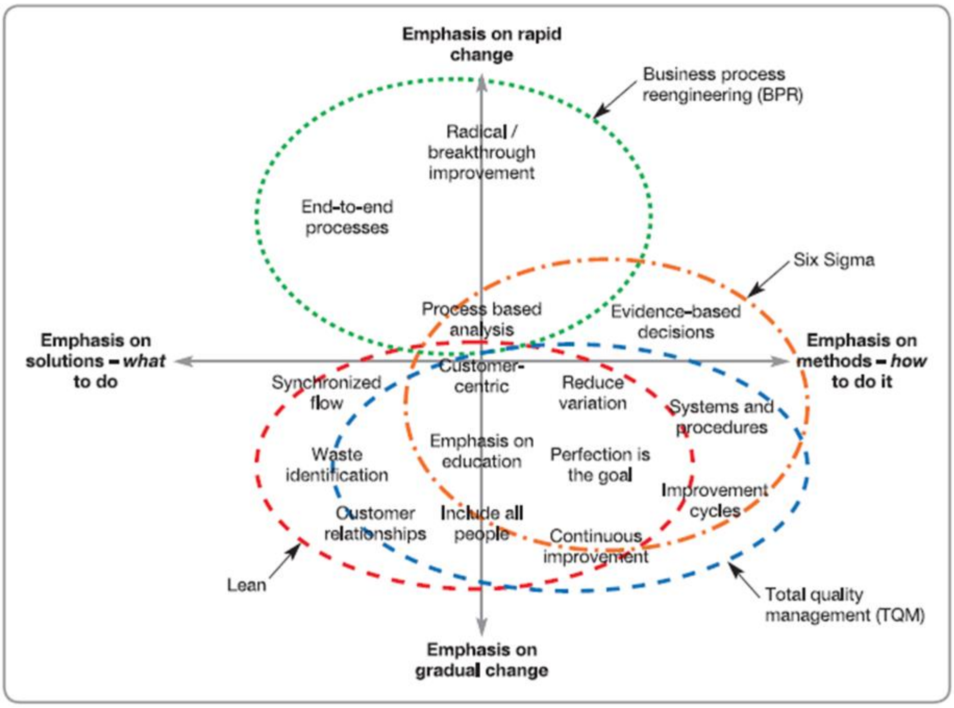


Figure 2 - BPR, Lean, Six-Sigma and TQM on a two dimensional grid (Slack et al., 2013)

From the earlier given information, it can be concluded that a combination of TQM, Lean and Six-Sigma will be most suited for this research. Since TQM is regarded as a very broad approach, it will be very suited as a guideline for the theoretical perspective. Also, the elements that TQM stands for really suite VMI. However, TQM also has its downsides which will be filled with the perspectives of Lean and Six-Sigma. These two approaches are also often combined in the Lean Six-Sigma approach (Slack et al., 2013). It has also been stated that Lean Six-Sigma is a very well-suited addition for TQM as they perfectly complement each other (Andersson et al., 2006). Therefore, a combination between TQM and Lean Six-Sigma is the theoretical perspective. Also, following Slack et al. (2013), this theoretical perspective perfectly fits within the wishes and needs of VMI as can be seen in Figure 2.

1.6. Outline

This thesis consists of the following chapters which result in an answer to the research question. A small description will be given regarding the contents of each chapter.

During chapter 2, first an overview will be given on the context of the assignment. This means that the cause of this assignment is discussed as well as several different topics that need to be explained to better understand the context.

Chapter 3 contains the result of the performed literature research. This combines the results from the Systematic Literature Review and also some additional relevant books that have been found and taken information from.

Chapter 4 is about creating the first design of the solution. Based on the results found in Chapter 3 and the given ideas by VMI, a solution has been drafted. For this solution, it was needed to first come up with a rough draft after which the literature study is used to fill in the gaps for which tools/techniques to use.

Chapter 5 is about the testing of the drafted design. These tests were performed using a PDCA cycle, created a clear structure whilst testing. Three tests have been performed after which the final solution is proposed to VMI.

Chapter 6 is the final chapter of this thesis and contains the conclusion, discussion and recommendations that are made towards VMI.

Chapter 2 Context Analysis

The goal of this chapter is to give some background information regarding the current systems in use as well as to give more background on the reasoning for the research. First, in Section 2.1, an explanation will be given on the system used for creating the estimated hours. Then, in Section 2.2, an insight will be provided on the Q-hours registration. Afterwards, in Section 2.3, an analysis is made on the given data and what can be concluded from this data.

2.1. Creation of Estimated Hours

If a delta is occurring between the estimated man hours and actual man hours, of course first an estimation needs to be made. Therefore, this process will shortly be described to give an insight in how this is performed at VMI.

As said during Section 1.1, the TWVB department create the estimations. The creation of the estimated hours are based on two different tools that are used. Also, the estimated hours could be based on any (validated) hours from earlier projects.

Within the compare tool, a technical work planner can create an estimation for the man hours based on five different scenarios, in which a combination of different codes is used. The codes can either be “EMPTY”, “A01”, “A02” and “A03”. The meaning of these codes can be found in Table 2.

Code	Meaning
EMPTY	No reference is found of this item.
A01	The estimation of this item is based on the calculation tool.
A02	The estimation of this item is based on a validation made earlier.
A03	The estimation is based on an earlier estimation, but this earlier estimation is not (yet) validated.

Table 2 - Description of Codes in the Compare Tool

As can be seen in Table 2, the “A02” code is based on a validation. During this process, the aim is to have a consensus on what the actual man hours should be of a certain item. This also means that this validation is only finished if everyone involved agrees. Therefore, this validation can be seen as the most reliable estimation for the man hours.
Also, in Table 2, the calculation tool is being presented. This is an inhouse built tool to determine the estimated hours based on the drawings and information that has been sent towards the technical work planners.

With the use of these codes, the technical work planners can compare the to be estimated item with an earlier produced item. This is done within the “compare” tool. Depending on the code of the to be compared item and what relevant items are present within the compare tool, an estimation is made. The combination of these tools and their result based on the most valid comparison is seen in Figure 3. For example, if the new item does not have any direct reference, so the code “EMPTY” is seen, and the most relevant compare item has been validated (A02), than the result will show a A03_K (K means a new result), is created.

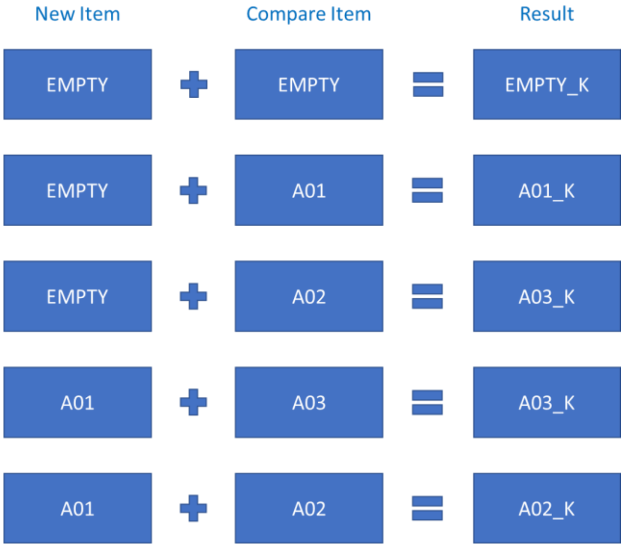


Figure 3 - Overview of Different Compare Combinations

2.2. Given Data

The occurring difference between the estimated and actual man hours is the starting point of this research. To solve this problem, VMI have already introduced a system which should help them with getting insight in this problem. This system is based on the earlier stated Q-hours.

2.2.1. Q-Hours

A difference between the estimated and actual man hours does not occur without a reason. Therefore, VMI has introduced the system for Q-hours to gain more insight in the problems that result in this delta.

The term Q-hours is an abbreviation for "Quality Hours". The definition VMI uses is that a Q-hour can be registered if an activity does not follow the "First Time Right" principle, or in other words, if an activity does not add value to a produced machine.

In the production process, if the critical path is followed and every process is synchronized to perfection, every activity should follow the "First Time Right" principle. However, in reality this is not possible and also not a true problem as long as the cause of the extra time is known. Therefore, VMI introduced this system to detect where the production of their machines is taking longer than expected to find these causes and being able to improve the production process.

The Q-hours can be registered by employees at the work floor. In Figure 4, the outline of this tool can be seen. For registering a Q-hour, the employee has to enter their name, the production order on which this Q-hour is stated and the fabrication step at which the Q-hour is registered. Then, they can select many different codes which all provide VMI with different information on why a project is taking longer than expected. Therefore, if these hours are registered with high accuracy, VMI is able to understand and tackle the problems that the production floor is facing.

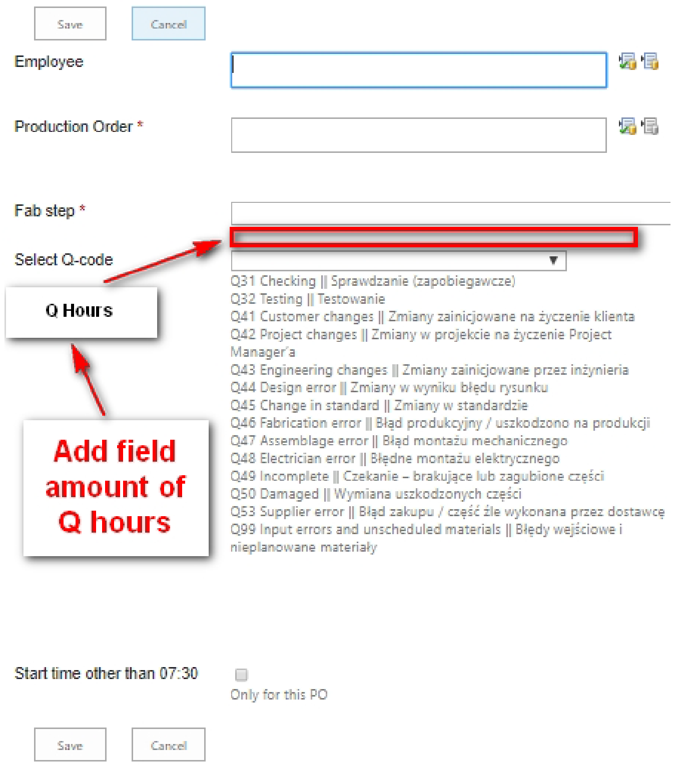


Figure 4 - Tool for the registration of Q-Hours

2.2.2. Current Situation

If VMI has full insight in the extra man hours that are present, the to be created methodology is not needed. Therefore, it would be interesting to see whether the Q-hour system entails most of the overrun based on the given data.

Below in Figure 5, the median is shown of the percentage of reported reactive hours (Q-hours) compared to the estimated hours over the period between 2011 and 2019. With red bars the median of the difference between the man hours and the estimated hours are shown. To avoid confusion, a negative percentage in the red bars means that the actual man hours exceed the estimated hours.

What can be seen in Figure 5 is that there is a significant difference between the overrun of man hours and the registered overrun. Also, for all of the projects the Q hours are at least half of the extra man hours (red bar). Therefore, it can be concluded that VMI needs extra insight in the occurring problems at the working space to understand the causes of the delta.

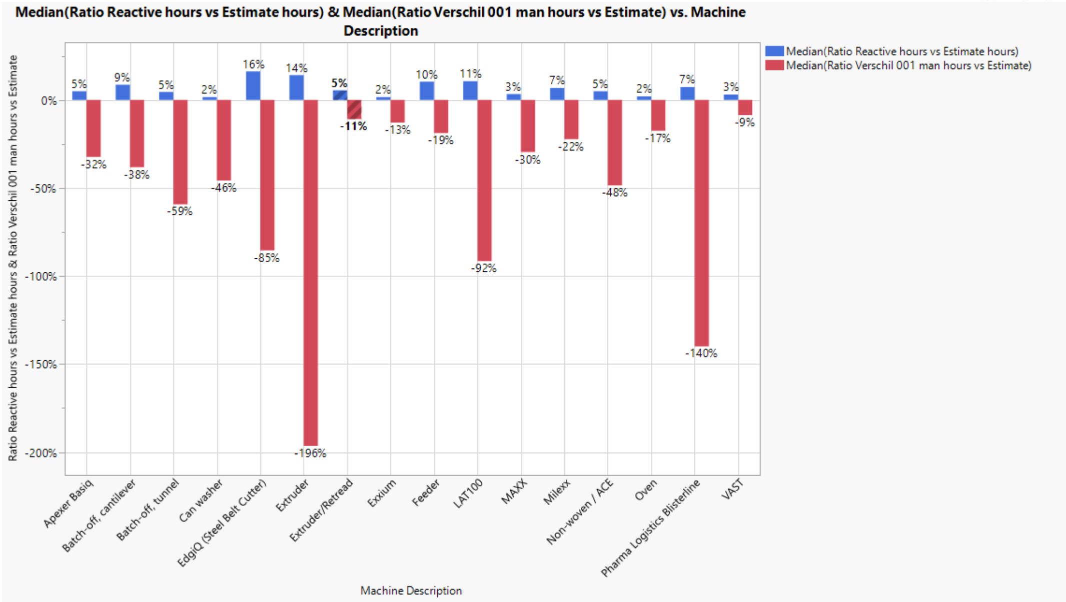


Figure 5 - Q-Hours vs. excess hours (2011-2019)

However, it will also be relevant to know where these hours occur as the man hours are not only produced in the production line, but also in other departments. Following Figure 6, which gives an overview of the actual and estimated hours for a selected machine over a year, it can be concluded that percentage wise most of the excess hours are produced either within the Global Field Service department (they assemble the machines at the customers) or within the production process. Since the global field service is also dependent on factors outside of the company's influence, it will first be useful to seek for causes within the internal production process of VMI.

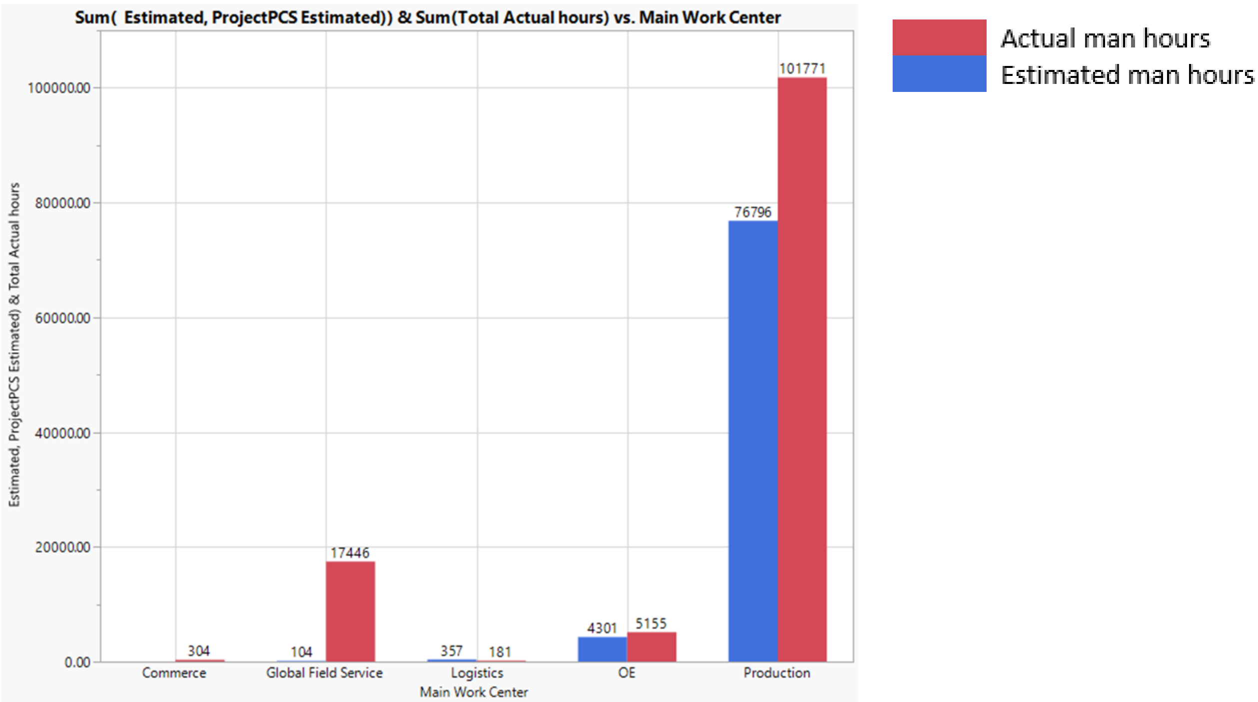


Figure 6 - Estimated hours vs. actual hours per department

2.3. Cost Assurance Process

The methodology that will be created is not a standalone process, but the aim is that it will be incorporated within a bigger process. This process is known as the Cost Assurance Process. Although this process will only be considered during the recommendations and further research that will be given to VMI, it will be useful to have a basic understanding of what this process is intended to look like.

In Figure 7, an overview is given of the different processes that will be implemented within this Cost Assurance Process (C). This process consists of four stages which starts at the C/Kaizen in Team. The aim of this part is to go towards the work floor and find possible causes of the delta. This information is then used for every department in a Cost Meeting (CM), which in the figure is depicted as CM-P or Cost Meeting Production, in which the respective departments can tackle the earlier found problems. Also, a regular Cost Pulse Meeting (CPM) is held with all departments together (cross functional, or in other words XF) to keep each other informed on what projects are running to solve certain problems. Finally, all this information is reported to the management (Mgt. Reporting) via a Cost Monthly Meeting (CMM).

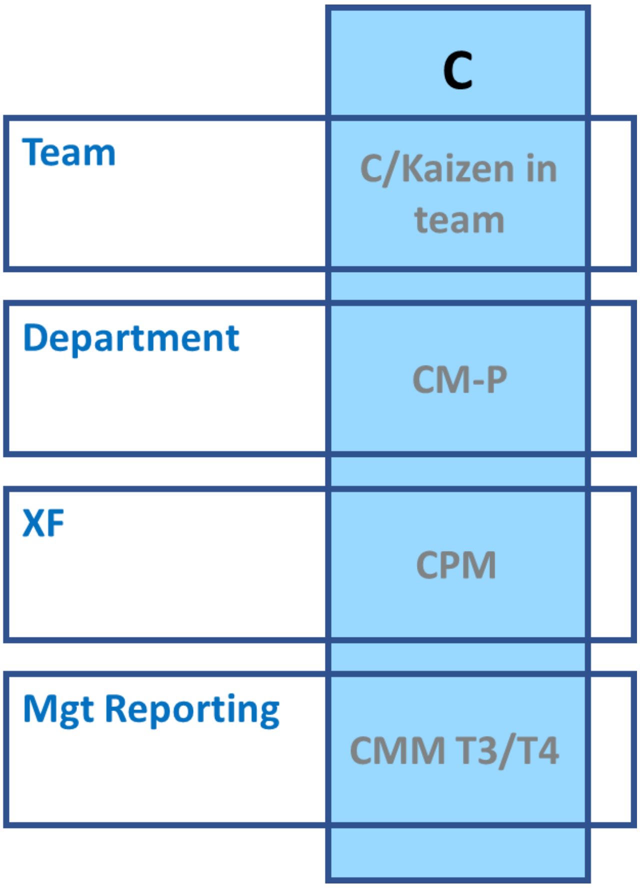


Figure 7 - Structure Cost Assurance Process

2.4. Conclusion

During this chapter, the context of the assignment has been given. This started by giving a quick overview of how the estimation of hours is created. Afterwards, the concept of Q-hours are explained as this was the starting point for this research. After this explanation, the data has been discussed on the actual man hours versus the estimated man hours as well as the reactive man hours versus the estimated man hours. From this data, it has been concluded that a gap is present between the known causes for the excess hours. Also, it has been discussed what process VMI wants to eventually implement to solve the problems around costs.

Chapter 3 Literature Review

The following step is to perform a literature study. During this literature study, the main focus revolves around the following research question: *“What theories and models are available for solving the core problem?”* as stated in Section 1.4.3. Also, a first step will be made to answer the research question *“What theories will result in a suited analysis methodology for VMI?”*, which will therefore mean that the fourth phase of the MPSM is also started. Whilst combining these two research questions, the following main research question is created for this literature study:

What relevant analysing techniques are available within the field of operations management to detect (possible) causes of a problem?

Solving this research question should result in an answer for the research question of *“What theories and models are available for solving the core problem?”*, whilst it should initiate the answer to the second stated research question during the previous paragraph.

The literature study itself consists of two parts. The first part is a performed Systematic Literature Review following required procedures and information found on several databases. This process can also be found in Appendix A. After this, some information from relevant other materials have also been added.

3.1. Systematic Literature Review

3.1.1. Improvement Cycles

Continuous improvement is a process which resolves around performing improvement cycles. Within the theoretical framework of TQM, Lean and Six-Sigma, three different cycles can be used.

The first improvement cycle comes from the “Kaizen” philosophy, which is a Japanese management philosophy. Kaizen can roughly be translated as “change for the better” and is a combination of the two Japanese words Kai (change) and Zen (good) (Fonseca & Domingues, 2018). Besides that, this philosophy is based on multiple values, and it is also one of the most well-known philosophies for continuous improvements. For this continuous improvement, the so-called PDCA (Plan-Do-Check-Act) cycle is one of its core concepts (Fonseca & Domingues, 2018). Within the Lean philosophy, this cycle is also known as the Deming cycle and also widely used in combination with the Lean philosophy (Realyvásquez-Vargas et al., 2018).

Within the Six-Sigma framework, the DMAIC (Define-Measure-Analyse-Improve-Control) cycle is “well established as a benchmarking tool for process improvement and customer satisfaction” (Gijo et al., 2014, p.194). Opposed to the PDCA cycle, this improvement cycle consists of five stages. Since this cycle is a bit more advanced, it is also often used within the combined Lean Six-Sigma philosophy. Within this framework, another improvement cycle can be used. Li (2018) states the DMADV (Define-Measure-Analyse-Design-Verify) cycle. Whereas the DMAIC and PDCA cycles are focussed on improving the existing processes, the DMADV is focussed on designing new processes (Li et al., 2018).

3.1.2. Identifying Waste

One of the core principles of Lean Manufacturing is to identify and eliminate all types of waste within a process (Magenheimer et al., 2014). Lean recognizes seven types of waste (7W) within a process, which are transportation, inventory, motion, waiting, overproduction, overprocessing and defects. To reduce the waste, different techniques/tools can be used within the Lean philosophy. For identifying the waste within a process, mostly the 5S's and Value Stream Mapping (VSM) will be of utmost importance (Sharma et al., 2017).

3.1.3. Other Tools

Using an improvement cycle can be used as a good basis for the to be created methodology. However, to efficiently perform the required steps, other tools might be important to use as well (Realyvásquez-Vargas et al., 2018).

For finding the (root) causes of a quality problem, many different tools are available. Some of the most known and simpler tools are known as "The Seven Basic Tools of Quality" (Pereira et al., 2019). These tools are the Pareto diagram, Ishikawa (cause-and-effect) diagram, check lists, scatter diagrams, histograms, and control charts. Another two effective tools to use for solving quality problems are the use of Gemba walks and using One Piece Flow (Cohen et al., 2020). The "Gemba" is roughly translated as "place where it happens" (Fonseca & Domingues, 2018) and is also prominent within the earlier stated Kaizen management philosophy.

3.1.4. Combination of Tools

Using only one tool with an improvement cycle will likely not be sufficient to gain as much information as VMI wants. Therefore, it will also be important to investigate what combination of tools can be useful.

To combine different tools or techniques, the best results will be achieved if these tools are used holistically (Sharma et al., 2017). Besides, it will also be important that the implemented tools will complement each other. Sharma et al. (2017) state that a very high correlation is present between the VSM and 5S and the Kaizen philosophy and 7W. A high correlation is noticed between VSM and Kaizen, VSM and 7W, Kaizen and 5S and Kaizen and also between the 5S and 7W tools.

The correlation between Kaizen, VSM and 5S has also been stated by Thomas (2018). That article also shows that the Pareto charts can have a strong impact on continuous improvement as well as using brainstorm sessions is suggested for waste identification. To make the Pareto Analysis as efficient as possible, the Five Why technique can be used to seek for deeper causes, whilst this can also be used during the brainstorming sessions.

With a practical implementation of the DMAIC cycle, a lot of success can be created with using Ishikawa diagrams. Within a related industry, such as the tyre building industry for VMI, the Ishikawa diagram can be used to find problems, which can later be solved for improving a production facility (Gupta et al., 2018). Also, a combination of DMAIC, an Ishikawa diagram and a Pareto Analysis showed great benefit to reduce the waiting time of a line supervisor at a car parts manufacturer (Kanyinda et al., 2020). The use of the Ishikawa diagram will be most efficiently used during the analysis phase of the DMAIC cycle (Sharma et al., 2018). Although the PDCA cycle does not involve an analysis phase, it has been shown to also cooperate well with an Ishikawa diagram (Pereira et al. , 2020) and it can best be implemented during the planning phase.

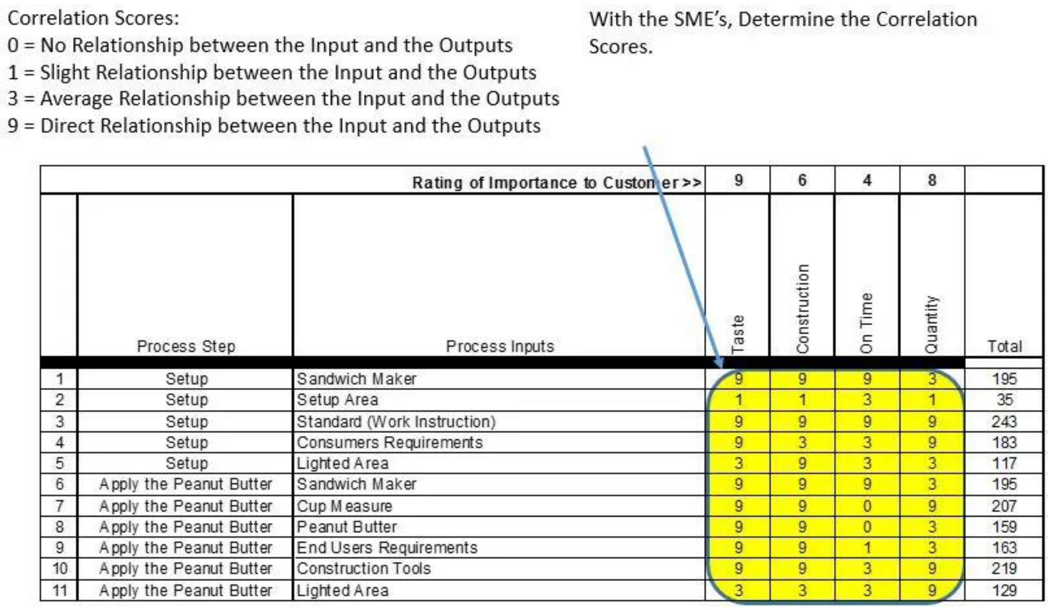
3.2. Other Literature

Another important topic within the Lean Philosophy is the use of the Mura (irregularity), Muda (wastefulness) and Muri (unreasonableness), also known as 3M. Following Lean, improvements within a production process can primarily be found by removing these three aspects. Following Theissens (2017), Muda stands for the typical waste which has also been explained during the previous part, so the 7 types of waste. Mura stands for variation, which is any variation ranging from the variation of customer demand to the cycle times. Muri is created when a team has an unreasonable amount of work to execute, so this term can also be referred as the overload of work on a person/team.

Another important aspect that Theisens (2017) writes about is the use of analysis tools that are often adopted within the Lean Six-Sigma Framework. Most of the time, a Pareto Analysis, a cause-and-effect matrix or an Effort Impact Matrix could be used.

First, he states that a Pareto Analysis can be a very useful analysing tool. This tool makes use of the 80-20 rule, in which, in this research, 80% of the unknown overtime is caused by only 20% of the total causes. Therefore, this would be a useful tool to use to which problems should have the priority to be solved.

The cause-and-effect matrix is another often used tool within the chosen theoretical framework. An example of this is shown in Figure 8. This tool makes use of the Key Process Output Variables (KPOV), which will be given a weight between 1 and 9 (low to high importance). Then, every input/influence of the process should be stated, which are the Key Process Input Variables (KPIV). Then a correlation should be quantified between every KPIV and KPOV, which can also be done on a scale of 1 to 9. Then, for every KPIV, a score can be determined by adding the multiplication of the correlations and weights. The most important inputs should have the highest score and thus should be solved first.


Correlation Scores:
0 = No Relationship between the Input and the Outputs
1 = Slight Relationship between the Input and the Outputs
3 = Average Relationship between the Input and the Outputs
9 = Direct Relationship between the Input and the Outputs

With the SME's, Determine the Correlation Scores.

		Rating of Importance to Customer>>	9	6	4	8	
	Process Step	Process Inputs	Taste	Construction	On Time	Quantity	Total
1	Setup	Sandwich Maker	9	9	9	3	195
2	Setup	Setup Area	1	1	3	1	35
3	Setup	Standard (Work Instruction)	9	9	9	9	243
4	Setup	Consumers Requirements	9	3	3	9	183
5	Setup	Lighted Area	3	9	3	3	117
6	Apply the Peanut Butter	Sandwich Maker	9	9	9	3	195
7	Apply the Peanut Butter	Cup Measure	9	9	0	9	207
8	Apply the Peanut Butter	Peanut Butter	9	9	0	3	159
9	Apply the Peanut Butter	End Users Requirements	9	9	1	3	163
10	Apply the Peanut Butter	Construction Tools	9	9	3	9	219
11	Apply the Peanut Butter	Lighted Area	3	3	3	9	129

Figure 8 - Cause and Effect Matrix (Clay K., 2021)

The third and final analysing tool is the Impact Effort Matrix as shown in Figure 9. With this matrix, a problem can be organized whether it will be "useful" to solve depending on the impact and effort. For example, a grid of 10 by 10 can be created of which (5,5) is the exact middle point. Then in the upper left quadrant, the Quick-Wins are realised, which are the problems of which solving would have a high impact for the company whilst spending low effort. For major projects, they will also have a high impact, but also take a lot of effort to get done. The bottom-right quadrant are the thankless tasks which take a lot of effort, but yield low impact. The final quadrant on the bottom left are the fill ins which have a low impact but are solved with little effort. This matrix can give an overview of what problems will be relevant to tackle (mainly the Quick Wins and Major Projects).

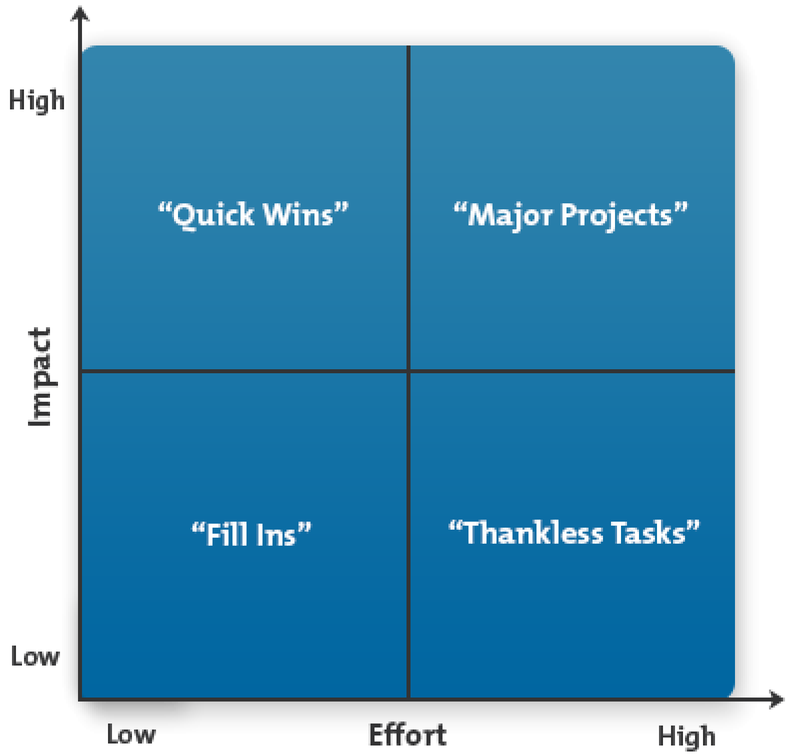


Figure 9 - Impact Effort Matrix (MindTools, n.d.)

Also, Theisens (2017) noted that Lean Six-Sigma mostly focusses on statistical tools to use during the improvement of processes. Many different types of statistical tools are available, but Theisens noted the following as most important and beneficial to use (randomly placed as they all serve a different purpose in different situations):

- Pareto analysis
- Check sheet
- Scatter plot
- Bar chart
- Pie chart
- Time series plot
- Histogram
- Boxplot

The use of these statistical tools can be found both during the selection of function blocks to be chosen as well as checking for VMI later on as improvements have been made.

3.3. Conclusion

Following this literature research, it can be concluded that a lot of different tools can be used and that therefore a tailored analysing methodology can be made for VMI. However, which tools will be tailored for VMI needs to be tested.

For brainstorming sessions, or finding ideas, it can be concluded that an Ishikawa diagram or an affinity diagram will fit within the framework. Also, although not considered within the framework but proven useful from experience, a mind-map is a useful brainstorming tool. Therefore, these can be used during the planning phase as well as on the work floor itself.

During the analysing of the found problems, a cause-and-effect matrix and action-priority matrix will perfectly fit the needs of VMI. Also, if a more statistical analysis needs to be performed, the Pareto analysis is a tool that can be used as well as comparing data with the use of the earlier noted statistical tools.

Chapter 4 Solution Design

Based on findings from the literature study (see Chapter 3) a solution for the problem that VMI proposed will be developed. Therefore, during this chapter, the following research question will be answered: *"What theories will result in a suited analysis methodology for VMI?"*. First, a general outline will be made to discuss the starting point of the solution. Afterwards, the inputs and outputs of certain processes will be discussed. Finally, the outline of each meeting will also be visualized after which the relevant theories can be chosen.

4.1. General Outline

To start generating the solution, VMI already gave some ideas and a general outline of what the solution should look like. After explaining this, it is also interesting to take a look at what information is needed for each part of the solution.

4.1.1. Given Concepts

To start, the goal was that CE should select a FB for which the data is "interesting". Then, a cost engineer should go to the work floor together with a production engineer and a technical work planner for about 4 hours, after which the improvement points could be found with some kind of analyses.

From this general description, it was first concluded that it would be needed to create certain focus subjects for each observation. Therefore, first a preparation meeting will be held in which the Cost Engineer will explain why the function block will be observed. After this explanation, it will be interesting to discuss the already known points to create a few guidelines and focus points for the observation.

After this preparation meeting, the team could go to the work floor to observe the certain mechanic. In this case, observing does not mean simply creating a check-sheet to detect the possible flaws in the production process. For this methodology, it means to have a conversation with the mechanic and "walk-though" his/her working station. The points found can then be written down and later be evaluated.

As for the evaluation, it will be important to discuss what points will be most interesting to solve. Therefore, some kind of analysis is needed on the found improvements.

4.1.2. Inputs and Outputs

With the VMIs general outline in mind and the already discussed implementation of these ideas, it was useful to discuss the different inputs and outputs that these processes need. Therefore, first these inputs and outputs will be discussed for each of the three different meetings.

4.1.2.1. Preparation Meeting

For the preparation meeting, it is firstly important that Cost Engineering creates a data-analysis which is understandable for every person present. Also, they must provide a reasoning which is sound for why a certain function block/small module will be observed. Another input that was needed was an elaboration on the estimated number of hours. Particularly where these values come from and how it was constructed would be beneficial as this could also be a reason for the occurring delta.

As far as the output goes, this will first be the focus points of the Gemba Walk. This is the main output and therefore also the goal of this meeting. Besides, it can also be important to decide on the Key Process Output Values whenever a Cause & Effect Matrix might be used to evaluate the found points.

4.1.2.2. Gemba Walk

The second meeting that must be scheduled is the Gemba Walk. This is the actual observation itself. The inputs for this meeting consist of the focus points which are determined in the preparation meeting. Also, the earlier meeting will confirm the methods that will be used during this meeting. Therefore, another input is the time plan as agreed upon.

Although this process will only have one output, it is also arguably the most important one of all of the meetings. The output is a clear overview of all problems that are present at the work floor. Also, some information from the mechanics could be needed for improving the Gemba Walk itself.

4.1.2.3. Evaluation

Once again, the inputs are mostly the same as the outputs from the previous activity. This means that this activity revolves around the occurred problems during the Gemba Walk. Also, if a Cause and Effect matrix will be used, the KPOV values should also be considered as the input and these would be determined during the preparation meeting.

The output of this activity will be two sided. The first is to further improve this methodology as this will not be performed perfectly all the time and might need some small adjustments. Therefore, it will also be important to have a quick discussion on the performance of the methodology which is also based on the inputs the mechanics will give. Also, the output towards other parts of the Cost Assurance Process are the action points for each department that will result from the performed evaluation.

4.2. Schematic Overview Meetings

With the needed inputs and outputs known, the schematic overview of the meetings can be constructed. This will be done with the use of flow-charts. In Appendix B, a brief explanation on the different symbols used can be found. These flowcharts will give a general outline on what activities will take place during each meeting. During the later stages of this thesis, the outline of these activities will be discussed into more detail.

First, the preparation meeting should be planned. The goal of this meeting is that everyone will be on the same page during the Gemba-Walk. This meeting will start with a small introduction of the members involved, after which the Cost Engineer will take over and start discussing the data analysis that is performed. This analysis should lead to the Technical Work Planner giving a brief description of the estimation that was made. Without having any insight on why the certain number of hours is estimated, one cannot discuss this. Afterwards, all of the different ideas that everyone has will be written down, after which the most important issues will be gathered and stated as focus points. Also, the time plan and methods used for the Gemba-Walk will be discussed, after which the meeting is over. The steps comprehending the preparation meeting are shown in Figure 10.

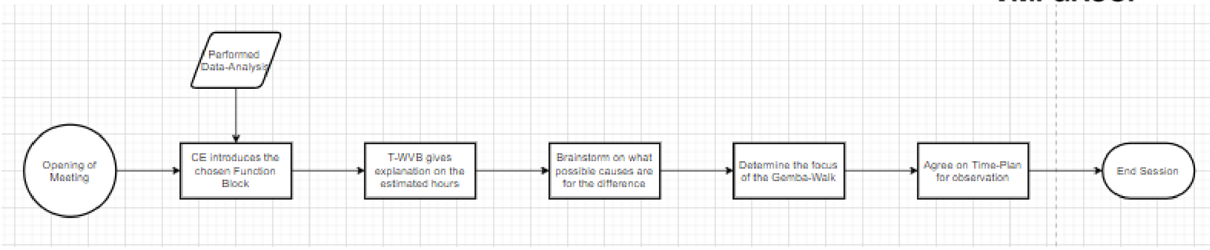


Figure 10 - Flowchart preparation meeting

The second phase is to implement the observation, which is now called the Gemba-Walk. Depending on the present members, a quick introduction will be given once again on the data as not everyone was present. Afterwards, a small recap will be given on what in the morning was discussed after which the Gemba-Walk truly starts. After this, the group will go to the workstation of the mechanic and discuss the focus points based on what can be seen there. Every problem that arises can than be noted down on the used tool. If all focus points are discussed, a quick discussion can be held with the group after which this session can also be ended. In Figure 11, the flowchart of this process can be found.

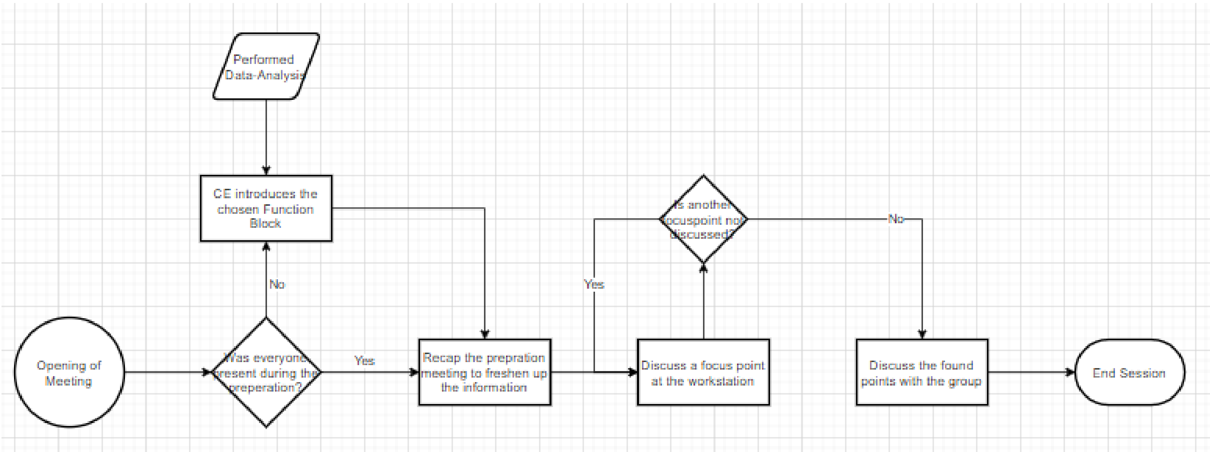


Figure 11 - Flowchart observation

The third and final meeting is the evaluation. This evaluation starts with a recap of what has been done during the Gemba Walk. Afterwards, the found problems should be evaluated, which will result in a list of the most important problems to solve. With this list, the (possible) action points for each department can be noted thought of and afterwards also being written down. Also, a quick evaluation of the process should be done to make sure that this process keeps on improving.

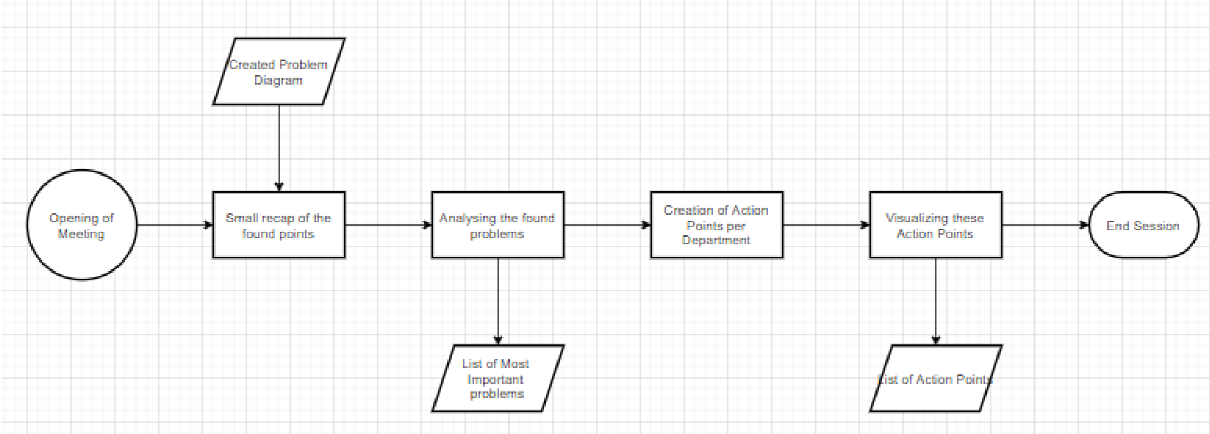


Figure 12 - Flowchart evaluation

4.3. Integrating Improvement Cycles

As stated during Section 3.1.1, an important part of continuous improvement is the use of improvement cycles. For this research, either the use of a Plan-Do-Check-Act (PDCA) or Define-Measure-Analyse-Improve-Control (DMAIC) can be used. Although these two cycles are closely related, it has been decided to use the Plan-Do-Check-Act cycle for this research. This improvement cycle is more in use when developing business models/processes. Therefore, the use of a PDCA cycle is more suitable for carrying out this research. However, when it comes to actually improving business processes based on data-driven choices, the DMAIC cycle will be better to use. Therefore, the DMAIC cycle will most likely be used during the later stages of the Cost Assurance Process.

What can also be concluded form both Sections 4.1.2 and 4.2 is that a lot of information flows between the meetings. For example, the outputs of the final evaluation meeting should be used to improve the following activities that will be scheduled within the same framework. Therefore, indirectly an improvement cycle is already implemented.

With the use of these different meetings and as the earlier said information flows between activities, a natural PDCA cycle is already created. The “C in Ploeg” part, which is the first step of the Cost Assurance Process (Section 2.3), is on its own already a PDCA cycle. It starts with the planning of the Gemba Walk which is done by CE to determine the FB to observe as well as having the preparation meeting. These are all the activities in the planning phase for the actual Gemba Walk which is the Do activity. The Check is performed during the evaluation whilst the Act is split into two ways. The first is to escalate the problems to other departments, which is further done within the Cost Assurance Process and within the “C in Ploeg” is the Act phase based on the improvements that can be implemented within the methodology.

4.4. Appropriate Tools

For the creation of the tool, some different tools will be used for the brainstorming sessions as well as the evaluation methods. Therefore, these will now be discussed and compared. Also, some data analyses is needed. This is performed by the Cost Engineers which will create their own tool to perform these data-analyses.

4.4.1. Brainstorm

During the execution of the methodology, the aim is to have two "brainstorm" sessions. The first one is during the preparation to find the focus of the observation. The second one is during the Gemba-Walk itself in which the found points need to be written down in an organized way. From the literature study performed earlier, it became clear that either an Ishikawa or Affinity Diagram will be most useful for this methodology.

As said during the earlier chapters, an Ishikawa is a well-known root cause analysis tool within the perspective of Lean Six-Sigma. Generally, the Ishikawa diagram, an example of which can be found in Appendix Cis used if certain specific causes of a problem need to be found. This tool usually starts with a bigger "problem" after which the more specific causes can be extracted.

The second possible tool to use is the affinity diagram. Opposed to the Ishikawa diagram, this tool is usually used for determining more general ideas on a specific topic. Therefore, this tool would be useful for creating a more general view of the "scope" of what subjects that need to be observed. Such a diagram can be found in Appendix D

Both of the possible brainstorming tools have their own strength and weaknesses. For this methodology, all of these stronger and weaker points will have their own place and both tools can be used very efficiently. Since the aim of the preparation meeting is to find different possible problems regarding the extra man hours of a part of the machine, it will be most beneficial to use the affinity diagram as this tool is great to find possible general problems regarding the machine. As for the brainstorming tool used during the Gemba-Walk, the Ishikawa diagram will be a great tool to use. With this tool, it is possible to create a great structure within all of the found problems.

4.4.2. Evaluation

During the evaluation phase, two possible methods could be used. The first of these methods is the Action-Priority Matrix or the Cause & Effect Matrix.

The first evaluation technique that might be useful is the Effort Impact Matrix, as also discussed during the literature study. Usually, this tool is used in the early stages of a project as this is a quick way of separating the much needed tasks from the not so needed tasks.

Although this tool is very instinctive and easy to use, it also has a few downsides. For example, there is not a true "scoring" area and is thus very subjective. Also, using one single scale for the effort of solving an issue can result in a very ambiguous matter of evaluating.

The second evaluation method is the Cause and Effect Matrix. The Cause and Effect Matrix is known for its clear show of correlation between the input variables and the customers outputs. Besides, if scoring is done objectively, it will give an objective view on the most important processes. The downside of this method is that it might be hard to understand at first for certain people. Also, creating a consensus on the scoring of each problem can be an issue if working with many different departments due to their own interests.

From the analysis made, it became clear that both tools can be very effective to use, but both have their advantages and disadvantages. However, to get a true comparison between the two, it would be fair to use them both and find which would fit the best. Therefore, both of these two methods will take part in a test.

4.5. Conclusion

During this chapter, the first intended design of the solution has been presented with the considerations needed between the different techniques/tools that could be used. This started by giving a general introduction by the outline VMI has in mind. This has then been transformed into a systematic way of addressing problems within different meetings. Then, the needed inputs and outputs of each session are discussed. After knowing what is needed, it was important to discuss how these different outputs will be reached within each meeting. After also integrating the improvement cycles, the different tools could be selected.

During the introduction of this chapter, it was said that the following research question would be answered: *"What theories will result in a suited analysis methodology for VMI?"*. From the analysis made during this chapter, it became clear that the use of an Affinity Diagram during the preparation meeting would be most appropriate whilst an Ishikawa diagram is most suited for the observation. As for the evaluation of the found problems, either a Cause and Effect Matrix or a Effort Impact Matrix will be most useful for the methodology.

Chapter 5 Solution Test

With the solution created, it is possible to test different configurations of the desired solution. The aim was to perform three tests at the work floor. However, due to certain unforeseen circumstances, the third test could not be performed. The planning of the third test will be discussed and also what would have been done if different results would have been yield.

5.1. Construction of Tests

The tests will be performed on different Function Blocks/modules, which will be discussed during Section 5.2. Furthermore, it will also be important to select the appropriate steps for testing the intended solution. Also, it should be kept in mind that the solution is iterative and is supposed to change over time as currently different variations are tested.

These tests will revolve around qualitative data. The tests will not be “scored” by giving them a grade. However, discussions will be held on the stronger and weaker points of the test. The found points should than also be considered for the next test. To make sure this will happen, a PDCA cycle will be performed for each test. Following these cycles, the improvements should be found and can also be implemented. After these three tests, the final solution could be made for VMI. This will therefore also be described later on.

5.2. Chosen Test Objects

Of course, the tests also must be performed on suited function blocks. However, as the aim of the test is to find causes for a delta, it does not matter if the delta is either positive or negative since for both situations, certain issues could be found.

From the Cost Engineering department, a selection of five function blocks was made which would be interesting to test. After a discussion, it became apparent that three of these five function blocks are heavily influence by already existing projects. Therefore, these projects were deemed as not suitable and two test subjects remained.

The two chosen parts to be investigated are the Combi Stitcher (which is actually a module, but the size of a function block) and the Green Tire Removal Assy/Unit. First, the reasons for the suited Combi Stitcher are discussed.

Following the chart in Figure 13, it can be seen that the actual hours of the Combi Stitcher are fluctuating a lot. Besides, it is expected that the estimated hours are steady, as this is an often made module within the production department of VMI and thus can be seen as a repetitive module. With the repetitiveness, a stable production process should be present with little fluctuations of hours. However, this is not the case for this module and that is one reason to test this module. Also, as can be seen in Table 4, an average difference is occurring of about 6 hours (43-37 hours) of which only 1 hour on average is noted as a Q-hour. Therefore, this module will be a good test subject.

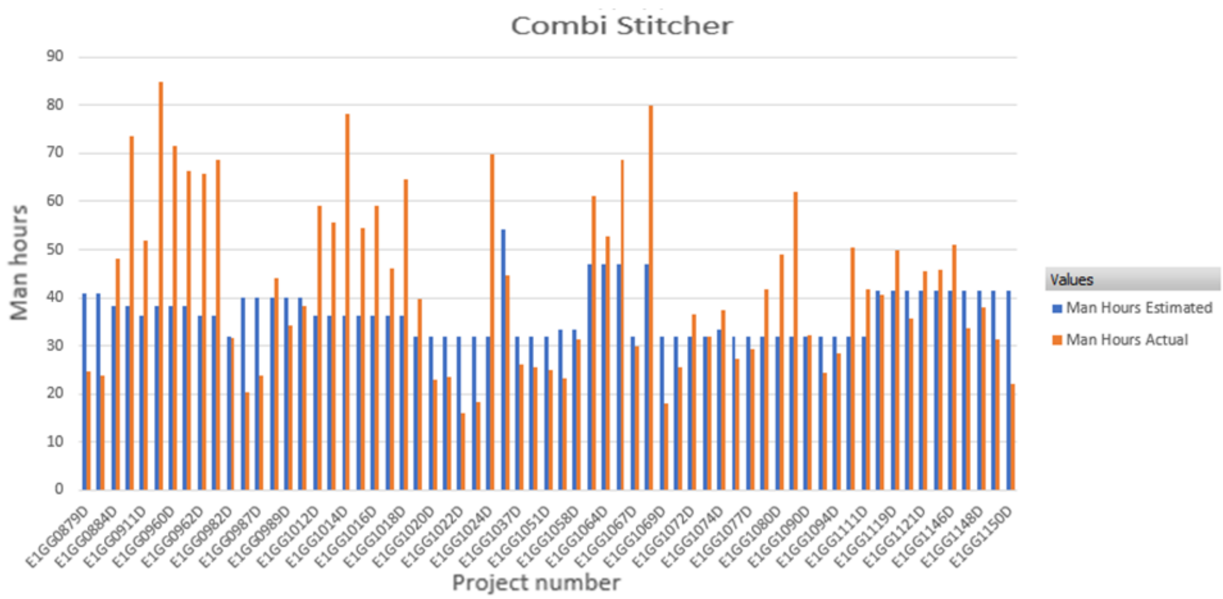


Figure 13 - Bar chart of man hours vs estimated hours Combi Stitcher

# Projecten	Avg EST	Avg Act	Avg Q-code	avg delta	Avg % Diff
65	37	43	1	6	116%

Table 3 - Averages of Values for Combi Stitcher

For the second function block, the Green Tire Removal Assy (also known as the Green Tire Removal Unit (GTRU)) was chosen. As can be seen in Figure 14 and Table 4, this function block clearly shows a significant delta of on average -24 hours. As said earlier, this negative delta might not be the main aim of the methodology to be used on, however, still the usefulness of this methodology could be tested.

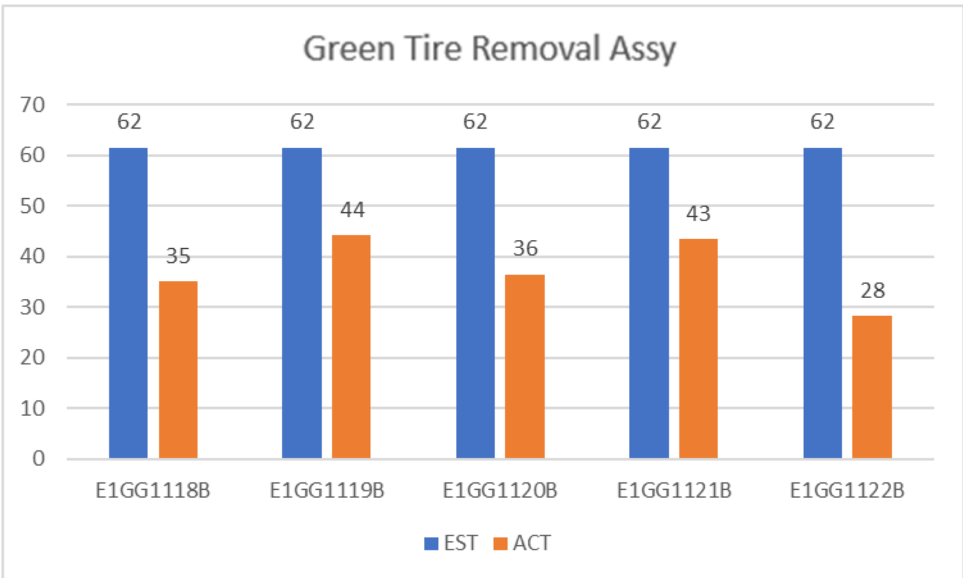


Figure 14 - Bar chart GTRU

Project Code	EST	ACT	Q-code	Delta	% Diff	Diff <> 10%
E1GG1118B	62	35	2	-26	57%	NOK
E1GG1119B	62	44	2	-17	72%	NOK
E1GG1120B	62	36	1	-25	59%	NOK
E1GG1121B	62	43	4	-18	71%	NOK
E1GG1122B	62	28	2	-33	46%	NOK
Total	**308**	**188**		**-120**		
Avg			2	-24	140%	

Table 4 - Detailed information of different projects of GTRU

5.3. Testing

After planning which modules were suitable for performing the tests, it was possible to actually execute these tests. As said, two tests were performed and the possible results of the third test will also be discussed. Afterwards, the (current) final solution could be created. The first two tests were performed on the Combi Stitcher. Both tests were performed with different mechanics, but the same people from Cost Engineering and Technical Work Planners departments. These two persons were always present unless stated different.

5.3.1. First Test

Plan:

The plan for the first test was to investigate the Combi Stitcher. During Section 5.2, it was already discussed why this module will fit the requirements to be investigated. The plan for the preparation meeting was to do this together with a mechanic and the foreman of this mechanic.

The aim of the preparation meeting is to find the focus points for the observation. This observation would be performed at the same day as the preparation meeting, only a few hours later. There, the mechanic would also be present and everyone would walk together through his workspace and ask (unprepared) questions depending on the findings at this workspace. The points that will be found should be written on post-its and placed on a sheet of paper which contains the structure of the Ishikawa diagram. After the observation would be finished, all of the earlier discussed focus points should have been addressed and, if all is performed correctly, several problems should also arise.

After the observation, the aim was to plan a meeting to evaluate the two earlier meetings, preparation meeting and observation. For this meeting, the focus was improving the methodology after which the results were also shortly discussed.

Do:

With the test planned, it was possible to also execute this test. During the preparation meeting, everyone but the foreman was present. Together with the mechanic, the data was discussed and several interesting points were found regarding possible reasons for the existing delta, which could be used as inputs for the observation.

During the observation itself, the Ishikawa diagram was used and it was filled in. The results of this Ishikawa diagram can also be found in Appendix C. With this Ishikawa diagram, all of the found problems were sorted based on the six categories of an Ishikawa diagram.

For the evaluation, only the Technical Work Planner was not present. A discussion was held between the author and the Cost Engineer about the positive and negative points of the preparation and observation. Also, it was noted down what was missing during these meetings. A further description of the results of this meeting will be given during the Check phase.

Check:
Since this is the first test, it will be useful to compare this test with the intended solution and what differences occurred and why these occurred. First of all, the preparation meeting did not have all the expected staff present. However, this did not create a problem since the mechanic had assembled many of the same modules in the past. Therefore, a lot of useful information was gained from this meeting.

Compared to the intended solution drafted in Section 4.2, this test did vary a lot from the earlier created solution, especially during the evaluation meeting. During the evaluation meeting, the first two steps as stated in Figure 12 were followed, however, the explanation of how the estimated hours are calculated was not given. These hours were discussed and deemed sufficient, so this was also not necessary since the mechanic agreed with this estimation and also the estimation was based on the validated hours. The brainstorming session turned out in a discussion with the mechanic and the two other people after which it was easy to deduct the focus points of these tests.

With respect to the Gemba-Walk, once again compared to Section 4.2, it followed exactly the same path as stated during this section. Therefore, the schematic overview was also deemed as useful and clear to follow. In this case, also all the same people were present which meant that no second introduction of the module was needed and the observation could immediately begin. The found points were also quickly discussed afterwards to recap the entire meeting.

The meeting which deviated a lot from the flow-chart is the evaluation meeting. However, as said during the earlier parts, the aim of the first test was not to actually determine the most important problems that were found. Therefore, the focus was to create improvements on the first two steps (preparation and observation) and thus evaluate on these processes, whilst the first iteration of the evaluation would take place during the second test.

Act:
From the evaluation of the performed observation, some interesting points were found. The evaluation itself was solely focussed on the techniques used and not on the problems found. In general, it was concluded that the Ishikawa diagram was working very well. However, a bit more information regarding when to put what point into the categories should be necessary to avoid confusions. Also, the idea to involve more people was created besides some other points regarding what will be done with the found issues in the process.

5.3.2. Second Test

Plan:
For the second test, once again the Combi Stitcher was chosen as the object to focus on. During the first test, everyone was still searching for their “roles” and it was concluded that the Combi Stitcher still had some possible causes left. Therefore, it was justified to take a look again at the Combi Stitcher.

As stated earlier, the plan was that to do the test with the same Cost Engineer and T-WVB employee. Once again, a mechanic was asked to join the preparation meeting. Also, a production engineer was asked to join the observation whilst the author and the Technical Work Planner would do the evaluation.

The techniques that were used during this test was first again a good conversation with the mechanic. Afterwards, an affinity diagram was used to perform the observation after which the evaluation would consist of an Effort Impact Matrix whilst also again having a discussion on the stronger and weaker points of the performed methods.

Do:
Due to a holiday, the Cost Engineer was not able to join the meetings during this test. Therefore, the data-side of this test was lacking. This also meant that it was harder to perform the preparation meeting. Only some general data was available (which is also given earlier) and therefore the preparation did not go as planned. However, the outputs of this meeting were still strong focus points for the later observation.

During the observation, the affinity diagram was used and also the improvement of last time, which was focussing on the earlier discussed points, was implemented. After the observation, the Technical Work Planner and the author came together to discuss the found points with an Effort Impact Matrix and to discuss the performance of the tool.

Check:
During this test, not everything during the preparation went as planned, but it was still possible to perform a solid preparation. Once again, the discussion in the beginning did give good focus points, however, the struggle was to visualize them, which in turn could easily be done by grouping these points and finding the general topics. Although this was not done with some post-its, it was discussed based on the notes created during this meeting.

After this preparation, the observation did go as planned with also strong results and a few repeated results from the first test, which gave confidence that the methodology was working. This time, in Appendix D, the results of this observation could be seen.

What really stood out from the observation was the use of different colours within the affinity diagram. This created a lot of structure and was also seen as a useful input to use in a possible Ishikawa diagram. A downside of this observation was that it became unclear if the focus was to detect possible causes for the overtime or why the overtime was not registered. Although the registration of the overtime is a possible cause of the delta, this was not the entire focus of the observation. However, whilst performing this meeting, the discussion was more geared towards possible ways to improve the registration and not focussing on its causes. Therefore, the focus should have been more geared on observing what problems are present instead of having a discussion on how a certain problem can be solved.

As for the evaluation, this meeting was the meeting which was the least efficient. The Effort Impact Matrix did not feel consistent and it was a lot of estimating for the impact and effort of solving an issue. Therefore, either this method will not be used again, or a mathematical model has to be created to determine the effort and impact a cause has on the delta, which is also done within the Cause and Effect matrix.

Act:
As for the lessons learned and the further improvements, this mainly had to do with the usage of both the affinity diagram and the Effort Impact matrix. As can be read during the “check” part of the PDCA cycle, the usage of different coloured post-its helped keeping focus on certain topics. Also, this

gave a clearer picture of the underlying problems. Therefore, it has been decided to use these coloured papers also during the following test in combination with the Ishikawa diagram.
In the evaluation phase, the Effort Impact matrix did not feel accurate and it was very hard to estimate the impact as well as the effort to solve an issue. Therefore, this needed to be resolved for the next test and therefore, it was deemed most useful to test the Cause and Effect matrix.

5.3.3. Third Test

Also, a third test was planned to be performed. However, due to the mechanics not being present on the day of the test, only the preparation was performed. Still, the plan for this test will be discussed and also what possible results would do for the final solution.

Plan:
The plan for this test was to observe the Green Tire Removal Unit. This change was made since it make the research more valid if it was tested on another module. The aim was once again to perform the preparation meeting as done before, but this time with creating the affinity diagram. Afterwards, the plan was to combine the inputs of the second test and to use an Ishikawa diagram with different colours of post-its for the focus of different points. During the evaluation, the plan was to perform the Cause and Effect Matrix.

Do:
The only part that could actually be tested was the preparation. Only a different mechanic could be present which was not part of the building of this function block. During this meeting, it was also said that no other mechanics were available which were building the machine. Therefore, the test was not performed and since no time was left to perform another test, this iteration could also not be tested. Although the mechanic did have some knowledge on the function blocks, this was not enough to perform a proper preparation meeting and results for this meeting.

Expected Results:
With two successful preparations that have been performed earlier , no issues were expected during this phase of the test. Therefore, the expected results were once again some focus points which could be clearly defined and used during the Gemba Walk. With the information gained on the affinity diagram, it seemed that this could be used for this meeting too as it gave a good overview of the general picture of the problem.

For the Gemba Walk, the aim was to combine the coloured post-its with the Ishikawa diagram. The results expected were to create an overview in which each of the six main areas of an Ishikawa diagram as well as the different focus points are visible.

The evaluation was planned with to use a combination of a Cause and Effect Matrix and pareto analysis. Of course, the expected results regarding what problems would be most important could not be created, however, it was expected that some problems would return from the two earlier performed tests, such as a difference in personnel and the understanding of the hour registration. Regarding the usefulness of the tool, since VMI uses a lot of Lean Six-Sigma tools and the earlier uses of a Cause and Effect matrix and pareto analyses, this was also not seen as a problem and could therefore result into a good analysis.

Discussion:
Although the test was not performed, a discussion was still held with the Cost Engineer and Technical Work Planner instead of the observation. This discussion was geared towards the further implemen-

tation of this methodology. During this discussion, it became clear that the Ishikawa diagram was preferred over the affinity diagram. However, this does not imply that the affinity diagram would be useless. Combining these two tools would yield the best results. This would be performed by using different coloured post its for the different categories of problems. For example, if a problem is found on the delivery of materials, this could have a different colour compared to a problem relating the availability of tools.

Another useful insight was that the impact effort matrix did not yield the wanted results. This was deemed as too much of guessing regarding the placements of the found problems. Therefore, using the impact effort matrix was biased during the test. Using a more objective and numerical approach, such as the Cause and Effect Matrix would be preferred. Also, this tool can be easily combined with a pareto analysis to create an even stronger analysis and find the most important topics.

The third and final important insight was to create more focus on the important topics during the Gemba Walks. During the tests, a problem that arose was that the Gemba Walks did not have a clear structure regarding what topics were tackled during the Gemba Walk. Therefore, this is something that can be performed better, for example by assessing the workplace topic for topic that were found during the preparation.

5.4. Final Solution Design

After the performed tests have been carried out, the goal was to create a final solution based on Section 4.2 and the improvements found during these tests. However, since only two tests were performed, a partial final solution is created for each phase and possible improvements/changes will also be noted.

5.4.1. Preparation

Based on the three performed preparation meetings, it became clear that the earlier created flowchart clearly represents the flow of this process. As for the tools to use, the suggestion towards VMI is to use the affinity diagram whilst brainstorming on the focus points of the Gemba Walk. Also, the Cost Engineer will need some statistical tools which can represent the earlier obtained data. This, of course, is partially dependent on the data available, but the advice is to use basic statistical tools such as a histogram or control chart to give an easy and quick overview of what and why a certain function block will be observed. In terms of personnel available, it would be advised to have mechanic(s), Cost Engineer, Technical Work Planner and a Production Manager, the author took the role of the Production Manager during the tests, present at the preparation. If needed, it could also be advised to invite the foremen of the mechanic(s) to obtain more pre-existing knowledge regarding the function block.

5.4.2. Gemba Walk

For the Gemba Walk, the overall flow chart earlier created also gives the correct and current best flow of this meeting. To note down the occurring issues, it is advised to primarily use an Ishikawa diagram. This tool clearly organizes the found problems. Besides, to be able to also gain more information on what problems relate to certain focus points, different coloured post its can be used for each focus point. As for this part of the methodology, it is advised to have a mechanic, Technical Work Planner and Cost Engineer present at this meeting. Also, having a production engineer available could be useful due to their interest in optimizing the production facility.

5.4.3. Evaluation

The third and final meeting is the evaluation of the performed Gemba Walk. Based on the earlier test, the flow chart created could not be validated or rejected. Therefore, this will also stay in place. The advised persons to be present are the Cost Engineer and Technical Work Planner. Besides, it could be advised to have someone present from the production staff and possibly also the mechanic if this is once again needed for a strong evaluation. Therefore, some more research would be advised on this topic.

5.4.4. Techniques Used

During the previous sections, an overview is given of the outline for each meeting as well as what techniques to use. The next step is to indicate when each technique should be used during each type of meeting based on the flowcharts created in Chapter 4.

As stated earlier, the preparation meeting will involve an affinity diagram, the Gemba-Walk will include a combination of the Ishikawa and affinity diagram, whilst the evaluation meeting will use a Cause and Effect matrix and a Pareto analysis. The affinity diagram for the preparation meeting can be used during the actions of "Brainstorm on what possible causes for the difference" and "Determine the focus of the Gemba-Walk" as stated in Figure 10. For the Gemba-Walk, a combination between the Ishikawa Diagram and affinity diagram can be used during the action of "Discuss a focus point at the workstation" as shown in Figure 11. Finally, the evaluation meeting will involve a Cause and Effect Matrix at the action of "Analysing the found problems" whilst the Pareto analysis can be used during the action point of "List of Most Important problems" as stated in Figure 12.

5.5. Conclusion

Designing a solution for the problem has been done. However, the created solution also needed to be tested. This was done during this chapter of the research. An overview was given on how these tests were performed. Although no quantitative data was obtained, a lot of insight was generated due to just performing what was intended. Finally, it can be concluded that a final solution design could be created, which was a third/fourth iteration of the first draft version. This solution consists of an affinity diagram used during the preparation meeting, a combination of an Ishikawa and affinity diagram used during the Gemba Walk whilst using a Cause and Effect matrix with possible implementation of a pareto analysis during the evaluation. In Table 5, an overview of the proposed techniques can be found. During the next chapter, more information will be given on how this methodology could help VMI optimize their production facility.

Meeting Type	**Techniques**
Preparation	• Affinity Diagram
Gemba Walk	• Combination of: ○ Ishikawa Diagram ○ Affinity diagram
Evaluation	• Cause and Effect Matrix • Pareto analysis

Table 5 - Overview used techniques

Chapter 6 Conclusion and Recommendations

With the research finished, it is now possible to give the conclusions and provide VMI with the recommendation that result from this research. Besides, it is also possible to give information on further research on the topics that were not discussed/came up during this research.

6.1. Conclusion

During this research, the following research question was answered:

How can VMI better understand the causes that result in a delta between the estimated and actual production hours?

In order to give an answer to this research question, several sub research-questions have been created, which needed to be answered after which the research question itself could be answered. Therefore, first the answer to these questions will be summarized after which a full answer to the research question will be given.

What theories and models are available for solving the core problem?

During the literature review performed in Chapter 3 research was performed on what tools can be used to create a methodology which would suit the needs of VMI. Following this literature research, it was found that the possible tools could be classified into four different categories.

The first category that was necessary is the use of improvement cycles. Within the theoretical framework, two main improvement cycles could be used, which are the PDCA cycle or the DMAIC cycle. Both of these cycles have their purposes and serve the same purpose, which is to create continuous improvements on systems.

The second category is identifying which waste is present within the production process. For this research, identifying waste can be done with three different tools. These tools would be to use the 7 types of waste principle, 5s or Value Stream Mapping.

Within the framework of Six-Sigma, it is also important to create statistical analyses to create numerical and/or visual proof of the problem. Many different types of statistical tools are present, and during the literature research, eight types of statistical tools were highlighted. These are to use either/or a check sheet, scatter diagram, histogram, control chart, bar chart, pie chart, time series plot or boxplot.

The fourth and final category are the analysing tools. During the literature research, it became clear that for analysing the problems, an Ishikawa diagram, affinity diagram, Pareto analysis, cause and effect matrix or effort impact matrix would be most useful.

What theories will result in a suited analysis methodology for VMI?

During research on the first sub question, it became clear what possible tools are available . Also, it had to be analysed which of these tools would actually be useful for VMI and the scope of this research. For the improvement cycles, a PDCA cycle is used within the cost assurance process. This would create a constant feedback loop and therefore also create opportunities for both the methodology and the core problem of creating more insights on the delta between the estimated and actual production hours. To perform this correctly, these two points therefore also need to be discussed during the different meetings. For the analysis tools, it was deemed that a Pareto analysis, effort impact matrix or Cause and Effect matrix would be used. The brainstorming and Gemba Walks would be performed by combining the affinity diagram and Ishikawa Diagram. With the use of (all) of these tools, a good methodology could be created for VMI which would yield the required knowledge for them to solve existing issues. For the statistical tools, this has not been considered during the research. However, in Section 6.3, it will be described how this can be beneficial to possible further research.

Final Solution
With the help of these earlier mentioned research questions, also the final solution could be created, which fills the knowledge gap of VMI and therefore also answer the research question. This research question has therefore been answered by creating a methodology which consists of three different phases (preparation, observation, evaluation). For each meeting, a flowchart was created to outline the actions that need to be performed as shown in Section 4.2. As stated in Section 5.4, this solution uses an affinity diagram during the preparation meeting to determine the focus points of the observation. This observation/Gemba-Walk will then be performed with an Ishikawa diagram with some elements of the affinity diagram. Finally, not all evaluation techniques could be tested, but with the existing knowledge, it is expected that a Cause and Effect matrix combined with a pareto analysis would be most useful. Therefore, the final solution consists of three phases all with their own flow of actions and techniques to be used.

6.2. Recommendations

Also, some recommendations are created for VMI for firstly implementing the created methodology as well as some recommendations regarding the problems found during the tests.

During Section 5.3.3, it was stated that a discussion was held regarding the implementation and drawbacks of this methodology and the problem in general. From this discussion, it first became clear that the methodology itself has a lot of potential, but might need some tweaking before being useful, which was to be expected as the methodology will also be continuously improved. Generally, some unknown problems were found and the involved people benefitted from the interaction with the people at the work floor. However, to use this methodology, it was noted that a more stable production process will first be needed. Currently, especially regarding the hour registration, not all hours are always registered correctly which results in data which is often not 100% representative for the actual hours.

The trustworthiness of the data is also something that VMI could look into. Currently, not every mechanic is consistent on the registration of hours (so also Q-hour registration). Therefore, the data on which the chosen function blocks are based on is less reliable. For VMI to actively improve their production facility in an effective approach, it is recommended to also try to improve these hour registrations.

A topic that returned during all of the preparation meetings was a difference of which mechanic was working on the items. This could result in a difference of actual manhours due to different working speeds. Therefore, it would also be advised to also try and decrease the difference of man hours between different mechanics. This then also corresponds to the trustworthiness of data as the man hours would be more reliable and have a steadier distribution.

Besides following the earlier given theoretical perspective, this solution will also fill the requirements of the chosen theoretical perspective of Lean Six-Sigma. If Figure 2 is once again analysed, it can be seen that this solution will fit within the Lean and Six-Sigma perspectives. First of all, improvement cycles will be implemented within the methodology and the analysis will be based on the production process. Therefore, this is within the Six-Sigma perspective. Multiple departments are present during the observations and continuous improvements are also a vital part of this solution. Therefore, this also falls within the Lean perspective giving this solution also Lean applications.

6.3. Further Research

Within the 10 weeks given for the research, it was impossible to investigate every singular part about the methodology. Therefore, it will be interesting to have some further research regarding the developed tool.

The first interesting research could be done before the observations take place. This could be a data study on what makes the number of actual man hours significant that it needs to be investigated further. Currently, VMI does not have a complete tool for this, so therefore this could be interesting to create a dashboard with a quick and easy overview of what production process needs to be investigated into more detail. Having a frequently updating dashboard makes VMI able to quickly respond to inefficient processes. This can, for example, include some earlier told statistical tools such as a control chart to seek for processes of which the man hours have an upwards trend or many outliers in terms of man hours. This could also be further extended by implementing meetings with mechanics to give them an overview of their performance, both when they are performing better or worse than expected.

Also, it would be interesting to conduct research on the actual influences of this methodology on the reduction of the delta. It should be understood that immediate effects are not present. However, in the long run, if some projects are launched, it will be interesting to see the impact of these projects and how this was developed from this tool. Over a longer period, VMI would be able to validate the proposed methodology by assessing whether the investigated modules have a smaller delta compared to before the observations, and its resulting actions, were performed and implemented.

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Appendix A Systematic Literature Review

Research Question/Knowledge Problem

In Section 1.4, multiple research question and/or knowledge problems are stated. The answers to some of these questions can be created by, for example, performing observations at the work floor. However, this is not case for every research question. To answer these questions, a Systematic Literature Research (SLR) must be performed to fill the knowledge gap. For this SLR, the following research question will be answered:

What relevant analysing techniques are available within the field of operations management to detect (possible) causes of a problem?

Research Goal

The general aim of this research is to create an analysis methodology tailored for VMI. With this analysis methodology, VMI will be able to detect the causes for their action problem, which is a delta between the estimated and actual production hours. As also stated in Section 1.5.2 of part 1, this research is performed within the theoretical perspective of TQM, Lean and Six-Sigma. However, to create such a methodology, first an overview of the available detection techniques and an assessment on their usefulness must be made. This will be the goal for this literature review.

Key Theoretical Concepts

The first step of performing a SLR is to determine the Key Theoretical Concepts for this research. These concepts are the most important concepts stated in the research question. These concepts are:

*What relevant **analysing techniques** are available within the field of **operations management** to **detect** (possible) **causes** of a known problem?*

The first concept are the techniques. This has been chosen as a key concept as this is what needs to be searched for. The second concept is "operations management". This is an important concept is this is the field in which the research will be operated. Also, as later noted, this will also imply the theoretical perspective taken on this research. The third and final key concept is "detecting causes". This is the eventual goal of this bachelor thesis. Therefore, it will be important to search for the techniques that will lead to this goal.

Scope

Operation Management is a very broad topic to cover. Therefore, it will be needed to select proper inclusion and exclusion criteria which will ensure that only relevant articles will be used during this SLR.

Inclusion Criteria		
Nr.	**Criteria**	**Reason**
1.	Include literature which revolves around TQM, Lean and/or Six-Sigma	This is the theoretical perspective taken on this research. Therefore, it will be important that the found results will be within these perspectives.

Table 6 - Inclusion Criteria

Exclusion Criteria		
Nr.	**Criteria**	**Reason**
1.	Pre-1979 articles about Six-Sigma	The creation of Six-Sigma started in 1979, thus this might yield wrong articles.

2.	Articles solely on process improvement techniques	This research will focus on the detection of the causes and not on how to solve them.
3.	Articles about healthcare	The review will be performed to find relevant theories and this research is not performed within the healthcare industry.
4.	Articles about education	The review will be performed to find relevant theories and this research is not performed within the educational atmosphere.

Table 7 - Exclusion Criteria

Search Strategy

To determine a good search strategy for this literature review, it is important to select the proper databases in which the literature will be found. Also, it will be important to convert the earlier stated constructs into search strings.

Databases

During this SLR, the databases of EBSCO (Business Source Elite) and Scopus will be used to collect the most related literature. Both databases provide searching with Boolean operators, which will increase the possibility of search strings. Also, both these databases possess different "types" of articles.

EBSCO, and most notably the Business Source Elite database, is the first database that will be used. The topic of operations improvement is a topic which is very relevant within the field of business research. Since the Business Source Elite database focusses on business research, this will be a good database to use for finding relevant literature.

The database of Scopus has also been chosen to use during this SLR. Scopus provides a lot of articles, which might be useful during this research as TQM and Lean both have a long history within the field of operations management. If any of these relatively old articles must be used, they most likely will be found within the database of Scopus. Therefore, this database is also used.

Search Strings

The earlier named databases will provide millions of articles. To find the relevant articles within the available ones, it is important to create proper search strings, which will create a good selection of articles. A good start is to create a search matrix, in which other, either broader, narrower, or related, search terms will be created. These other terms have been created by performing an exploratory research on each construct as well as using a thesaurus to find related search terms. Also, the construct of continuous improvement has also been added as this is what VMI wants to do. It should also be noted that the search language is based on the database of EBSCO.

Constructs	**Related Terms**	**Broader Terms**	**Narrower Terms**
"Analysing Techniques"			"Quality Tools"
"Operations Management"	"Operations Improvement" "Quality Improvement"		Lean Six-Sigma "Total Quality Management"
Detecting N3 Causes	Find* causes Spot causes	Detect* N3 Causes	"Root Cause Analysis"

			"Waste identification"
Continuous Improvement			Kaizen

Table 8 - Search Strings

Search Log

Table 9 shows the search log of this SLR.

Date	**Database**	**Search terms**	**Number of hits**
04-06-2021	EBSCO	("Analysing Techniques" OR "Quality Tools") AND (lean OR "six-sigma" OR "total quality management")	79 (6 selected)
04-06-2021	EBSCO	(kaizen OR "continuous improvement") AND (techniques OR tools) AND ("operations management" OR "operations improvement")	121 (4 selected)
04-06-2021	EBSCO	"Root Cause Analysis" AND (techniques OR tools OR method*)	317 (4 selected)
07-06-2021	Scopus	((detect* OR find* OR spot) W/3 causes) AND (lean OR {six-sigma} OR {Total Quality Management})	136 (7 selected)
07-06-2021	Scopus	{quality improvement} AND {waste identification}	6 (1 selected)
Total found			25
08-06-2021		Removing duplicates	6
08-06-2021		Select based on exclusion criteria	3
09-06-2021		Removed after complete reading	3
Total selected for review			13

Table 9 - Search Log

Concept Matrix

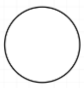
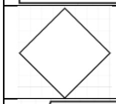
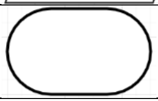
Table 10 shows the conceptual matrix of this literature review. For each article it is shown which perspective the article uses. These are the three perspectives which are also explained during Section 1.5.2, which are TQM, Lean and Six-Sigma.

	Conceptual Matrix				
Year	Author(s)	**TQM**	**Lean**	**Six-Sigma**	Description
2020	Cohen et al.		X	X	The usefulness of the Lean Six-Sigma improvement tools is dependent on what needs to be improved. If costs are the focus, VSM and the Takt Time are most useful. For an improvement regard productivity, Kanban will be most useful and for Quality either One Piece Flow or Gemba is suggested.
2018	Fonseca et al.	X	X	X	Provides a clear overview of Lean, Six Sigma, Lean Six-Sigma, and continuous improvement.
2014	Gijo et al.			X	A case study on the implementation of a DMAIC cycle within the foundry industry.
2018	Gupta et al.			X	A case study on the application of Six-Sigma at a tyre manufacturer.
2020	Kanyinda et al.			X	A study regarding a practical implementation of a Six-Sigma DMAIC improvement process at a car parts manufacturer.
2014	Magenheimer et al.		X		Study focussed on a methodology regarding the identification and evaluation of waste. This is performed within the philosophy of Lean Management.
2018	Li et al.	X	X	X	Case study on the implementation of the DMAVD cycle within a private Chinese organisation under the TQM philosophy.
2019	Pereira et al.		X	X	A case study within the mould industry to explore the optimization of internal processes. A DMAIC/PDCA cycle is used with a further implementation of Lean techniques such as VSM, Pareto analysis and OEE.
2020	Pereira et al.		X	X	A study on the implementation of a PDCA cycle within the cardboard industry to identify the main problems in the processes.
2018	Realyvásquez-Vargas et al.		X	X	A case study on the implementation of a PDCA improvement cycle with an in-depth literature research on the topics of PDCA, Pareto charts and flowcharts.
2017	Sharma et al.			X	An analysis which provides the correlation between different tools/techniques within the Lean philosophy.
2018	Sharma et al.		X	X	A detailed research paper on the implementation of a DMAIC cycle to identify and eliminate multiple sources of variation within an amplifier production process.
2018	Thomas		X	X	An explorative study on the integration of different tools/techniques within the Lean and Six-Sigma frameworks.

Table 10 - Concept Matrix

Appendix B Legend Flow-Charts

For the flowcharts created in Section 4.2, a legend should be made to make sure that everyone understand what every symbol means. Therefore, a legend is made below in which the meaning of every used symbol can be found. These symbols are based on Computer Science Adda (2020) from which only the starting symbol has been made different.

Symbol	Meaning
	Start: This circle stands for the start of the process that is being visualized.
	Activity: This symbolizes an activity that will take place during the process that is visualized.
	Decision: This symbolized if a decision has to be made. The answers will be shown near the arrows it represents.
	Input/Output: This shows the inputs and/or outputs that are present in the process
	Terminator: This symbolizes the end of the process

Appendix C Results of First Test

Preparation Meeting

The first meeting was the preparation meeting. This resulted in some different focus points for the observation. These points were as follows:

- Different mechanics
- Different variants of the module
- Hour registration

Observation

After the preparation meeting, the observation was done. Below, an image can be found of these results displayed on an Ishikawa diagram. Also, this has been transferred to a digital version (see Figure 16). As can be seen, quite some problems have been found which can be solved for VMI to reduce the delta between the estimated and actual man hours.

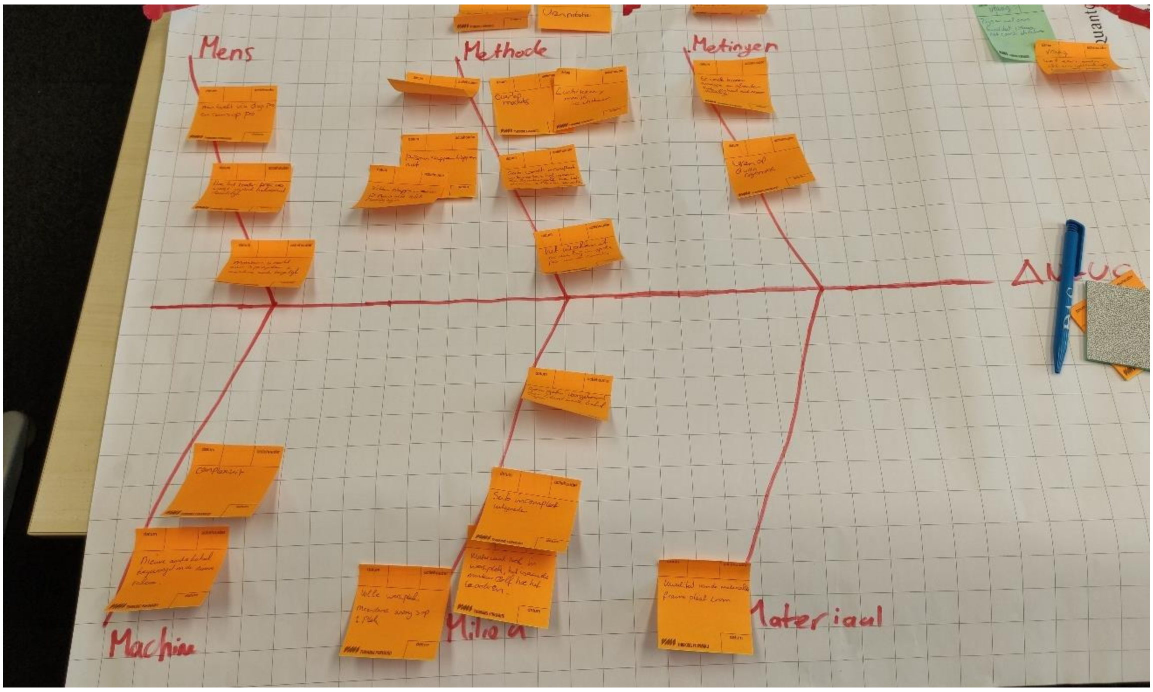


Figure 15 - Ishikawa diagram first test

The digital version:

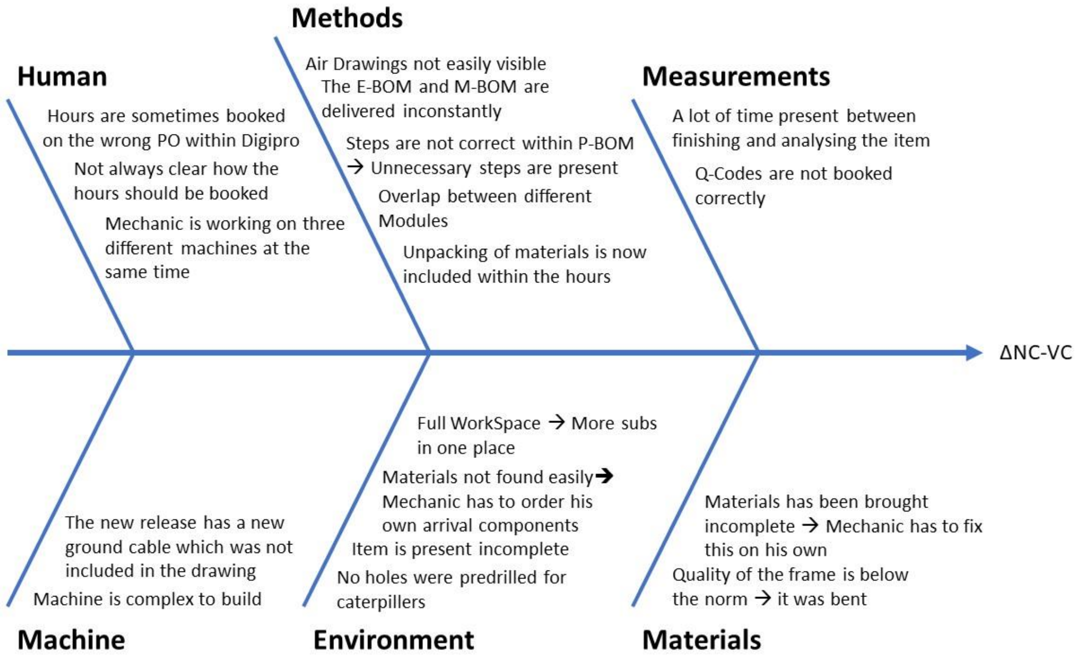


Figure 16 - Digital Ishikawa diagram test 1

Evaluation

During the evaluation meeting, a discussion was held on what could be improved for the earlier meetings as well as noticing the strong points. Below, a bullet point list can be found of the results from this discussion:

Methodology:

- Ishikawa was pleasant to work with ➔ Better understanding of machine, people, methods etc. could be advisable.
- It would be beneficial to dedicate a certain time on different aspects
  - Focus often switched between focus points, which did not help the observation
- Who is present during which phase?
- What will happen after an evaluation?
  - Where and how will the action points be written down
  - How does the work floor benefit from their inputs?

Appendix D Results second Observation

In this Appendix, the results of the second test will be shown. First, the focus points of the preparation meeting will be given, after which also the affinity diagram of the observation will be shown. Also, the take-away points from the evaluation and the problems found will be given.

Preparation Meeting

During the first meeting, some new insights were given regarding the Combi Stitcher. Therefore, also some new focus points were created together with the old ones. The bullet point list below will show these points:

- Hour registration (Pink)
- No “workable work” (Orange)
- Difference of mechanics (Green)
- Feedback of given feedback (Blue)
- Other (Yellow)

Observation

The second meeting was the observation. The affinity diagram can first be found below and also a clearer digital representation can be found below.

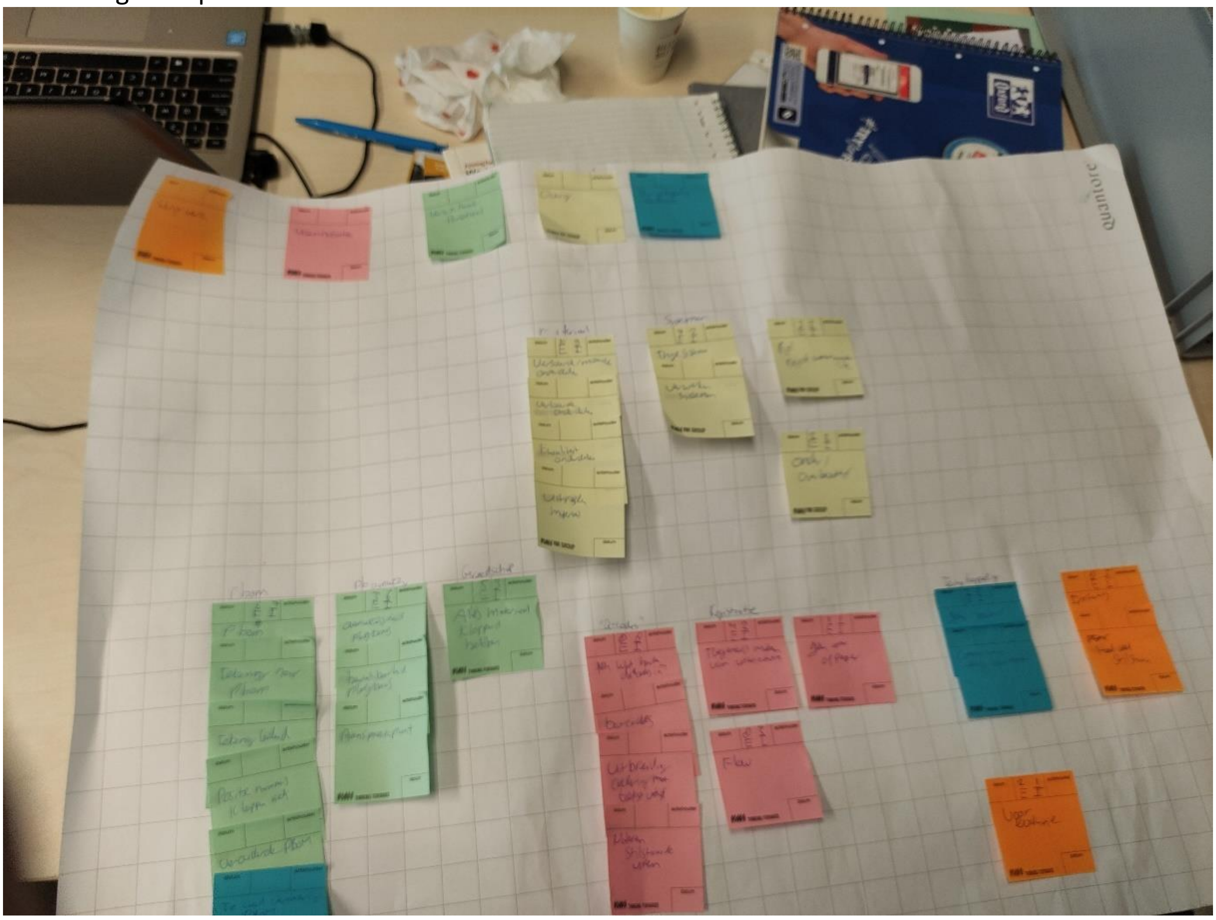


Figure 17 - Affinity diagram second test

Below, the created digital version can be found.

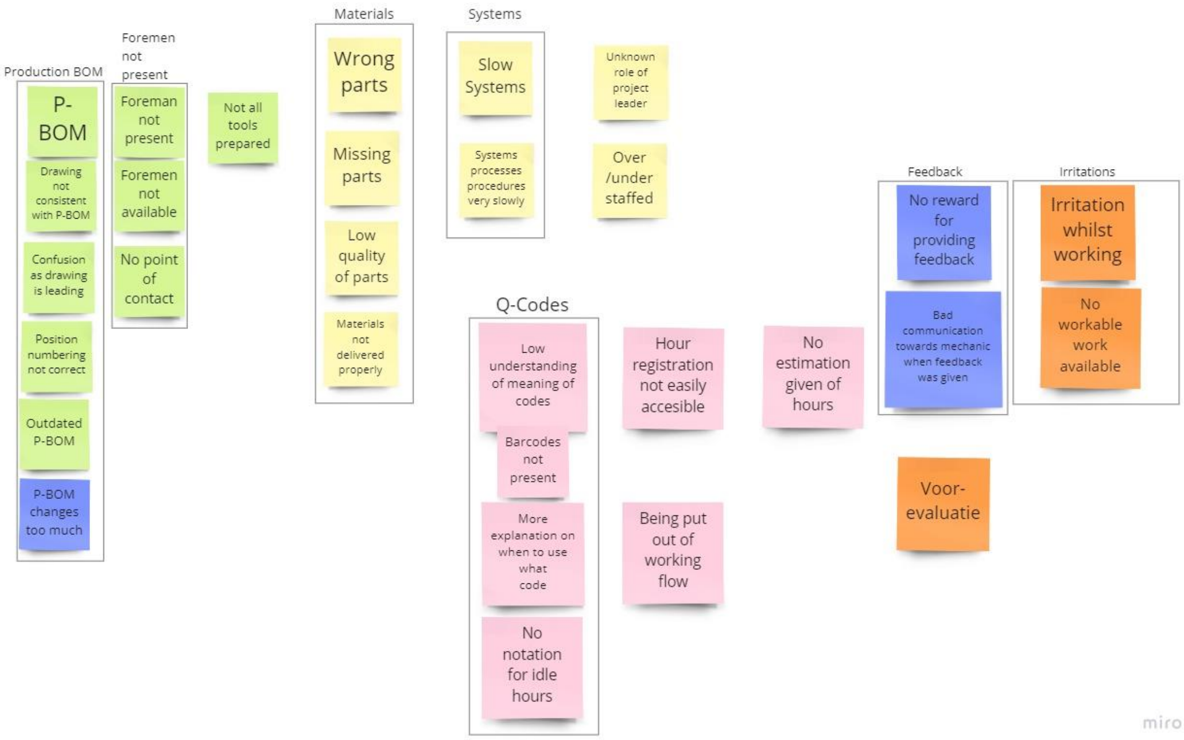


Figure 18 - Digital affinity diagram second test

Evaluation

The first part of the evaluation was to use the Effort Impact Matrix to determine the importance of each point. This matrix can also be found below:

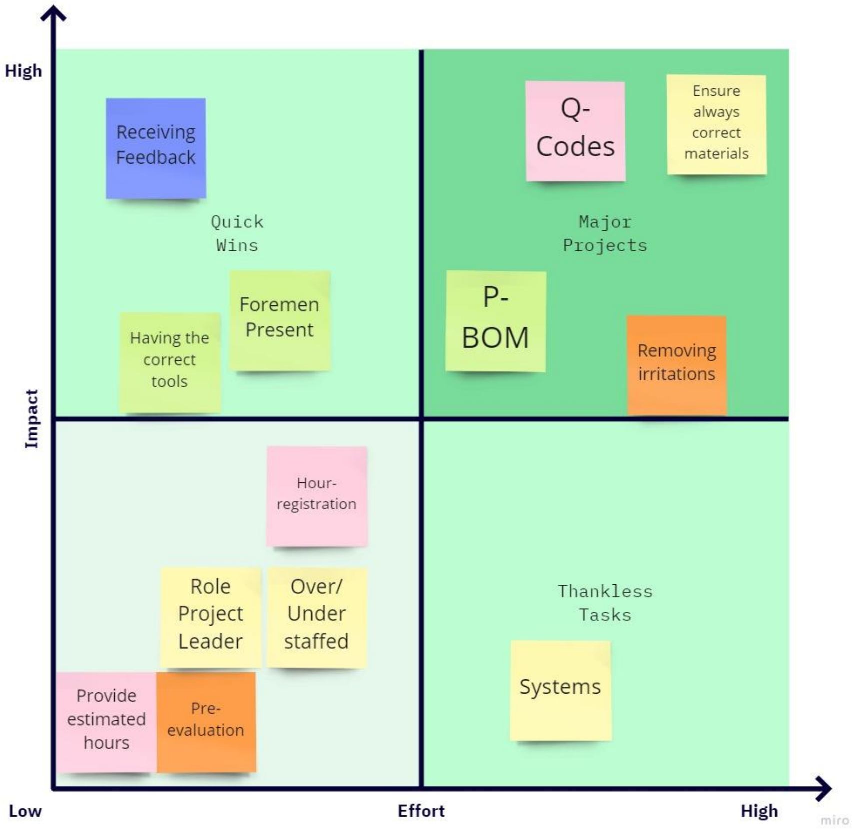


Figure 19 - Effort Impact matrix second test

Besides, the methods themselves have also been evaluated. The summary of this discussion is as follows:

Methodology:

- Affinity diagram did work in essence
  - Ishikawa is preferred, but some points could be used of the affinity diagram
- Combination of affinity and Ishikawa diagram by using the different colours of post its within the Ishikawa diagram
- Effort Impact matrix was too much guessing
  - Estimating between 1 and 10 did not always result in a consensus
- Estimated optimal evaluation is to group the points (like the affinity diagram) and use the Cause and Effect matrix also based on these points
- Focus of the observation was not always clear
  - Partly on how the hours could be made more visible and partly on why these hours are made
    - Clearer goal is needed for the Gemba Walk

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